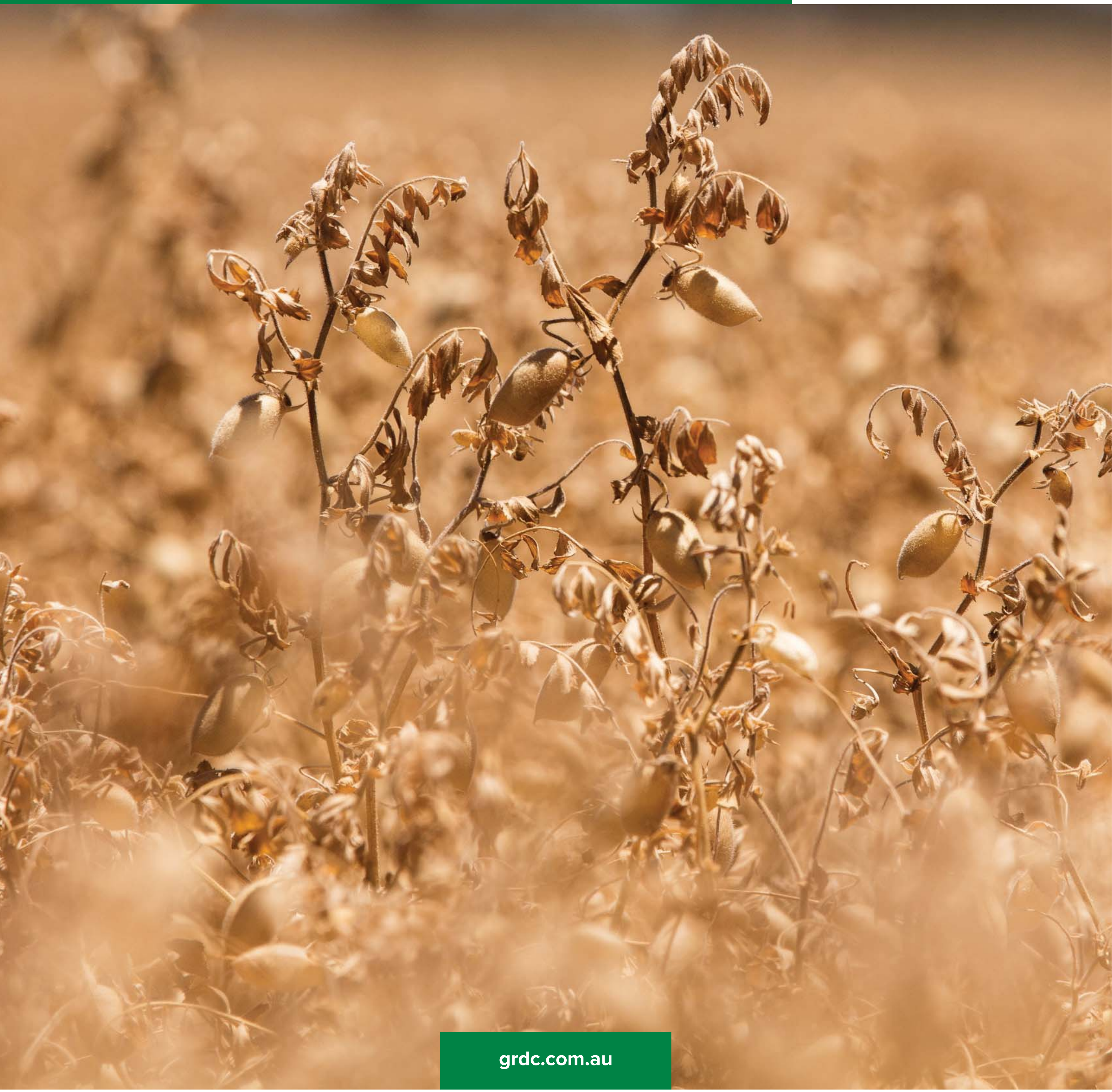
DUBBO
NEW SOUTH WALES
TUESDAY 27TH AND
WEDNESDAY 28TH FEBRUARY 2018

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION



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GRDC Welcome

Welcome to the 2018 GRDC Grains Research Updates

Ensuring growers, advisors and industry stakeholders are informed about the latest research and development outcomes in their quest to improve on-farm profitability is a key role of the annual Grains Research and Development Corporation (GRDC) Updates.

As an industry we face new challenges in terms of climate variability, technology and market conditions, so it is important for all of us to have up-to-date knowledge to make informed decisions and drive practice change.

Last season, New South Wales and Queensland grain growers experienced everything from moisture stress, to heat stress, frosts and waterlogged paddocks. This highlights the importance of robust and rigorous research to help underpin profitability across a range of climatic and environmental conditions.

It also emphasises the value of GRDC investments into regional extension to equip growers and advisors with the information and support they need to make key farm management decisions.

For 25 years, the GRDC has been driving grains research capability and capacity with the understanding that the future of Australian grain growers' hinges on relevant, rigorous, innovative research that delivers genuine profitability gains.

Despite the challenges the grains industry remains confident about the future, willing to embrace new concepts, and keen to learn more about innovations and technology that bring cost efficiencies, promote sustainability and grow productivity.

The GRDC Updates deliver research direct to growers, agronomists and industry. This year the Updates will offer information from the latest research and development from short- and medium-term investments that address on-farm priority issues from farming systems, agronomy, soils, weeds to pests and diseases.

So I hope you enjoy the Updates and that the events provide a valuable opportunity for learning, knowledge sharing and networking. I encourage you to use these events to interact with GRDC staff and GRDC Northern Panel members, who are committed and passionate about your success and the future of the northern grains industry.

Jan Edwards

GRDC Senior Regional Manager North

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PROGRAM DAY 1 – TUESDAY 27 FEBRUARY 2018

Time	Topic	Speaker (s)
10:00 AM	**Welcome**	***GRDC***
10:10 AM	**Agronomists driving practice change** - process to identify client temperament and modify message delivery to improve grower uptake.	***Cam Nicholson*** *(Nicon Rural Services)*
10:45 AM	**Spray quality data for nozzles** are changing to better reflect the impact of formulation and adjuvants on the droplet sizes produced. What are the implications for your advice?	***Bill Gordon*** *(Nufarm)*
11:10 AM	**Barley disease update** • Fungicide resistance • New information on NFNB in Commander[ⓓ] & Compass[ⓓ] • Powdery mildew - pathotypes and management • Spot Form Net Blotch - impact of resistance and epidemic severity on yield • Loose smut - management and what to look for.	***Lislé Snyman*** *(DAF Qld)*
11:40 AM	**NDVI, yield maps and other pretty pictures** - process to convert these into profitable decisions.	***Andrew Smart*** *(PCT)*
12:15 PM	Lunch	
1:15 PM	**Concurrent session 1** *(See concurrent sessions for details)*	
3:00 PM	Afternoon tea	
3:30 PM	**Concurrent session 2** *(See concurrent sessions for details)*	
5:15 PM	Close	
7:00 PM	**Pre-dinner drinks: Dubbo Plains Zoo** *(Supported by Nufarm)*	
8:00 PM	**Dinner, Dubbo Plains Zoo with comedian Sean Woodland**	

PROGRAM DAY 2 – WEDNESDAY 28 FEBRUARY 2018

Time	Topic	Speaker (s)
7:30 AM	**Early risers panel session. Nutritional legacies from 2017 / implications for 2018 in Central West NSW.** Informal time with key speakers *(Starlite room)* ***Mike Bell*** *(QAAFI)*, ***Mark Peoples*** *(CSIRO)*, ***Richard Daniel*** *(NGA)*, ***Nikki Seymour*** *(DAF Qld)*, ***Jim Laycock*** *(Incitec Pivot). Chaired by* ***Tony Cox*** *(NSW DPI/ExtensionAUS).*	
8:30 AM	**Concurrent session 3** *(See concurrent sessions for details)*	
10:15 AM	Morning tea	
10:45 AM	**Concurrent session 4** *(See concurrent sessions for details)*	
12:30 PM	Lunch	
1:30 PM	**Setting the farm up for automation; sensors, telemetry, data capture and management** - experience from the UNE SMART Farm.	***David Lamb*** *(UNE)*
2:00 PM	**At what stages are wheat, barley, canola, chickpea and field pea most sensitive to temperature and water stress?**	***Fernanda Dreccer*** *(CSIRO)*
2:25 PM	**Managing resistance to insecticides in *Helicoverpa armigera*** and other grain pests and an update on Russian wheat aphid.	***Paul Umina*** *(Melbourne University)*
2:55 PM	Close	

LOCATION & TIMING OF CONCURRENT SESSIONS

	Theatrette	Starlite 2	Starlite 3
DAY 1 Session 1	Canola	They do 'what' in the paddock?	Chickpea
DAY 1 Session 2	They do 'what' in the paddock?	—	Chickpea
DAY 2 Session 3 & 4	Cereal agronomy & frost	Farming systems	Weeds

Canola (Day 1, session 1 only)

Time session 1	Topic and Speaker (s)
1:15 PM	**Advances in canola agronomy** and linking critical growth stages with agronomy, nutrition and environment. ***Rohan Brill*** *(NSW DPI)*
1:45 PM	**Canola establishment** - a survey of 90 commercial paddocks in central NSW and precision seeding trials at different establishment rates. ***Colin McMaster*** *(NSW DPI)*
2:15 PM	**GOA nutrition trials** - focus on N and P. ***Maurie Street*** *(GOA)*
2:40 PM	**Windrow timing and harvest management decisions in canola** - open pollinated vs hybrid varieties and harvest delay impact on harvest losses. ***Rick Graham*** *(NSW DPI)*

They do 'what' in the paddock? (Day 1, sessions 1 & 2)

Time session 1	Time session 2	Topic and Speaker (s)
1:15 PM	3:30 PM	**Integrating livestock into cropping systems** - using diverse feed sources to optimise profit. ***Cam Nicholson*** *(Nicon Rural Services)*
1:45 PM	4:00 PM	**Managing dual purpose cereals in mixed farming systems** • Variety impact on grazing and grain recovery • Comparing grazing cereal types • N management for dry matter & grain production • Crop phenology and key growth stage differences in grazing varieties. ***Mehrshad Barary*** *(NSW DPI)*
2:15 PM	4:30 PM	**Managing risk in mixed livestock and cropping systems.** ***Cam Nicholson*** *(Nicon Rural Services)*
2:40 PM	4:55 PM	**Panel discussion:** Integrating livestock and crop systems. Issues, processes and solutions. When do profit limiting feed shortages occur and what are the management options? ***Bob Freebairn*** *(Facilitator)*

Chickpeas (Day 1, sessions 1 & 2)

1:15 PM	3:30 PM	**Chickpea** - temperature & other factors affecting flowering, pod set and yield. ***Andrew Verrell*** *(NSW DPI)* & ***Angela Pattison*** *(Uni. of Sydney)*
1:45 PM the	4:00 PM	**Chickpea water use efficiency** - From where in profile and at what time of the season does chickpea need water? Water use profiles from neutron probes. New data on biomass manipulation. ***Kerry McKenzie*** *(DAF Qld)*
2:15 PM	4:30 PM	**Rules of thumb for calculating N requirements and mineralisation in pulse-cereal rotations.** ***Mark Peoples*** *(CSIRO)*
2:45 PM	5:00 PM	**How much N is fixed by different pulse crops and what factors affect the amount?** ***Nikki Seymour*** *(DAF Qld)*

Cereal agronomy & frost (Day 2, sessions 3 & 4)

Time session 1	Time session 2	Topic and Speaker (s)
8:30 AM	10:45 AM	**Understanding and managing frost risk** • Accessing frost risk and climate information • Regional and national research • How seasonal forecasts influence frost decisions • Optimum flowering time & selection of maturity type based on APSIM modelling of heat, frost & water. ***Peter Hayman*** *(SARDI)*
9:00 AM	11:15 AM	**Using the drivers of phenology in wheat** - varieties to better manage frost risk in a variable climate. ***Felicity Harris*** *(NSW DPI)*
9:30 AM	11:45 AM	**Matching phenology, environment and variety to optimise wheat yield.** How early is too early? ***Rick Graham*** *(NSW DPI)*
9:55 AM	12:10 PM	**Stay-green, root research and early vigour traits in barley.** Wheat and barley root angles - should we care? ***Lee Hickey*** *(QAAFI)*

Farming Systems (Day 2, sessions 3 & 4)

8:30 AM	10:45 AM	**Tillage, stubble and zero-till** - understanding the data underpinning no-till systems for production & resource sustainability. ***David Freebairn***
9:00 AM	11:15 AM	**Key farming system decision points in red soils** - impacts water use efficiency. ***John Kirkegaard*** *(CSIRO)*
9:30 AM	11:45 AM	**Analysis of risks and returns for different crop sequences in CWNSW.** Climate and financial risks in different rotations. ***Jeremy Whish*** *(CSIRO)*
9:55 AM	12:10 PM	**Managing stubble in the farming system** - findings from the GRDC Stubble Initiative project relevant to central NSW. ***John Kirkegaard*** *(CSIRO)*

Weeds (Day 2, sessions 3 & 4)

8:30 AM	10:45 AM	**How widespread are different types of resistance in CNSW?** How farming systems select for different types of resistance? ***John Broster*** *(CSU)*
9:00 AM	11:15 AM	**Alternate double knock options for paraquat** - potential roles for glufosinate and Group G herbicides on milk thistle and fleabane. ***Richard Daniel*** *(NGA)*
9:30 AM	11:45 AM	**The impact of pre-emergent herbicides on soil biology.** ***Nikki Seymour*** *(DAF Qld)*
10:00 AM	12:15 PM	**New data on the Harrington Seed Destructor on a wide range of weed species, including fleabane and milk thistle.** ***John Broster*** *(CSU)*

**Further information - Contact John Cameron or Erica McKay on 02 9482 4930 or northernupdates@icanrural.com.au
Or register on-line at http://www.icanrural.com.au**

Agenda is subject to change

Contents

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General plenary session day 1

Agronomists as drivers of practice change

Cam Nicholson, Nicon Rural Services

Key words

Grain and Graze, temperament, Myers Briggs Type Indicators

GRDC code

SFS00028

Call to action/take home messages

As an agronomist, temperament typing is a valuable tool to help make you more effective in the advice you give.

To use this skill effectively you need to:
- Identify your own temperament type;
- Develop observation and questioning skills to identify your client's temperament types; and
- Learn how to adapt your advice to better match the clients' temperament.

The effectiveness of an agronomist is strongly influence by the connection and rapport made with the client. I imagine we all have clients that we click with, where our advice seems to strike a chord and adoption follows. Yet we may also have had interactions with other growers, that no matter how hard we try, the message just doesn't seem to get through. Why might this be the case?

Part of reason may be the 'pitch' we use in conveying the information. Work in the Southern Grain and Graze program examined how temperament influenced the messages received by the grower and how creating a range of 'products' and approaches around the same message, and then using the most appropriate one based on their temperament, could improve the effectiveness of uptake.

Temperament is the combination of the mental, physical and emotional traits of a person that shapes how they learn and communicate, make decisions and consider risk. For a farmer these traits ultimately reveal themselves in how they farm. A neat workshop or gates that don't swing or tracks with potholes that have been driven around many times are all indications of the temperament of that farmer. So are the comments they make in conversation, both about the farm but also other non-farming or family matters.

Rod Strachan first discussed how 'skewed' rural temperament types required a rethink of how the research and advisory sectors engage with farmers (Strachan, 2011). After extensive testing of more than 3000 farmers across Australia, he described a unique farming culture that was markedly different to the wider Australian population. Information collected by Strachan and colleagues using Myers Briggs Type Indicators (MBTI) was further refined to describe four distinct temperament types (based on Kiersey, 1987). Additional investigations, although nowhere as in-depth as Strachan, were conducted around the agricultural advisory sector, one retail organisation and natural resource management personnel (Nicholson, 2017; Nicholson & Long, 2015) (table 1).

Table 1. Distribution of temperaments in selected rural industries, advisors and the Australian population

	SJ	SP	NT	NF
Beef farmers (n=1,336)	57%	25%	13%	5%
Cropping farmers (n=1,418)	52%	25%	17%	6%
Crop advisors (n=123)	30%	18%	29%	23%
Retail (n=50)	28%	20%	40%	12%
NRM facilitators (n=185)	23%	17%	36%	24%
Australian sample (n=19,994)	42%	13%	26%	18%

SJ = Sensing, judging, SP = Sensing, perceiving, NT = Intuitive, thinking, NF = Intuitive, feeling.

The data showed about 80% of farmers were the 'SJ' or 'SP' types. These are people who like detail. They focus on the present and what is real and concrete. They like to learn using all five senses and work through problems from the beginning, progressing in a logical, incremental and sequential way. While they like to see facts they trust their intuition, local examples of success and past experiences to inform their learning. You would describe them as practical and down to earth, if not a bit conservative. Importantly they are inclined to resist change, or only change once there is good reason to do so.

The remaining 'N' types (NT, NF) jump in the deep end, motivated by the possible outcome, big results and what could be. The details get worked out as they go. They value innovation, can be speculative and are imaginative, liking theories and possibilities. They learn by connecting patterns or bits of the jigsaw. They are future focused.

Table 1 also shows a distinct difference between the 'support fraternity' and the farmers they are potentially engaging with. While the sample size is small and may be biased because of who participated in the surveys, it does show a proportional skew compared to the farming population they are likely to be engaging with.

Rarely does a person's temperament neatly fit into one of these four types. There are always grey areas, but people tend to be more dominant in one (or possibly two) types. Further there is no better or worse type. They all have their strengths and weaknesses.

So why does this matter? Primarily because our default or natural tendency is to approach learning, communication (advice), decision making and consideration of risk associated with a practice or approach that same way that we would like to. By recognising the different temperament types we are engaging with, our approach can be modified to better match the client.

More on the four temperament types

Undertaking the complete MBTI analysis takes about one hour (Briggs Myers, 1980) and results in 16 possible personality descriptions. Personality type can then be condensed into one of four temperament groups (Keirsey 1987), but relies on completing the initial MBTI. Shorter but less comprehensive approaches are available but still take time and are often intrusive on the audience.

The Grain and Graze program (Nicholson & Long, 2015; Nicholson et al, 2015) has taken the MBTI approach and temperament typing to create four descriptions, and colloquial names, that can be used by advisors to quickly align behaviours they observe in their clients with a temperament type (table 2).

Table 2. Description of the four temperament types

Temperament	Description
'SJ' types (Dependables)	They are proud of the industry they work in and believe what they do is of great value and service to the community. They like being called a farmer and achieve great satisfaction from growing products that look and taste good. Dependables have a strong work ethic. They value consistency and routine, often getting pleasure out of doing the same task day after day until the job is done e.g. shearing, sowing, harvest. They are careful and value reliability, consistency, loyalty, security and order, so tend not to 'rock the boat' and protest. If they don't like something they simply don't participate. They like to be helpful and will often involve themselves in the local community through sport, services e.g. fire brigade or local committees, but more as a helper than a leader. Their skills include attention to detail, reliability and a capacity to work to a deadline. They like solid facts and are good at developing policies and procedures. They dislike change for change sake, but will take on new innovation once it has been tried and tested and a process or guideline has been developed, usually by the pioneers. They are more risk averse than the other groups. If you visit their farm, most are likely to have a shadow board in the workshop with the tools neatly arranged in their place. A whiteboard will show the jobs list and this is marked off as completed. Machinery is neatly parked around the sheds, most gates swing and the woolshed is tidy after shearing is over. They like to be provided with a detailed plan from their adviser. Being clear about things like pesticide or fertiliser rates is important to them and will double check the detail. They like to have a contingency plan for alternatives like an early or late break.
'SP' types (Doers)	Doers like farming but don't hold the same level of consistency and routine of the Dependables. They like to jump into things and get them done even if all the detail hasn't been sorted out. It is common to see them with multiple activities on the go at any one time, many of which will not be finished. They work hard, often at a frantic pace but generally have a good sense of timing. They are more likely to take on new ideas, are at their best when the pressure is on and don't mind taking risks. They will do whatever works for a quick and effective payoff even if they have to ignore convention and rules. They are good with detail, realistic, open minded and fairly tolerant but are impatient with theories and abstractions. They also have a shadow board in the shed, but not all the tools are in their place. However they usually can put their hands on what they need when they need them. Machinery will often be in pieces, taking a part off one implement to put on another so the job gets done. Enjoying practical hands on activities, they are likely to favour spending time in the technical aspects of farming such as fixing machinery, building fences and making things. They like working in the business not on the business. While they still value the detailed plan from the adviser, they don't follow it as closely as the Dependables.
'NT' types	Pioneers will try almost anything and will often be the first in the district to try

(Pioneers)	something new. While they love getting their teeth into the start up, they have to concentrate to sustain interest once the project is past the design phase. Pioneers are consistently good at generating new ideas. Their strengths include problem solving, strategic planning and understanding complex systems. They see patterns in complexity and are the innovators of new technology. Their potential weakness is failing to focus on the needs of other people because they are too wrapped up in the next thing. The Pioneers are likely to have several projects on the go at once, this may show up as an untidier farm yard. They will often have trials on their property; evaluating new products or ideas. They are often the first in the district to try something new such as a new crop or pasture. Gates often don't swing, the woolshed still has the oddments from shearing lying about and there are a lot of 'I must get around to that' jobs to do. When working with advisers they will talk conceptually about the plan for the year, identifying the goals and outcomes and are not so interested in the detail of the plan, as they will work it out as they go along. The adviser will often find the plan they prepared has changed since their last visit.
'NF' types **(Team builders)**	Team builders are genuine people with integrity. They are always trying to reach their goals without compromising their personal code of ethics. They speak mostly of what they hope for and imagining what might be possible. They tend to focus on the people needs of a business or community and make great community leaders. They support inclusive decision-making and firmly believe the strength of the business lies in the people. Their strengths include developing a vision and empowering others to join them. They often avoid conflict, strive for harmony and may ignore problems in the hope that they will go away. Team builders are more likely to recognise the sometimes difficult role women can experience in farming businesses and where conflict can arise. They recognize the differences between genders and work to accommodate these. Team Builders with staff will like their adviser to visit early in the week so activities can be planned to ensure the staff have family time on the weekend. It's important to them to have a harmonious team and value social events to show their appreciation.

An alternative (fun) approach has been to use a series of photo cards that depict the types of behaviours described in the four temperament types. Usually only 5 photos of each temperament type is required to enable some determination to be made. An example of each of the four temperament types is provided (figure 1) and the full set is available by contacting the authors.




Figure 1. Examples of images for the 'SJ' (dependable) top left, 'SP' (doer) top right, 'NT' (pioneer) bottom left and 'NF' (team builder) bottom right.

Adapting the message

Once the temperament type is known, advisors need to recognise the subtle differences required to extend the same message but by using different approaches. Suggestions on some possible ways to enhance engagement are taken from Nicholson and Long, 2015 (table 3), along with an illustration on how the insights from table 3 can be applied using integrated weed management as a topic.

Table 3. Four broad temperament types and key considerations for enhanced engagement

Temperament type	**Key considerations that may enhance engagement**
Dependables	• Avoid saying what they have been doing is 'wrong' (no longer best practice) because they may take offence and turn off • Change needs to be incremental, with motivation built on evidence and facts that relate immediately to them and not some remote example • Introduce ideas that don't disrupt current practices too much (small steps) • Localise the solution and information as much as possible because they only trust local and proven • Design programs that allow farmers to test their own issues and help them monitor changes on their farm • Value and explore their past experiences and intuition as this is the foundation of their learning • Use small scale demonstrations of different approaches identified by participants (some of which may not work) to learn from because they are strong experiential learners • Discuss problems in a group setting (but maybe not as a stand-alone topic) so participants know they are not alone and that it is a district problem that we need to work on collectively to solve • There needs to be a long term commitment to this temperament type because change is slow and methodical and they are developing their own procedures, not adopting them from somewhere else.
Doers	• Have bolder type suggestions on possible solutions that they may test • Invite other farmers who have already had a go to tell their story • Go direct to the paddock scale trialling but be prepared to offer some support because they will get too busy and may miss potentially critical timing and measurements • Avoid boring them with theories and left field ideas, concentrate on what seems to be working and what we could do next to build on this success • Be prepared for them to drop the practice if a short term gain can be made by reverting to their 'old ways', but encourage them to start again, using this as a learning experience e.g. a crop that is inappropriate in a rotation to achieve long term weed control will be introduced because the price that year is really high, so when they come back to the rotation discuss what might have been lost compared to what has been gained • Facilitate discussion around how they could make these ideas work in their farming system, what changes would need to be made and how they might make these changes • Offer to mentor them so they become a speaker for the dependables (as people in this group have a lot of things in common with the dependables but maybe are a bit bolder).

Pioneers	• Sell the problem without offering a solution • Be a 'gopher' to support them with information and data that they need to answer the questions they have • Provide a sounding board for their ideas without sitting in judgement, however be prepared to challenge their thinking, especially with how these possible changes may affect others in the business • Never sell your solution as tempting that this may be, because their thinking is likely to be ahead of yours and they can contextualise the problem within the farm business much better than you can • 'tidy up' the story of what they have done with a focus on the bottom line e.g. a case study, because they will have moved onto something else and the insights could easily be lost • Invite them to 'sell' the issue to industry leaders • Don't ask them to design programs for the dependables or doers (because these people are often on panel or boards or committees but think differently so don't really appreciate what the dependables and doers want).
Team builders	• Broaden the big picture problem used with the Pioneers to grab the ethical and moral side to the story as well e.g. the sustainability and environmental issues, long term legacy for future generations, family harmony etc. • Support them with information and data (like the Pioneers) • Capture their story but focus on the people considerations and key statements they are likely to make that will resonate with other farmers • Offer to pay for their services to spread the message to others (they will be inclined to want to do so anyway and payment is recognition of their expertise)

Example: weed resistance issues

Consider a cropping operation that is beginning to encounter major herbicide resistance problems because of the over reliance on repeated use a small number of chemical groups. The grains industry (who are usually represented by 'N' temperament types), see the likely solution in an integrated approach to weed management (IWM). To achieve this would require some major changes to the practices and possibly the enterprise mix on farms. There is growing experimental data to support the need for change, some good theories about what to do and some useful extension materials.

The four temperament types will respond differently when confronted with this problem (as will some advisors). The same thinking can apply to individuals or if dealing with a group of farmers.

The Dependables and Doers (~75% of the farming population) will struggle to recognise the long term implications of the problem because they tend to focus on detail and not the big picture (tactical not strategic). They would rather work solving today's challenges than think too much about the future. The long term is too far away and possibly too confronting to think about, so they tend gravitate to dealing with the here and now.

The Dependables are more likely to be focussed on finding the next chemical to hit the market than implementing an IWM program. IWM is just too disruptive and the GRDC should just invest in new chemistry. However the next chemical is the starting point for discussion, because this is where their thinking is at. While exploring what's new on the horizon, we also discuss how the problem has arisen (not their fault) and that it is a paddock by paddock problem that we don't have all the answers to. We offer farmers the opportunity to submit some of their own samples for resistance testing (this creates ownership of the problem) to determine the extent of the issue we are facing.

Once the results are available, a further discussion is held to examine the findings and their meaning. At this discussion some simple alternative strategies such as annual fodder crops, crop topping or green manure crops may be raised, as this is relatively easy to try and reversible if it doesn't work. For both the findings and alternatives, we discuss their past experiences with these alternative strategies and anecdotal stories of resistance. To test these ideas we think are worthy (even if some may not work to learn from as they are strong experiential learners), we offer to set up a small trial of different fodder options (strips in a paddock) and do some basic monitoring that are observed over time. As we reflect on the results, we look to take the next small step towards change.

A slightly different approach is used with the Doers compared to the Dependables. Elements such as weed resistance testing are included, but we talk up the 'crisis' element of the problem and that a solution will require us to think differently and take a punt (appeals to their greater appetite for risk and solving 'in the moment' problems). We present a few ideas of what others who have faced similar problems are using e.g. windrow burning, chaff carts, crop topping and invite them to a meeting we organise where speakers from outside the district will talk about what they have done. A short trip follows.

At a debriefing from the presentations and trip, we ask who would be willing to try a paddock with an alternative approach. We offer to undertake some monitoring of things like weeds and dry matter production so we can quantify the effect of the treatment. Results are discussed with the individual but we also hold a follow up meeting where the experiences of individuals are shared with others. Particular emphasis is placed on how we could make these ideas work at the whole farm level. A few shining lights are approached to talk to members of the dependable group.

For the Pioneers and Team builders we start with the problem, warts and all and the long term implications to their farming business. We discuss where we need to get to (the goal) and some high level strategic approaches that might help us get there. We act as an investigator, finding out about different approaches the farmer thinks may work. We avoid designing a solution for them, instead feeding in ideas, testing and critiquing the approaches they are formulating. For the Team builders our questioning also includes asking about the reactions of other people in their business to the possible changes being proposed e.g. bringing sheep back onto the property.

We make a commitment that their pioneering endeavours are not lost to the industry by capturing their 'journey' in a case study that can be used by others. We also make contact within the industry to make sure key decision makers know about what is happening (good news story) but also so they can shape the investment agenda.

Conclusion

Using temperament typing in agriculture is relatively new, but early experience through the Grain and Graze program suggests it has potential to greatly enhance the interaction between farmers, advisors and organisations that invest in extension activities.

An important aspect will be to better understand the temperament type of the advisory sector so appropriate activities can be conducted to tailor any potential knowledge and skills training that might be offered.

Useful resources

Farm Decision Making: The interaction of personality, farm business and risk to make more informed decisions. GRDC Canberra.: https://grdc.com.au/__data/assets/pdf_file/0033/16989/farmdecisionmaking_final_lowres2.pdf.pdf

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Spray quality data for nozzles – Implications for use and advice

Bill Gordon, Nufarm Australia

Key words

spray application, spray quality, adjuvants, droplet size

Call to action/take home messages

Advisors and growers need to critically evaluate the claims made on adjuvant labels or in technical literature about the products they plan on using, as well as the spray quality data for nozzles supplied by their manufacturers for legal compliance, efficacy and drift control.

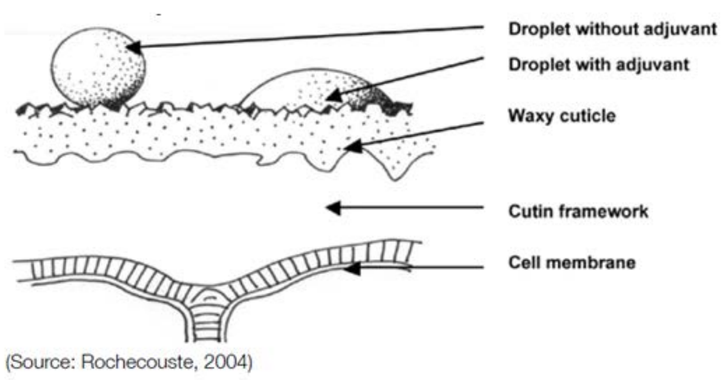
Ensure growers select nozzles based on current spray quality information, such as the GRDC nozzle selection guide, 2017.

Why do we use adjuvants?

The primary purpose of adding an adjuvant to the tank mix should be to improve efficacy.

This may be achieved through different mechanisms, such as;

- increasing spread of the droplet on the leaf surface,
- modifying the leaf cuticle to improve penetration,
- adjusting the pH of the solution to reduce interactions with cations in the water or on the leaf surface,
- reducing evaporation to allow more time for the product to enter the target,
- reducing undesirable interactions between products in the tank mix, or
- improving droplet retention by reducing droplet bounce or shatter.



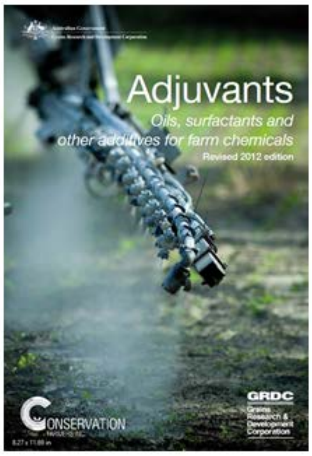


Figure 1. Behaviour of droplets on a leaf surface (with and without an adjuvant).
Source: Adjuvants – Oils, surfactants and other additives for farm chemicals, GRDC 2012.

To change the behaviour of the spray solution, or of a droplet on the leaf surface, the physical and chemical properties of the spray solution usually need to be modified in some way. The most obvious effect of adding an adjuvant to the spray solution is a change in the dynamic surface tension.

Lowering the surface tension causes droplets to spread on the leaf surface, which can increase contact with the leaf surface, improving uptake. However, reducing surface tension of the spray solution can also modify how the droplets themselves are formed as they leave the nozzle, typically reducing their size (compared to water alone).

Table 1. Typical dynamic surface tension values (dynes/cm) for some common adjuvant types

Water alone	72 dynes/cm
Water + Collide™ 700 / LI 700®	48-49 dynes/cm
Water + Wetter 1000 (non-ionic) products	32 dynes/cm
Water + an organosilicone (penetrant)	22-23 dynes/cm

One of the main factors influencing the droplet sizes produced by a nozzle is the nozzle design itself, that is some nozzles are coarser or finer than others. The spray solution also has an influence, where products with a lower dynamic surface tension tend to produce finer droplets than product with a higher dynamic surface tension. Other factors including viscosity and solution temperature can also impact on how droplets are made through various nozzles. Typically, the more uniform the pattern is as is begins to break up, the more uniform the range of droplet sizes produced will be (compare the uniformity of the emulsion in figure 2, to the other solutions).

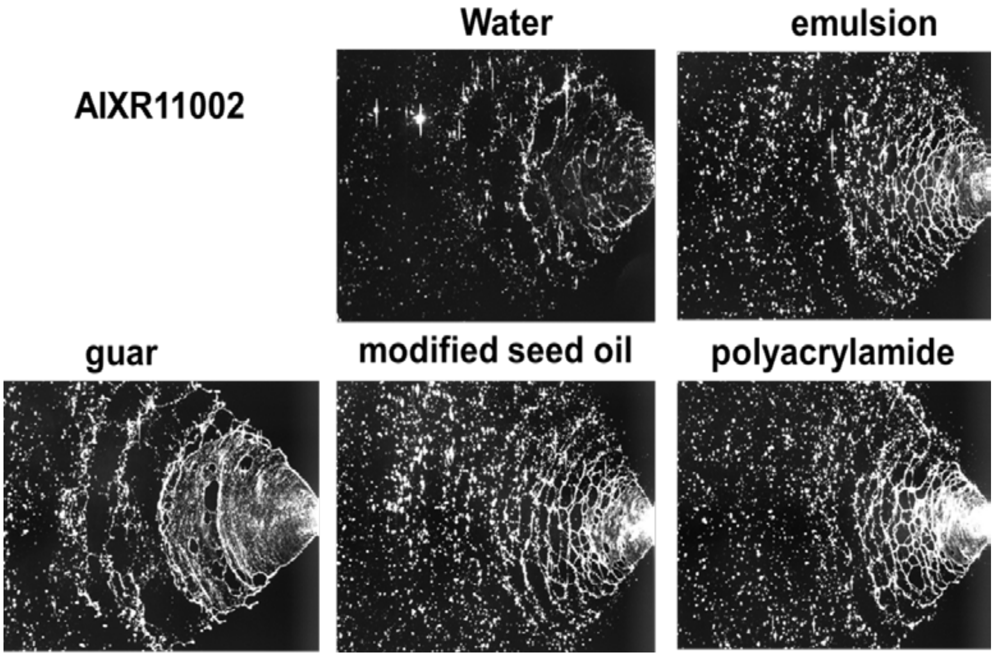


Figure 2. Effect of various adjuvant types on a TeeJet® AIXR11002 at the same pressure.
Source: University of Queensland, C-START

Spray quality according to various standards

Spray quality is not a direct measurement of drift, but a measurement of the range of droplet sizes produced by a nozzle. Spray quality data may be reported by nozzle manufacturers against a couple of different standards including the British Crop Protection Council (BCPC) or the older American Society for Agricultural Engineers (ASAE) Standard S572, which are both mentioned on some Australian labels.

Both the BCPC and older ASAE standards report spray quality based on <u>water alone</u> being sprayed through the nozzle.

More recently the ASAE has changed its name to the American Society for Agricultural and Biological Engineers (ASABE) and has adopted a new standard for spray quality known as the ASABE S 572.1. The new standard requires that testing of pre-orifice and air induction nozzles include the addition of a 40 dynes/cm adjuvant to water as the test solution. This has been designed to provide data that better reflects the spray quality that a typical tank mix may produce, rather than water alone. As a result, recent nozzle charts (see figure 3) may show spray qualities that may appear to be finer than older charts that may still be in circulation. It is important that nozzles are selected based on the best available data.

OLD	Hypro	pressure (bar)	1.5	2	3	4	5	6	7	8
	Gaudian Air 110-025	Spray Quality ASAE S572	XC	VC	C	C	C	M	M	M

NEW	Hypro	pressure (bar)	1.5	2	3	4	5	6	7	8
	Gaudian Air 110-025	*Spray Quality ASABE S572.1*	XC	VC	C	M	M	M	M	M

Figure 3. Comparing old and new spray quality data for the same nozzle.
Source: GRDC Grownote – Spray Application for Grain Growers, 2017.

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NDVI, yield maps and other pretty pictures

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Canola concurrent session

Canola - tactical agronomy still made a difference in a tough 2017

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Keywords

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

GRDC codes

CSP00187, DAN00213

Call to action/take home messages

- In 2017, low yielding, unprofitable canola crops grew near profitable crops that had strict attention to the farming system and timely agronomic management.
- Matching the phenology of a variety with sowing date was paramount for grain yield, largely avoiding major frost damage. At all sites, yield was optimised with treatments that flowered close to the optimum start of flowering date (OSF).
- Canola responded well to high rates of nitrogen at moderate yield levels (2.0 t/ha), even in a dry and frosty year.
- Hybrid canola generally outperformed OP canola in 2017, but sound agronomic management must accompany hybrids to maximise return on the extra investment.

Introduction

In the western and northern cropping regions of NSW extreme weather conditions experienced in 2017 made it difficult to grow canola profitably, yet there were crops that were profitable with grain yield of 1.0 to 2.0 t/ha even in the same landscape where many crops yielded less than 0.5 t/ha. In the south-eastern half of 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 nitrogen.
4. Matching phenology and sowing date so that flowering starts close to the optimum start of flowering (OSF) date to minimise environmental stresses and maximise growth.
5. Sowing hybrid canola varieties (although this alone did not guarantee success).
6. Application of sufficient nitrogen 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 focussed 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.

Optimum start of flowering (OSF) dates

For all grain crops there is a period in the growing season that is most favourable for flowering and reproductive development. This period will be where the risk of stress (such as frost, heat and drought) is minimised and where resource availability (water and light) is maximised. Recent enhancements in the APSIM model have enabled OSF (optimum start of flowering - defined as when 50% of plants have one open flower) dates to be identified for major canola growing locations, including for NSW in Table 1 (full document available at https://grdc.com.au/10TipsEarlySownCanola). This paper will report on the results from 2017 in the context of the simulated OSF dates for the three experimental sites.

Table 1. Optimum start of flowering (OSF) dates for key canola growing locations in NSW

Location	OSF date
Nyngan	7 July
Walgett	12 July
Moree	18 July
North Star	22 July
Hillston	23 July
Condobolin	25 July
Trangie	26 July
Finley	27 July
Lockhart	31 July
Narrabri	31 July
Gunnedah	1 August
West Wyalong	1 August
Canowindra	2 August
Parkes	3 August
Wellington	5 August
Wagga Wagga	5 August
Cowra	6 August
Culcairn	8 August
Temora	13 August
Young	21 August

2017 research

The site details of three experimental sites in NSW in 2017 reported in this paper are summarised in Table 2.

Table 2. Location, fallow rainfall (1 Nov to 31 March), in-crop rainfall (1 April to 31 October) and soil nitrogen 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	313 mm	122 mm*	77 kg/ha
Ganmain	Riverina	180 mm	190 mm	123 kg/ha
Narrabri	NW Plains	359 mm	165 mm	211 kg/ha

*25 mm 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.

Condobolin

The experiment at Condobolin was designed to determine the optimum sowing date, plant type, phenology and nitrogen management to optimise biomass accumulation, harvest index and ultimately grain yield under two contrasting scenarios; irrigated (supplementary water rather than full irrigation) and dryland. Four varieties were sown in a full factorial combination of sowing date, nitrogen rate and added irrigation (150 mm, equivalent to 1.5 ML/ha) (Table 3). An irrigation treatment was included to determine if management of sowing date, variety type and nitrogen should vary under different moisture scenarios. 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.

Table 3. Treatments used in an agronomy experiment at Condobolin, 2017. Varieties (four), sowing dates (two), nitrogen rates (two), and irrigation treatments (two) were applied in a factorial combination.

Varieties tested	Sowing dates	Nitrogen rates[1]	Irrigation[2]
Archer (slow hybrid Clearfield® (CL)) or	6-Apr or	50 kg/ha or	Nil (dryland) or
Diamond (fast hybrid Conv.) or	20-Apr	150 kg/ha	150 mm (irrigated)
ATR Wahoo⊕ (mid-slow open pollenated (OP) triazine tolerant (TT)) or			
ATR Stingray⊕ (fast OP TT) or			

[1]All plots had 50 kg/ha N broadcast as urea before sowing. An extra 100 kg/ha of N was applied as urea for the 150 kg/ha treatment at 6-8 leaf stage.
[2]Two irrigations of 30 mm were applied to the irrigated treatment in March prior to sowing, one irrigation of 30 mm applied 20 June and four irrigations of 15 mm applied on 15 August, 1 September, 5 September and 20 September.

From the early (6 April) sowing, the fast varieties Nuseed® Diamond and ATR Stingray⊕ started flowering in late June/early July (Table 4), 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 4. 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 Stingrayᶲ	5 July	21 July
ATR Wahooᶲ	6 August	16 August
Archer	9 August	18 August

The mid-slow variety ATR Wahooᶲ and the slow variety Archer both yielded around 1 t/ha in the dryland early sown treatment, as their delayed flowering meant they were not too far into podding when the severe frosts occurred (although some frost damage would have been sustained (Figure 1)). The yield of both Archer and ATR Wahooᶲ was reduced by sowing later, as flowering was delayed until mid-August and pod development was limited by higher spring temperatures and greater water stress. The faster varieties Nuseed Diamond and ATR Stingrayᶲ were heavily penalised by frost at both sowing dates as flowering started (from both sowing dates) before the OSF date of 25 July. It is recommended to sow these fast varieties after 25 April in most environments of southern NSW.

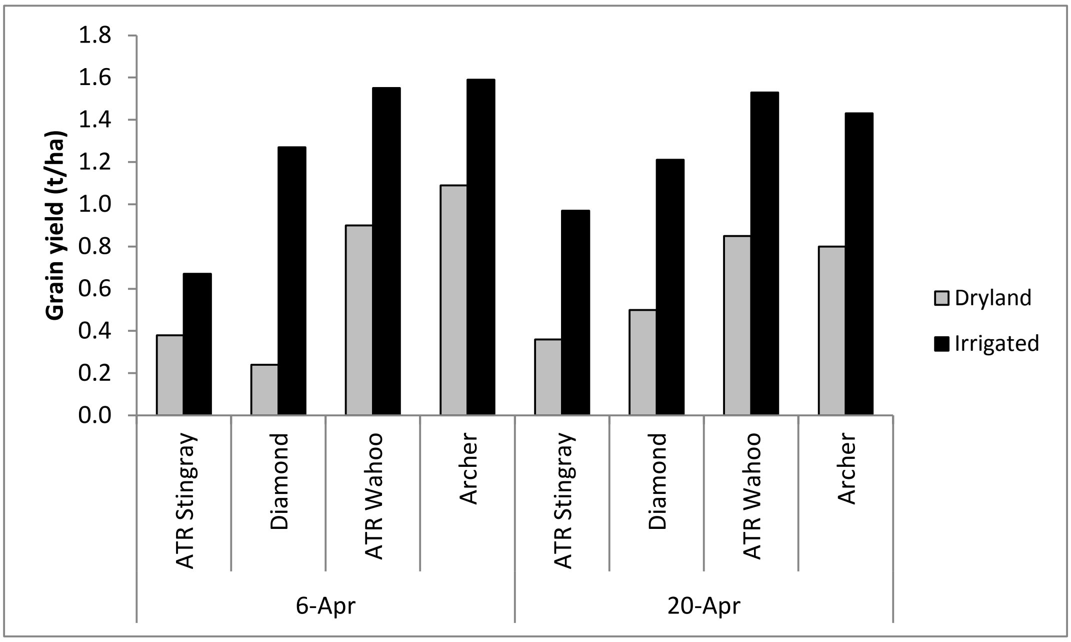

Figure 1. Grain yield of four canola varieties sown at two sowing dates, with (irrigated) or without (dryland) irrigation, at Condobolin in 2017 (l.s.d. P<0.05 = 0.26 t/ha).
(ATR Stingrayᶲ and ATR Wahooᶲ are protected under the Plant Breeders Rights Act 1994)

Irrigation (150 mm total) doubled the average experimental yield from 0.64 t/ha to 1.28 t/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 late July 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 that crop roots can access.

Despite the relatively low starting soil N level (77 kg/ha) at the Condobolin site, there was no response to increasing N rate from 50 to 150 kg/ha in either the irrigated or dryland treatment. The highest yielding treatment yielded 1.6 t/ha which would have required 144 kg/ha N to be available (assuming 50% efficiency), which would have been provided through a combination of mineral N, 50 kg/ha of applied N plus some mineralisation.

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 (long term average growing season rainfall = 275 mm) 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 (2.1 t/ha) was still close to average for the region (1.8 to 2 t/ha) due to deep stored water from spring rainfall in 2016.

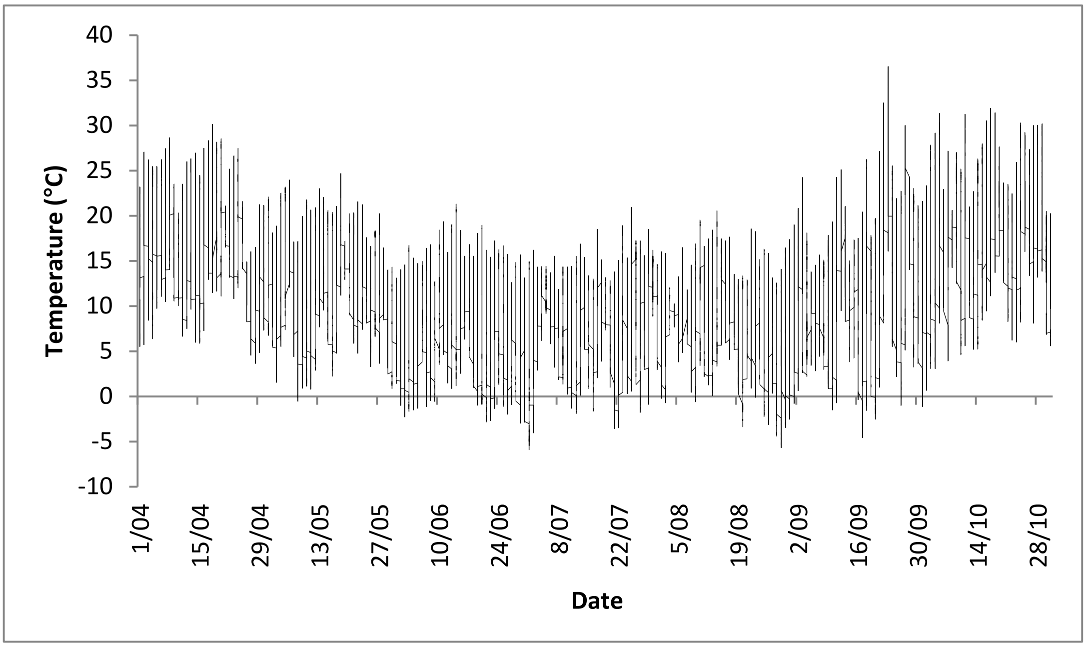

Figure 2. Temperature (°C) from 1 April to 31 October at the Ganmain experimental site, 2017

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 3). Early sown Nuseed Diamond and ATR Stingray⊕ flowered in early July and both averaged less than six seeds per pod. From the same sowing date, Archer and ATR Wahoo⊕ 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.

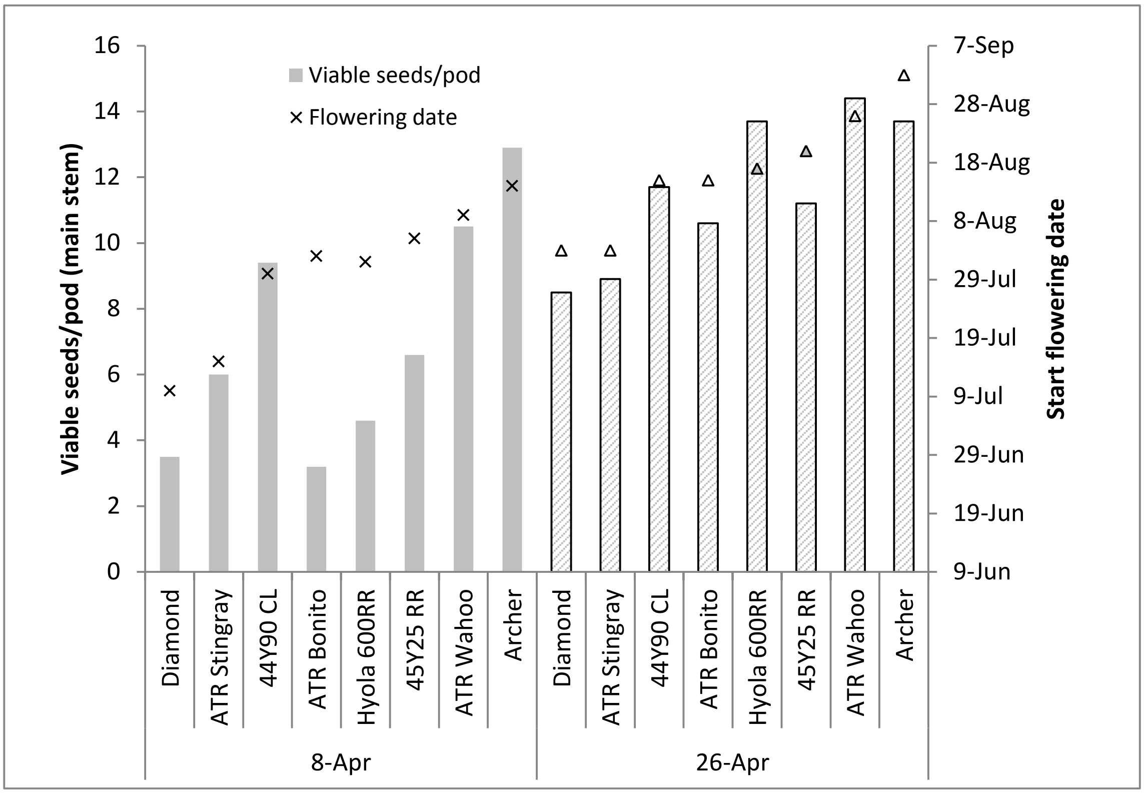

Figure 3. Viable seeds per pod (columns) and flowering date (× and Δ) of eight canola varieties sown at two sowing dates (averaged across N rates) at Ganmain, 2017 (Viable seeds/pod l.s.d. P<0.05 = 2.1). (ATR Stingray, ATR Bonito and ATR Wahoo are protected under the Plant Breeders Rights Act 1994.)

In this experiment, increased yield came from sowing varieties in their optimum window to achieve the OSF date (5 August for nearby Wagga Wagga) and where they were well fertilised with nitrogen (Figure 4). The fast varieties (Nuseed Diamond and ATR Stingray) were heavily penalised by frost from early sowing (early flowering, see flowering dates in Figure 3) and the slower varieties (e.g. Archer and ATR Wahoo) 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 nitrogen 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 sown early (flowering in early August) but minimal response when sown later (flowering in later August). Conversely there was a strong 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 nitrogen at both sowing dates (Figure 4).

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

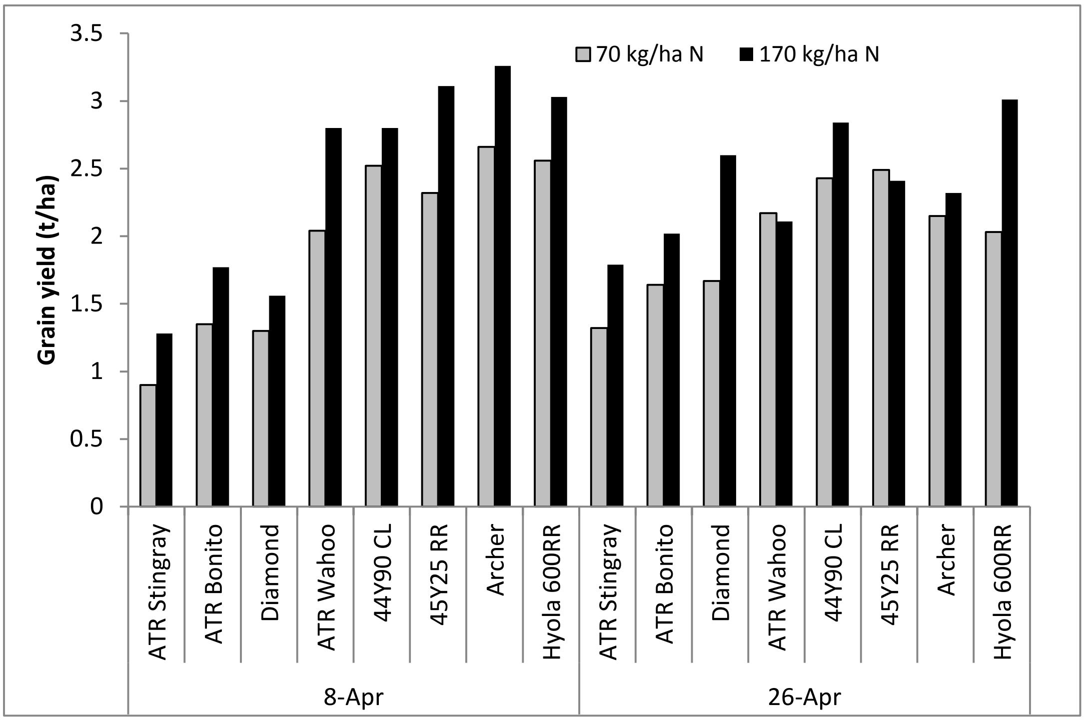

Figure 4. Grain yield of eight canola varieties sown at two sowing dates and fertilised at two nitrogen rates at Ganmain, 2017 (l.s.d. $P<0.05$ = 0.38 t/ha).
(ATR Stingray⦶, ATR Bonito⦶ and ATR Wahoo⦶ are protected under the Plant Breeders Rights Act 1994.)

Narrabri

An experiment was sown at Narrabri with six varieties (same as Ganmain but with the exception of the Roundup Ready® varieties Hyola 600RR and Pioneer 45Y25 (RR)), two sowing dates (19 April and 8 May) and two nitrogen rates, nil and 65 kg/ha N. The frosts were also severe at Narrabri with similar minimum temperatures recorded as Ganmain and Condobolin but with a greater diurnal (difference between minimum and maximum temperature) variation, i.e. the maximum temperatures were much higher (in excess of 20°C) on the same day as a -5°C frost event.

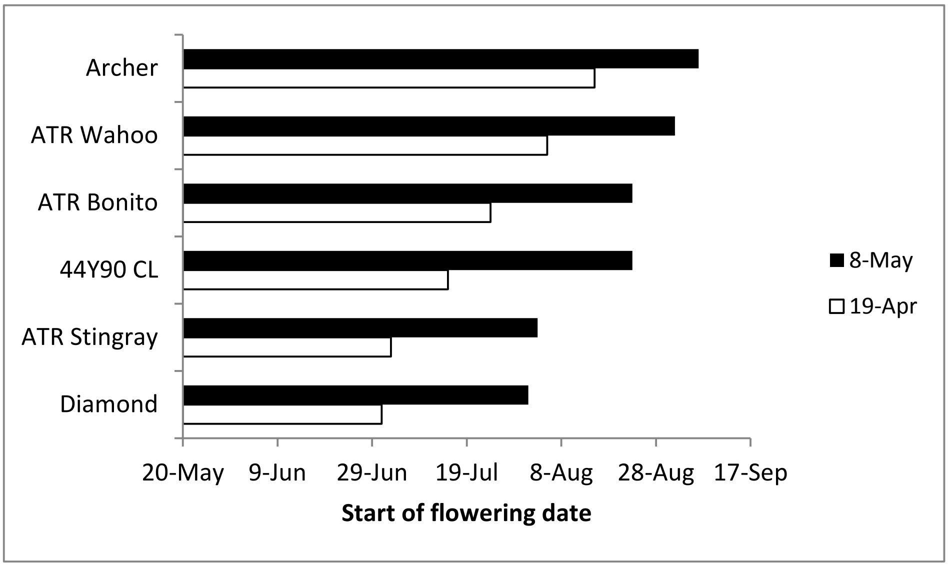

Figure 5. Start of flowering date of six canola varieties sown at two sowing dates at Narrabri, 2017. (ATR Stingray⫯, ATR Bonito⫯ and ATR Wahoo⫯ are protected under the Plant Breeders Rights Act 1994.)

The Narrabri trial had good early vigour and grew well but the frosts caused significant yield loss and there was little recovery as the season quickly transitioned from frosty to very warm and dry. Nuseed Diamond and ATR Stingray⫯ were the earliest varieties to flower (early July) from early sowing (Figure 5) but were the hardest hit by frost and yielded less than 0.1 t/ha. Later sown Nuseed Diamond that flowered on 1 August (close to the OSF date for Narrabri of 31 July) was the highest yielding treatment at 0.9 t/ha (Figure 6). There was no effect of increasing N rate to 65 kg/ha on grain yield.

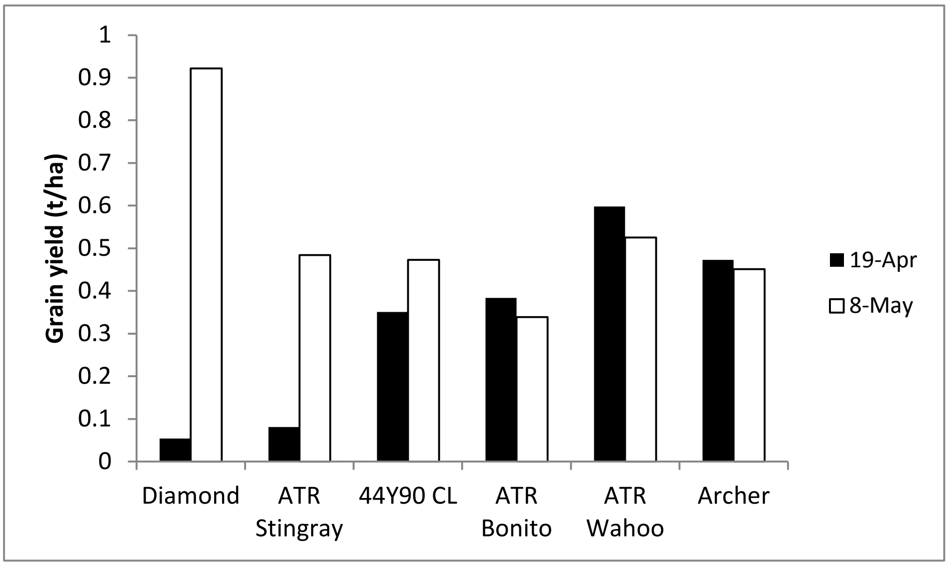

Figure 6. Grain yield of six canola varieties sown at two sowing dates at Narrabri, 2017 (l.s.d. $P<0.05$ = 0.18 t/ha). ATR Stingray⫯, ATR Bonito⫯ and ATR Wahoo⫯ are protected under the Plant Breeders Rights Act 1994.

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 paddock elevation. The correct matching of sowing date with phenology to target the OSF date for the location is the main message from 2017, reaffirming a consistent message from recent years of canola research. Secondly managing the crop with optimum nitrogen fertility, and finally with those factors in place, choosing hybrid varieties (especially in medium-high yielding environments).

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 close to the OSF date 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 the pre-crop management had a major bearing on outcomes for canola in 2017. Management of points 1 to 3 in 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 return from the agronomic management.

Acknowledgements

The projects supporting this research are co-investments from GRDC, NSW DPI, CSIRO and SARDI. Thanks to technical staff for assistance including Craig Ryan, John Bromfield, Warren Bartlett, Sharni Hands and Sophie Prentice.

Further reading

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

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Canola establishment

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Can applying nitrogen fertiliser in the fallow period increase fertiliser efficiency in wheat?

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Key words

nitrogen urea, fallow, top dressing, cereals, soil testing

GRDC code

GOA00002

Call to action/take home messages

- Applying nitrogen (N) during the fallow period did not consistently improve the efficiency of applied N when compared to in-crop applications.
- Applying N during the fallow period often did not result in any penalty when compared to in-crop applications.
- Overwhelmingly, the greatest response in yields and protein was to the rate of N applied.
- Growers should primarily focus on applying the most appropriate rate of N, with the timing a secondary concern.

Background

It is generally accepted that cropping paddocks are declining in fertility, which includes the available nitrogen (N) (Laycock, Bell 2009). This has been exacerbated by a gradual shift to continuous cropping systems, dropping the pasture or lucerne phase, which has been the traditional time for rebuilding soil fertility and N levels, particularly deeper in the soil profile. While our current farming systems tend to include a legume, the N contribution from this phase is rarely enough to support the full requirements of the subsequent crop. Similarly, for those farmers who do use N fertiliser the amount applied is more often than not outweighed by N exported in grains (Norton, 2016).

With this decline in fertility, it would be easy to assume that adding fertiliser N should reliably provide yield and grain quality benefits. Yet growers have often been disappointed in responses to applied N, with grain yields not reflecting what is applied, and/or grain protein being under par. A recent study by Daniel 2018 suggests N recovery in increased yields from applied N can be as low as 10%. This is far short of the often quoted N use efficiency of circa 40-50%. Such low efficiencies would have a significant downward pressure on the economic argument to apply N fertiliser.

So what if the N we are applying is simply in the wrong spot at the wrong time? Dowling (2014) has described this as 'positional availability', where active root mass is at distance from mineral N sources for a significant period of the crop growth.

Winter cropping in the northern region relies heavily on fallow rainfall to maximise production. Accumulating moisture in the profile results in the subsequent crop drawing its requirements from deeper in the soil during drier periods of growth. Typically, this occurs in spring, which is also the period of most rapid biomass accumulation, grain fill and protein accumulation.

In our current wheat farming systems, N is typically applied at any time from seeding to stem elongation. This may influence the depth in the soil to which the N will be distributed.

Physical placement of N is generally limited to 0-10 cm when applied with the planting equipment, whilst any topdressing application places N on the soil surface. Any deeper movement of N during the growing period relies on rainfall events. It is therefore easy to imagine that when in-crop rainfall is limited, there is limited opportunity to move nitrates any deeper into the profile.

It is plausible that N in the topsoil may become ‘perched’ or positionally unavailable at times when the crop requires it, and temporarily may not have the ability to use it because it is accessing moisture from deeper in the profile.

Could the conversion of applied N to increased yields be improved by N being distributed deeper in the soil profile? Could this be achieved by applying N fertiliser in the fallow period and allowing the rainfall to transport N deeper into the soil profile as it recharges the soil profile?

Grains Orana Alliance (GOA) has run eleven trials since 2015 investigating this hypothesis. The trials look at whether applying N fertiliser at the beginning of a fallow period has resulted in improved efficiency compared to when it is applied at sowing or top-dressed at Z30 stage of the cereal crop.

Aims

To assess if applying N during the fallow period would result in improved yield and protein responses over that of when N was applied at the more traditional timings of sowing or topdressing after crop begins elongation (Z30+).

Methodology

Eleven trials were established between 2015 and 2017 across the GOA region. Trial sites were selected for low soil N status, confirmed by soil testing.

The trial design was a full factorial design with 32 treatments and three replicates. The treatments included;

- A higher and a lower biomass variety, EGA Gregory⊕ and Longreach Lancer⊕ respectively
- Four to five N application timings: early fallow, mid fallow*, sowing, split* and topdressing.
- Four N rates: 0, 50, 100 and 200 kg/ha applied as granular urea (46% N)

*Initial trials in 2015 incorporated a split timing with fertiliser N equally divided between early fallow and topdressing. This treatment was replaced by a mid fallow timing in the 2016 & 2017 trials

All N was applied as urea and was drilled for the fallow and sowing N treatments (except the sowing treatments in 2017) using a plot seeder to a depth to ensure reasonable soil cover (typically 5-8cm). All other treatments were broadcast. The 2017 sowing treatments were broadcast ahead of seeding and incorporated by the sowing process. Topdressing treatments were hand broadcast ahead of predicted rain events after the crops had reached Z30. In all cases sufficient incorporation rainfall was received.

A number of treatments were soil tested prior to sowing to assess any differences in N distribution. The two wheat varieties, EGA Gregory⊕ and Longreach Lancer⊕, were sown and managed to best management practices to assess if there were varietal differences between responses. Plots were harvested by plot header and assessed for yield, protein, screenings, test weight and moisture. Statistical analysis was provided by the GRDC Statistics for the Australian Grains Industry (SAGI) project team.

An across sites analysis for each of the traits yield, protein and screenings was undertaken using a linear mixed model framework, with fixed effects included for site-year, variety, the rate of applied N, the timing of N application and the respective interactions between the effects. Predictions of the significant effects (α=0.05) were provided from the model as empirical best linear unbiased estimators (eBLUEs). All analyses were conducted using the ASReml package in R.

Error bars within graphs below illustrate the standard error of the predicted value, if the bars overlap between any treatments within a site being compared, the reader can assume there is no statistical difference.

Results and discussion

Impact on grain yield

The range of locations and seasons meant that yields ranged from 2 to 8 t/ha. All sites were N responsive, however the magnitude of response was much greater in 2016 than in 2017 and 2015, which both had much lower rainfall. In 2016, yields increased up to the highest rates of applied N, reflecting the wet season, while in 2015 and 2017, most of the yield response was from the addition of the first 50 kg N/ha, reflecting the dry seasons.

There was no significant interaction with variety with the response to the rate or timing of N applied, as such the results shown in Figure 1 are combined for both varieties.

In the majority of trials there was no yield advantage in applying N at any one rate either at the early or mid-fallow timings when compared to the same rate applied at either sowing or topdressing as illustrated in Figure 1 below.

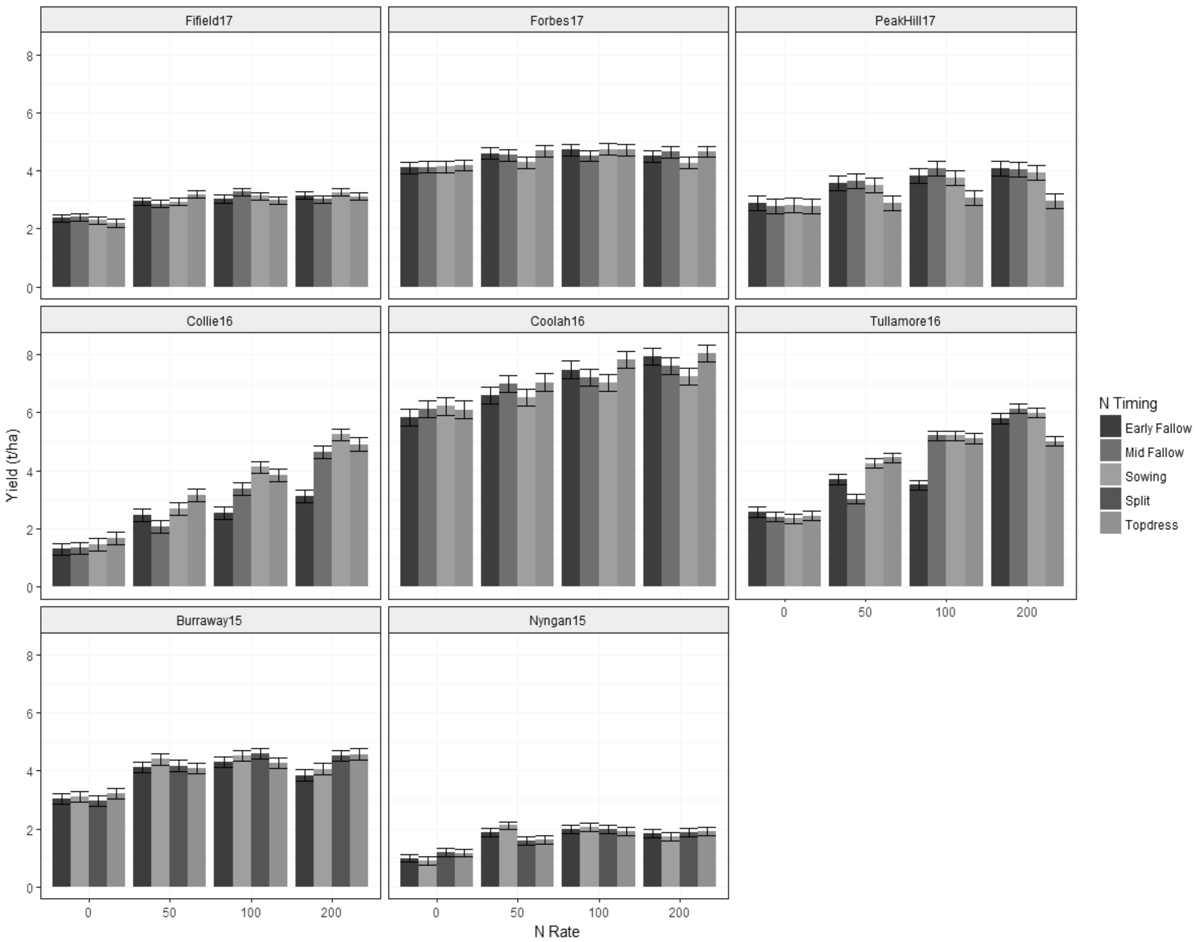

Figure 1. Yield (t/ha) response to four rates of applied N at four application timings, combined by both varieties.(Note: Split treatment at Burraway and Nyngan only, replacing mid fallow treatment applied at other locations)

There are however a few exceptions-

- Peak Hill 2017- early and mid-timings both outperformed the top dressing timing but not the sowing timing.
- Tullamore 2016- early and mid-timings both outperformed the top dressing timing but again not sowing timings, but only at the highest rate of 200 kg/ha N

There were however and number of cases where the early or mid-fallow timings underperformed when compared to the sowing or top dressing timings also illustrated in Figure 1.

Impact on grain quality

The low protein levels in the treatments where N was not applied confirms the low N status of the sites selected.

Similar to the yield responses, applying N in either of the fallow timings generally did not significantly improve grain protein compared to applying the same N rate at sowing or topdressing.

The one exception was Fifield 2017 where applying 100 or 200 kg N/ha at early or mid-fallow had a significant protein advantage over application at sowing or as a topdressing, where protein levels were increased by 1.2% and 2.4% respectively. In 4 out of the 6 sites there was a protein improvement by the topdressing application of N over that of when the same N rate was applied at other timings, which is not unexpected (note that generally these came with a yield reduction).

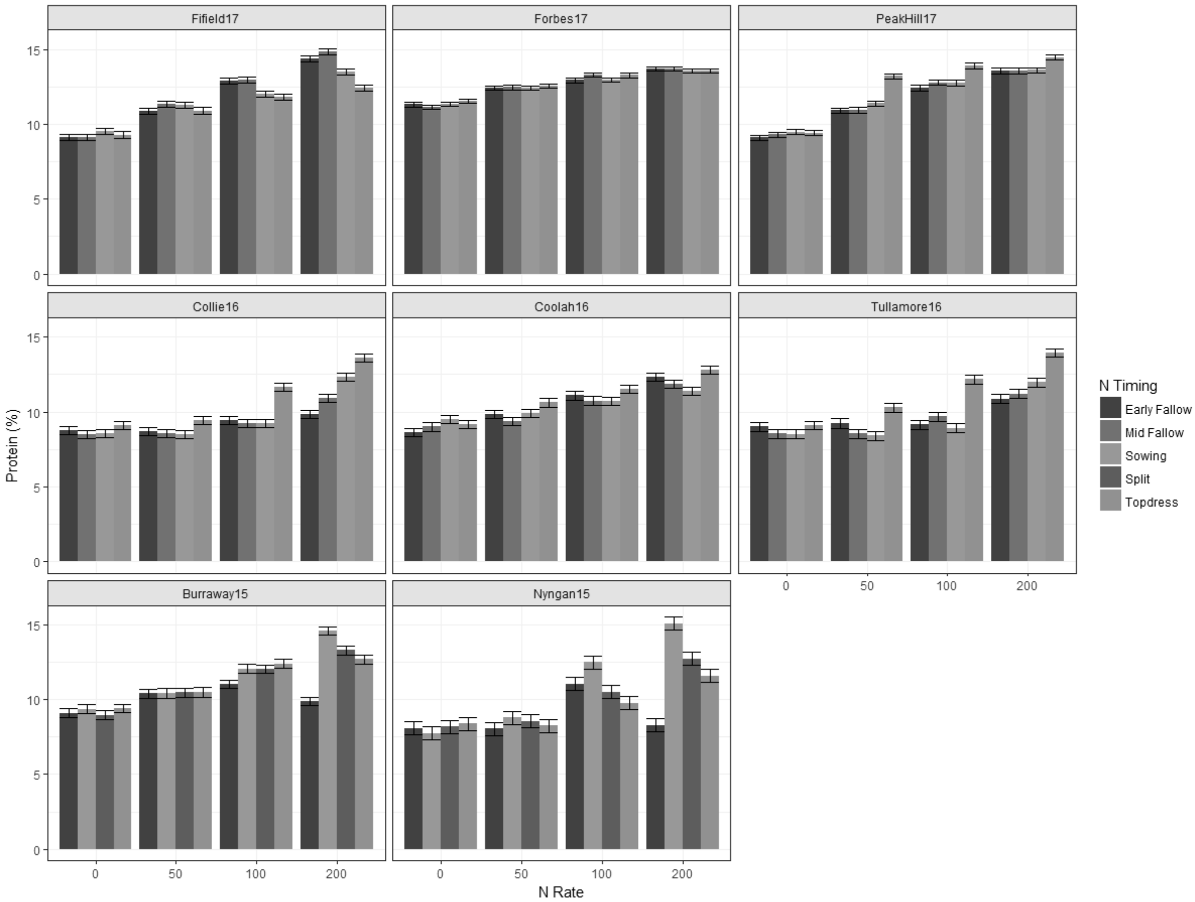

Figure 2. Protein (%) response to four rates of applied N and four application timings (yields combined for both varieties) (Note: Split treatment at Burraway and Nyngan only, replacing mid fallow treatment applied at other locations)

Screenings

Similar to the yield and protein responses applying N at either of the fallow timings had little impact on screenings (Figure 3). In 2016 and 2017 the screenings tended to decrease with increasing N rates, where both seasons had relatively ‘soft’ finishes, on the other hand in 2015 screenings tended to increase with increasing N rates, in a season with a dry finish.

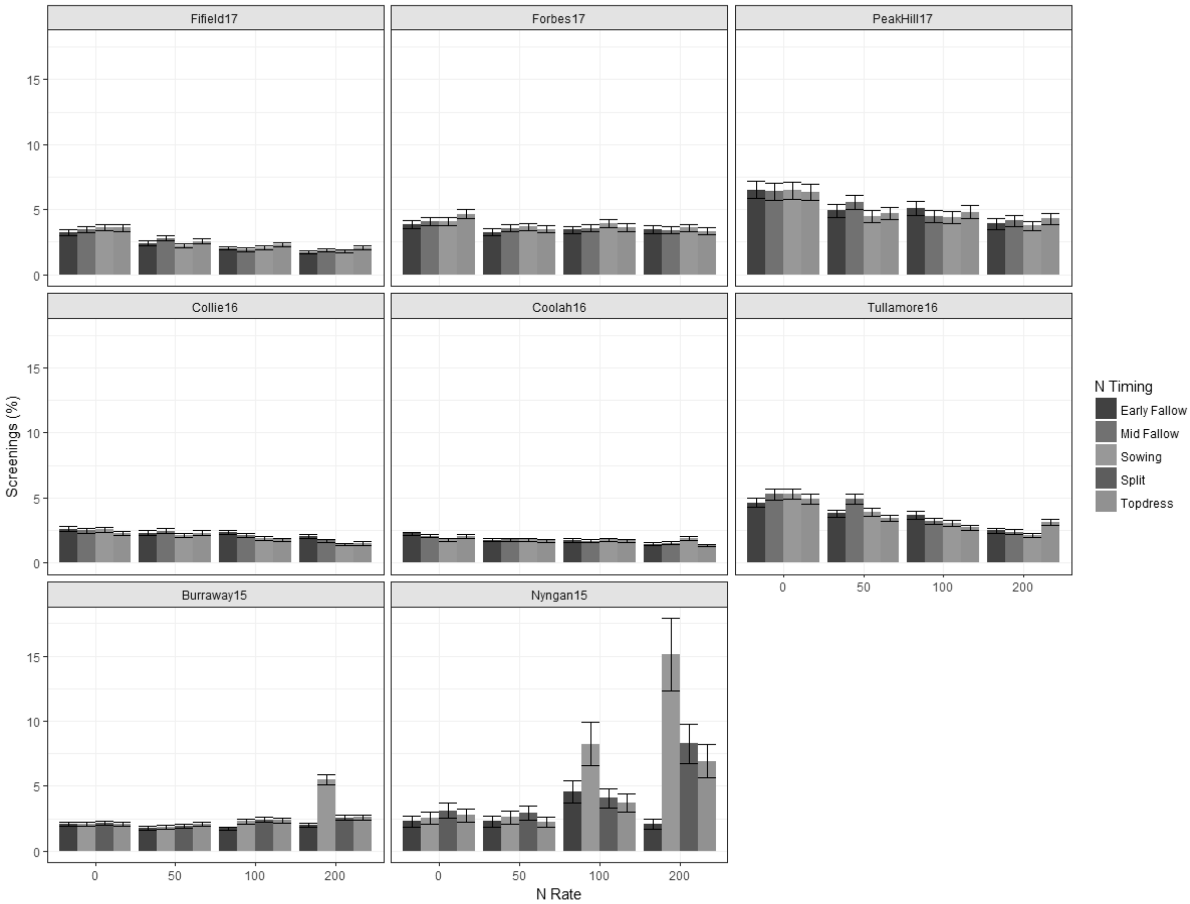

Figure 3. Screenings (%) response to four rates of applied N and four application timings (combined results of 2 varieties) (Note: Split treatment at Burraway and Nyngan only, replacing mid fallow treatment applied at other locations).

Discussion

The three years of this trial had very different seasonal conditions. 2015 season had an average start and dry finish, 2016 was a very wet year while 2017 was dry for most of the season with rain and cooler conditions in the spring and late stages of crop maturity, however all seasons had typical fallow rainfall.

With the exception of the Forbes 2017 site, all sites demonstrated N responsiveness with the magnitude of response dictated by the seasonal conditions/in-crop rainfall. However, in terms of application timing, there was no clear or consistent yield or grain quality benefit to application of N in the fallow when compared to application at sowing.

These findings are similar to that found by trials undertaken by Northern Growers Alliance (Daniel *et al* 2018) where in 10 out of 11 trials they found no advantage of application of N in the fallow compared to application at planting.

One possible reason for this might be that N moves less in the soil than what is considered the current convention. Soil testing by GOA within these trials failed to show any significant amount of either vertical or lateral movement of N despite reasonable amounts of rainfall. Daniel *et al* (2018) found in their investigations that most of the N applied in the fallow was still in the top 15 cm of soil at planting. A key assumption for this research was that rainfall in the fallow would be sufficient to move N deeper into the profile however this appears not to be the case, and upon reflection there is likely to be close correlation between the relatively low fallow efficiencies experienced in the Central West and the lower than expected N movement.

It is possible that there are still benefits to be gained by increasing the N deeper in the profile, however it is evident that applying N (broadcast or drilled) in the fallow does not achieve this objective. There may be benefit in looking into options for rapid N transfer deeper into the soil, or looking at increasing the overall soil fertility, where the fertiliser applied in one crop, will also have benefit for the subsequent crop.

However, it is worth highlighting that although the fallow application timings did not often result in any benefit in terms of improved yields, they sometimes did result in reduced relative efficiencies when applied at high rates. For example, a small number of cases at Collie 2016 and Tullamore 2016 showed that applying N in the fallow period resulted in less yield than achieved when applied at sowing or topdressing. The explanation of any potential reasons for these reductions are not detailed in this paper, other than to say that situations were observed where banding high rates of N in the fallow caused penalties in terms of N response.

Conclusion

Overall, applying N fertiliser in the fallow periods did not consistently result in improved N efficiencies in terms of improved yields or grain quality over that of more conventional timings. However, some situations were observed where fallow applications out yielded topdressing timings, however the improved efficiency was tempered by the higher protein levels in the topdressing timings. Conversely there were a small number of cases where fallow application at high rates resulted in poorer outcomes than those of later N application timings.

In almost every case the overwhelming response was to N rate, regardless of its timing. Suggesting growers should focus more on applying the appropriate amount of fertiliser and be less concerned with the timing. If applying N in the fallow period facilitates more convenient input of N into the farming system, growers should not be concerned about doing so.

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ⓟ Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994

Windrow timing and harvest management decisions in canola

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'They do 'what' in the paddock?' concurrent session

Integrating livestock into cropping systems – using diverse feed sources to optimise profit

Cam Nicholson, Nicon Rural Services

Key words

livestock, mixed farming, grazing crops, stubble, risk, decision making

GRDC code

SFS00028

Call to action/take home messages

- The feed sources in a mixed farming operation (pasture, winter crops, stubble, summer fodder) are more variable than pasture and greater skill is required to match feed supply with animal demand.
- The pasture component in a crop rotation can be used successfully to control weeds, build nitrogen and improve soil conditions, but there are pitfalls.
- Mixed farming reduces downside risk compared to straight cropping, but usually lowers the chances of making very big profits.
- Integration and diversity created by mixed farming creates a level of complexity that requires sophisticated decision making to be successful.

Livestock numbers on farms in the traditional mixed farming areas of Australia have been in decline since the 1990s, although in the past few years these numbers have stabilised and are now on the increase (Bell et al, 2014). The reasons for the fall are a combination of commodity prices, the adoption of full stubble retention, operator frustration with the competition for time and resources between crop and livestock and the rapid technological advances in cropping compare to the animal system. However with major improvements in livestock and wool prices, a questioning of the no till means no livestock philosophy, the emerging challenges with weeds and organic matter decline and the desire by growers to increase on farm diversity to manage risk, means there is renewed interest in re-introducing or expanding livestock on grain farms.

Unfortunately decades of giving livestock the 'poor cousin' status has meant infrastructure has degraded or been removed and management skills lost with generational change. New knowledge created in the livestock industry in the past 20 years is unfamiliar to many growers and advisors. A 2013 survey of farm business operators showed not only their confidence in using the whole farm feed base was lower than their confidence with other practices such as stubble management, crop rotations and integrated weed management, but this has declined over the previous four years (Roberts, 2013).

The Grain and Graze program has been operating during this declining and now emerging resurgence in livestock, running from 2003 to 2016 across large parts of the mixed farming zones of Australia. The program started through a collaboration of the Grains Research and Development Corporation (GRDC), Meat and Livestock Australia, Australian Wool Innovation and the former Land and Water Australia. The second phase from 2009 to 2013 involved the GRDC in partnership with the Department of Agriculture and the final smaller extension phase just involved the GRDC (2014 to 2016).

This paper attempts to summarise the take home messages from growing and utilising various feed sources in a mixed farming system. It is not a complete summary of the work undertaken in Grain and Graze and readers are encouraged to visit the Grain and Graze website for more information (www.grainandgraze3.com.au).

Managing feed sources

Fortunately a lot is known about what animals need to reach certain levels of performance and the consequences if these benchmarks are not reached. Matching the right quantity and quality of feed to animal demand is an ongoing challenge even for single enterprise livestock graziers. In a mixed farming operation, there are different sources of varying quality and quantity feed at different times of the year (figure 1). Making best use of these different sources can be challenging because of the variability of feed quantity and quality.

Table 1. Likely availability of different feed sources during the year (lighter grey represents less reliability).

Feed source	**Availability**											
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Winter crops												
Crop stubbles												
Winter fodders												
Summer fodders												

Considerable work was undertaken in the Grain and Graze program to appreciate the opportunities presented by these additional feed sources and how they can be utilised while minimising any downside impacts.

Winter crops

One obvious feed source is winter crops, especially cereals. The decade of work in Grain and Graze on grazing winter crops is summarised in the *Grazing Cropped Land* booklet (Nicholson et al, 2016). Most work has been on cereals, especially wheat and barley. Information was collected on the dry matter production (table 1) at different times of sowing and the herbage quality (figure 2).

Table 2. Range in dry matter (kg/ha) for wheat and barley trials at different sowing times for low rainfall (n=48) and high rainfall (n=149) environments across Southern and Western Australia.

Rainfall zone	Crop	Time from sowing (weeks)	Dry matter (kg/ha)		
			Average	Min	Max
Low	Wheat	~ 6	**150**	120	170
	Barley	~5	**300**	130	760
	Wheat	~ 9	**300**	70	900
	Barley	~8	**600**	220	1320
High	Wheat	~ 9	**740**	510	1310
	Barley	~9	**1270**	390	2440
	Canola	~11	**670**	110	1490
	Wheat	~ 12	**1190**	100	3410
	Barley	~ 12	**1490**	170	2850
	Canola	~14	**1460**	210	2450

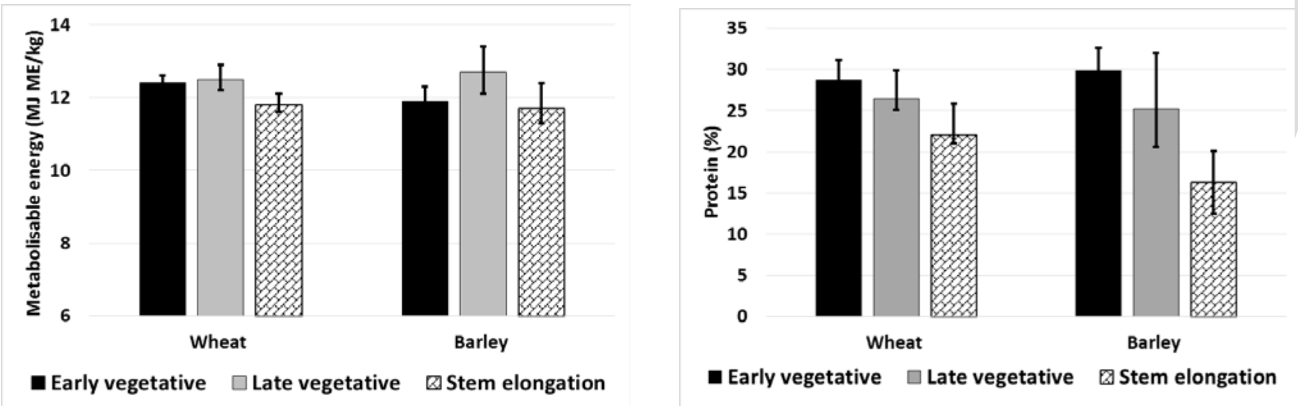

Figure 1. Range in metabolisable energy (left) and protein (right) for wheat and barley trials at different growth stages (n=125). Error bars is one standard deviation.

A common fear of growers and agronomists is the impact grazing may have on grain yield (Creelman et al, 2015). Measurements comparing grain yields with and without defoliation up to growth stage 30 over a 10 year period showed both decreases and increases in grain production (figure 2). These results were from multiple varieties, grazing regimes and sowing dates. A third of all measurements resulted in a small grain yield loss (< 250 kg/ha). Equally a third of measurements resulted in an increase in grain yield, primarily due to reductions in disease pressure and lodging.

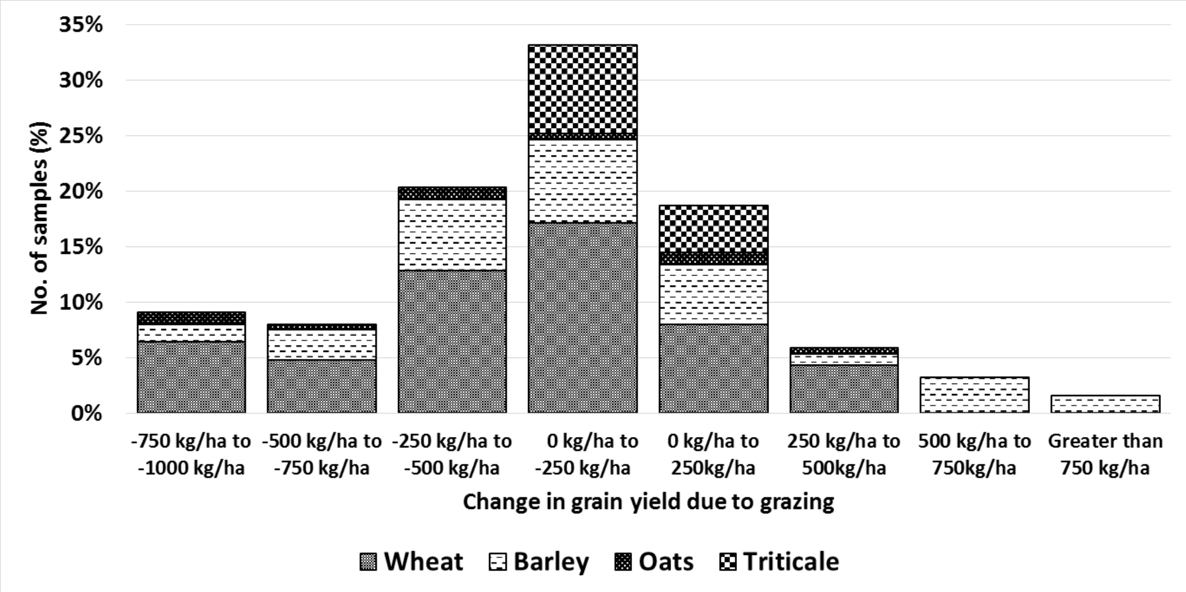

Figure 2. Change in cereal grain yield (kg/ha) due to grazing for wheat, barley, oats and triticale (n=187).

Multiple factors are believed to contribute to the range in responses including variety selection, crop growth stage and residual biomass left at the end of grazing, length of time between grazing and anthesis and post grazing conditions (moisture and heat). Key guidelines to emerge for grazing winter crops to minimise yield loss are presented (table 3).

Table 3. Key recommendations on grazing winter crops

Recommendation	Reasoning
Sow winter varieties early (March - April), on opportunistic soil moisture	Earlier sowing increases likely dry matter production providing the opportunity for earlier grazing and longer periods of biomass recovery.
Graze earlier (June/July) rather than later	The time and environmental conditions between the end of grazing and anthesis has a major influence on grain yield. The longer this recovery period the better.
'Clip graze' in lower rainfall or moisture stress years	Retaining some leaf area reduces the amount of new biomass that needs to be regrown after grazing but before anthesis.
Complete grazing before GS 30	Grazing after GS 30 may remove elongating grain ears.
Match variety to the growing environment	Grazing will also delay maturity and with long season varieties may expose ripening crops to heat and moisture stress.

Other important findings from the grazing winter crop work include;

- Canola established at a 'traditional' late autumn sowing time and then grazed in winter commonly incurred significant yield losses compared to ungrazed canola. Early autumn, summer or even spring sowing appears to provide a more suitable dual purpose canola grazing opportunity.
- Stubble will be reduced after grazing, even when defoliated at the early vegetative growth stage.

- Grazing resulted in visual changes to the soil surface but no changes to subsequent water infiltration, soil water storage or crop yields. Grazed soils had a remarkable ability to 'repair' themselves.
- Grazing does not necessarily increase weeds, however weed free paddocks are the safest to graze. Experiments showed weeds increased, stayed the same or decreased as a result of grazing but there was no consistent reason for the change.

Crop stubbles

Winter crop stubbles can provide a valuable source of feed, primarily from residual grain and green shoots from shot grain and weeds. Standing straw and trash have much lower quality (energy and protein) which are below maintenance requirements for all classes of livestock. Therefore animal weight gain is directly linked to the amount of grain and green material in the stubble (assuming no supplementary feeding).

Improved efficiency of harvest machinery means not all crop paddocks have grazing value and only those with sufficient high energy material should be grazed, otherwise sowing and herbicide efficacy problems can be created with livestock laying over standing straw. Experiments indicate there needs to be at least 40 kg/ha of residual grain or 40 kg/ha of green material for a sheep to maintain or gain weight (although the gain is difficult to predict). Below these values animals lose weight, irrespective of how much straw or leaf trash remains.

A simple guide to help assess the amount of grain in a stubble is presented (table 4) along with photos of different levels of green materials (figure 3).

Table 4. Cereal grains and green shoots counts needed per 0.1 m^2 to obtain 20, 40, 60 or 80kg residual grain or green material per hectare.

Number of cereal grains per 0.1 m^2 and approx. quantity of grain/ha		Number of cereal green shoots per 0.1 m^2 and approx. quantity of green/ha as dry matter	
Grains counted (number / 0.1 m^2)	**Equivalent quantity of grain (kg/ha)**	**Green shoots counted (number / 0.1 m^2)**	**Equivalent quantity of DM (kg/ha)**
6	20	7	20
13	40	14	40
20	60	21	60
26	80	28	80

The equivalent of 40 kg/ha for crop legumes is approximately 4 grain per 0.1 m^2 quadrant for lupins, 2 for field peas and chickpeas and 1 for faba beans.

40 kg/ha green (some shoots eaten) **60 kg/ha green** **140 kg/ha green**

Figure 3. Visual indication of green shoot material available for grazing

Other critical points when grazing stubble;

- Grazing should be conducted to retain between 50% and 70% groundcover so as to avoid wind erosion or decrease water infiltration.
- In medium and low rainfall areas, removing green material in stubbles is recommended to conserve soil moisture, therefore only the residual grain should be considered as having grazing value.

Winter fodders

Unlike a 'grazing only' situation, winter pastures in a cropping rotation are commonly grown for reasons other than just feed. Most commonly fodder are used to assist in weed control before the next cropping phase, to add biological nitrogen and to improve overall soil condition. Maximising fodder production for livestock is therefore only one of a number of possible objectives. When these objectives are combined with a farmer's affinity towards and access to livestock, the fodder phase length they want, preparedness to resow each year and the potential 'weed' problem created in the subsequent crop, it creates a massive number of possible winter pasture options. There is no single 'right' answer.

The most suitable option needs to be formulated on a case by case basis, taking into account the relative importance of multiple objectives and other considerations described above. To assist with these considerations, the advantages and disadvantages for different legume and grass winter pastures tested in the Grain and Graze program are presented (tables 5 and 6).

Other key observations worth highlighting;

- There was a very large variability in overall fodder production from year to year. While annual production differences were anticipated because of seasons, the range was 0.5 to 12 t/ha. In general, grass fodder grew more dry matter of similar quality than legumes grown at the same time.
- Annual ryegrass can be dramatically reduced (to <10%) after 2 years of a pasture phase if seed set can be prevented. However it is essential to control late germinating annual ryegrass (October – November) that grows when applied herbicides are no longer effective. In contrast wild radish remains problematic, with no reduction in plant numbers recorded after many years of a fodder phase.
- Growing fodder legumes does not guarantee an accumulation of soil nitrogen and where accumulation does occur, it may be lower than the common rules of thumb of about 20 kg of shoot N/t dry matter (Peoples et al, 2013). Measurements of total soil nitrogen

accumulation under legumes ranged from 0 to 150 kg/ha. There are multiple reasons why sub optimal fixation may occur (legume species, rhizobia efficiency, residual soil N) but one suggestion is the residual effect of common cropping herbicides, especially group B (Martin Barbetti, pers comm Nov 2016).

- Lucerne was the least beneficial fodder break crop in the 500mm+ rainfall areas because overall dry matter production was less than other fodder legumes, it captured most soil nitrogen so the next crop started from very low nitrogen levels and the release of organic nitrogen was much slower compared to other legumes (peaked around year 3). In addition, lucerne dried the soil profile more than other legumes which resulted in a greater soil moisture deficit if winter rainfall after removal was below average.
- Crops sown in years after a legume break that receive below average growing season rainfall can be oversupplied by the mineralised soil N, leading to higher screenings.

Table 5. Advantages and disadvantages of various fodder legumes

Attributes	Annual fodder legumes (arrow leaf, Persian, balansa, sub clover, medic)		Annual pulses (peas, beans)		Perennial legumes (lucerne)	
	Advantages	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**
Feed quantity		Generally grows less dry matter than grasses	Generally grows more dry matter than fodder legumes		Out of season growth if summer rainfall occurs	Slow to establish and reach maximum production (usually year 2)
		Sub clover may grow less in first year while building the seed bank	Quick to establish and achieve ground cover			Annual production less than most other species
		Winter growth may be slow especially if not sown early				
Feed quality for grazing	High quality feed when vegetative, usually better than grasses but not cereals or canola				Out of season high quality feed if rainfall occurs	Grazing lush lucerne can create digestive issues e.g. bloat, red gut
Grazing	Provides in season grazing			Cannot be grazed in the vegetative stage	Can provides out of season grazing if rainfall occurs	
Seeding	Can sow same species year on year	May need to be re-sown each year - depending on species or if seed set is compromised by weed seed set control		Unable to sow same crop year on year	Only sown once	
Carry over seed / removal		May create a ‘weed’ problem when in the next cropping phase.	Unlikely to cause a ‘weed’ issue in subsequent crops		No carry over seed	Established lucerne can be hard to kill
Disease break	Provides an effective grass disease break		Provides an effective grass disease break	Builds pulse disease population	Provides an effective grass disease break	

Nitrogen	Provides nitrogen but amount depends on effective nodulation	Unable to control mineralised nitrogen release	Provides nitrogen but amount depends on effective nodulation	Unable to control mineralised nitrogen release	Provides nitrogen but amount depends on effective nodulation	Very effective at scavenging any residual soil nitrogen
	Provide rapid mineralisation from dry mater		Provide rapid mineralisation from dry mater		Release of nitrogen over many (3+) years	No rapid release on nitrogen because of large tough roots that have to break down. Sub optimal soil N may occur in the first year after removal.
Herbicides	Provides some alternative pre and post emergent herbicide options	Some herbicides may affect nitrogen fixation	Provides some alternative pre and post emergent herbicide options	Some herbicides may affect nitrogen fixation	Provides some alternative pre and post emergent herbicide options	Some herbicides may affect nitrogen fixation
Green manure	Can be green or brown manured effectively		Can be green or brown manured effectively			Difficult to manure
Fodder conservation	Higher quality fodder, usually of better quality than grasses or cereals		Limited fodder conservation options		Good quality fodder	
Post spring grazing	Nutritious carry over feed	Grazing can result in reduced ground cover	Nutritious carry over feed	Grazing can result in reduced ground cover	Retains quality late into the season. Possible regrowth if rainfall occurs out of season	
Soil moisture	Dries soil profile similar to cereal crop		Dries soil profile similar to cereal crop			Dries soil profile more aggressively than other fodders, so may compromise stored soil moisture for the following crop

Summer fodders

Summer fodder crops have lost favour with many advisors and farmers in the Southern regions. The findings that retained soil moisture on fallows increases water use efficiency and that the gains in grain yield outweighed keeping the weeds for summer stock feed (Hunt, 2013) meant there was no incentive to include a summer water using plant. This thinking was widely adopted across Southern Australia, including the high rainfall zone. However work from Grain and Graze showed the need to conserve soil moisture was less applicable in areas of higher winter rainfall. In these areas the soil type results in high evaporative losses of soil moisture over summer through capillary rise, even without any plants actively growing and with reasonable amounts of retained stubble (approximately 4 t/ha). In addition, the limited water holding capacity of most soils in the high rainfall zone (HRZ) combined with the high probability of winter rainfall exceeding the soil water holding capacity, meant stored summer rainfall was of limited value to the next winter crop and in some cases led to more rapid waterlogging the next winter (Creelman, 2016).

Eight trials in the HRZ clearly illustrated there was no impact of growing a summer fodder for grazing on the subsequent winter crop, although grazing did significantly reduce the available soil nitrogen at the time the winter crop was sown (Nicholson, 2015).

These insights, combined with the release of canola with a strong vernalisation requirement, enabled out of season sowing of a brassica to be used for grazing over summer, followed by locking up the grazed plants to take through as a traditional winter crop for harvest. The quality of the canola dry matter was comparable to other fodder brassicas, with dry matter typically between 0.5 t/ha and 4 t/ha depending on summer rainfall. Subsequent grain yields have proved equal if not better than ungrazed canola sown in late autumn (GRDC, 2016). Significantly earlier sowing of wheat with strong vernalisation requirements is also being tried.

The long term disease, nitrogen and weed implications still need to be understood, however the approach provides an exciting way to change the thinking of utilising a dual purpose crop.

Conclusion

A lot has been learnt in the Grain and Graze program about the feed base opportunities arising from running livestock in a cropping operation. There are many potential benefits but to realise these will require changes to the way we think about livestock (class of animals, ownership models, essential infrastructure) and the cropping operation (what and when to sow, when to graze and how to include fodders in a rotation). These are complex decisions.

Useful resources

www.grainandgraze3.com.au (an archive of all publications, tools and resources from the program since 2003).

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Dual-purpose cereal variety performance in NSW farming systems

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Key words

grazing, dry matter, grain recovery, flowering time

GRDC code

DAN00184

Call to action/take home messages

- Cereal varieties differ in their forage production; growers need to balance this against grain yield recovery and maximum grain quality (based on varietal grade classification).
- Matching a variety's flowering time and maturity to the local growing environment is important for maximising grain yield recovery following grazing of a dual purpose variety.
- Selecting a suitable variety based on the region, an appropriate sowing time, grazing management and crop nutrition are the main parameters for growing a successful dual-purpose crop.
- The newly released wheat varieties LRPB Kittyhawk⛉ and Longsword⛉ are suited for use as dual-purpose grazing crops across NSW and have performed comparably with the industry benchmark EGA Wedgetail⛉.

Introduction

Mixed farming systems in NSW including dual-purpose grazing crops have a long history. In recent years dual-purpose cropping systems have attracted more consideration because of greater profitability and sustainability.

Dual-purpose grazing crops give growers an opportunity to produce additional forage in key periods of the year when pasture systems might not be able to meet livestock requirements. They can be substituted for grain-only crops or, in more intensive livestock operations, for forage-only crop types. Selecting the right crop type, variety and then managing them properly can boost returns across both the livestock and grain production units in the farm business. The most common crops used in mixed farming and dual-purpose cropping are cereals. A jointly funded project between the NSW Department of Primary Industries (NSW DPI) and the Grains Research and Development Corporation (GRDC) has been evaluating new cereal varieties for suitability as dual-purpose types across NSW for the past four years. This paper presents some of the results of this project.

Methods

The project included a series of grazing cereal trials across NSW in 2016 and 2017. The trials were sown from the first week of April to the first week of May in 2016, and from the last week of March to the first week of April in 2017.

Key measurements recorded at all sites included dry matter (DM) production through the season at key periods – mid tillering and then before stem elongation i.e. growth stage (GS)31 on the Zadoks scale (Zadoks et al. 1974). The experiments are then grazed by livestock following DM measurement and allowed to recover for either further DM assessment or carried through to grain production.

Growth stages were also recorded for all varieties when DM measurements were taken. Grain yield and the grain quality parameters such as grain protein, screenings, grain size and test weight were also measured at harvest.

At Wagga Wagga, the core research site, as well as measuring variety performance, also assessed the influence of sowing time on DM production by varieties, and the time of flowering response by varieties of wheat and triticale. Additional plant measurements such as flowering time, number of tillers and leaf area on a core group of varieties were recorded at the Wagga Wagga site to better understand how the different varieties accumulate DM and then recover for grain production.

Results and discussion

Seasonal overview

The results discussed in this paper are from the 2016 and 2017 seasons. The 2016 season was one of above-average rainfall compared with 2017. 2017 was dominated by below-average rainfall through winter and early spring (Table 1), with seasonally late frosts throughout NSW. The growing season rainfall (April–November) for the sites in 2016 was 24–75% above the long-term average (LTA) for the sites, whilst 2017 was 9–68% below LTA. When viewing the results, the distribution and amount of rainfall needs to be considered, as this significantly affected the early forage production and then the opportunity for varieties to recover and produce grain.

Table 1. Monthly rainfall (mm) for trial sites in NSW for 2016, 2017 and the long-term average (LTA; mm) rainfall for the closest Bureau of Meteorology weather station.

	Bathurst		**Cudal**		**Holbrook**			**Purlewaugh**		
Month	**LTA**	**2016**	**LTA**	**2016**	**LTA**	**2016**	**2017**	**LTA**	**2016**	**2017**
January	68	105	63	49	45	75	31	90	111	48
February	58	13	53	0	66	28	12	81	23	21
March	52	40	52	47	54	24	37	63	35	142
April	42	23	44	58	42	16	78	52	18	9
May	41	39	47	63	49	100	44	54	63	19
June	44	104	53	122	67	94	6	57	126	10
July	49	105	53	95	67	80	58	55	39	2
August	50	88	52	78	70	69	80	53	74	15
September	47	139	49	163	64	147	20	51	183	4
October	59	49	56	53	54	45	53	59	63	67
November	61	60	54	57	61	37	78	65	20	19
December	66	45	59	24	45	43	95	71	33	26
Total	640	810	636	809	714	756	593	751	788	381

	Somerton			**Spicers Creek**			**Wagga Wagga**		
Month	**LTA**	**2016**	**2017**	**LTA**	**2016**	**2017**	**LTA**	**2016**	**2017**
January	79	97	82	72	88	0	38	59	11
February	64	18	11	61	0	0	37	20	16
March	43	2	100	53	46	113	38	43	35
April	34	2	10	45	19	6	39	11	33
May	39	80	55	47	63	51	44	102	20
June	41	124	55	52	108	13	51	100	3
July	38	33	14	52	95	10	49	87	60
August	37	101	20	51	76	17	48	68	33
September	39	122	3	48	162	7	49	178	4
October	53	65	80	56	79	86	51	79	52
November	60	10	74	64	37	64	41	28	48
December	66	38	48	61	26	42	41	54	131
Total	594	693	552	656	798	408	527	827	444

Wheat, triticale and barley variety evaluation

In recent years breeding companies have increased investment in evaluating and releasing cereal varieties that are potentially suitable for grazing and grain production. The newer releases now offer growers a wider choice of maturity compared with EGA Wedgetail⊕, which has been the industry benchmark for over a decade. These newer varieties not only offer differences in maturity and flowering time, grain quality and disease tolerance, they have different lengths of vegetative and reproductive phases, which allows growers to more closely match their local growing conditions to maximise forage production and grain yield.

The project evaluated 48 wheat, triticale and barley entries in 2016 and 36 in 2017, of which over half were new or late stage breeding lines from various companies across Australia.

In this paper, only the dry matter and grain yield results are presented; the full seasonal report for 2016 is available on the NSW DPI website and includes grain quality for the wheat, triticale and barley lines, dual-purpose oat evaluation and a brief economic comparison of the varieties at selected sites.

When comparing individual varieties, not only look at the difference in dry matter and grain yield, but also the stability of rank across the various trials as an indicator of reliable performance.

There are significant difference between early dry matter production by varieties (Tables 2 and 3), with the slower winter types being less vigorous compared with the fast–medium winter types and the mid-season spring types. These differences were not as significant for the second dry matter reading following grazing (Tables 4 and 5). The impact of grazing on a variety’s ability to recover is also shown in Tables 4 and 5. The shorter season varieties such as Tuckerbox and EGA Gregory which had high initial dry matter production, showed poor dry matter production at the second measurement as the plants were damaged (loss of growing points) compared with the more prostrate later developing varieties.

Grain yield recovery (Tables 6 and 7) was driven in both seasons by rainfall following grazing, with the later-maturing varieties taking advantage of the wet spring in 2016. In 2017 it was combination of the late rain and frosts that affected a variety’s ability to perform. Varieties in 2017 that were less developed at the time of the frost events avoided damage and also matured later, so were able to take advantage of the rain in October and early November.

Recently released and evaluated lines include:

- Cartwheel – A long-season dual-purpose triticale that is suitable for an early March to early April sowing. A stripe rust resistant replacement for Tobruk. Straw strength is good and has shorter stature than Tobruk. In each of the 2016 and 2017 multi-environment trial (MET) analyses, there was no significant difference in dry matter production compared with Tobruk. Grain yield after grazing was also equivalent to Tobruk.

- Kowari – A new triticale variety registered in 2016. This longer season variety is a tip-awned, dense grained triticale that suits early sowing and grazing. Limited testing in 2016 only at Wagga Wagga, more widely tested in 2017. Kowari showed no difference in DM1 compared with Tobruk, but significantly lower dry matter production at DM2 in the across sites MET analysis. Grain yield was significantly lower than Tobruk.

- Longsword – A fast-maturing winter wheat, derived from Mace, most suited to April sowings. Longsword is a true winter wheat and has three winter genes and is relatively quick to mature. This earlier flowering and quicker maturity provides growers in medium–low rainfall environments a more suitable variety for their growing environment then EGA-Wedgetail or similar mid-winter types. Longsword[A]’s DM1 and grain yield in the across site MET analysis for 2016 and 2017 was not significantly different from EGA_Wedgetail. In 2016 DM2 compared across all sites was significantly higher than EGA_Wedgetail.

- LRPB Kittyhawk – A winter wheat, with a similar maturity and planting window to EGA Wedgetail. Has improved stripe rust resistance and grain quality over EGA Wedgetail. Dry matter production and grain yield from the MET analysis across all sites in 2016 was not significantly different from EGA Wedgetail. In 2017 across all sites LRPB Kittyhawk had lower dry matter production at the first grazing, but DM2 and grain yield were not significantly different from EGA Wedgetail⊕.

- RGT Accroc – A red winter wheat of feed grain quality, suited to the higher rainfall zones. Suitable for sowing late February to early April for early grazing. Good stand ability. Flowering time and maturity is later than EGA Wedgetail⊕. RGT Accroc's performance compared with EGA Wedgetail⊕, has been variable with consistently higher grain yield following grazing in 2016, but not significantly different in the 2017 season. Dry matter production has been consistently lower than EGA Wedgetail⊕ at the first grazing.
- Sunlamb⊕ – An awnless, long-season spring wheat suited to early April plantings, with strong photoperiod sensitivity. Suited to grazing and grain recovery across NSW. Similar flowering time to EGA Wedgetail⊕, and a few days earlier than Naparoo⊕(Matthews et al. 2017). Grain yield performance has been variable across seasons, with equivalent grain yield in 2016, but significantly lower grain yield in the 2017 season. Dry matter production was significantly lower in both 2016 and 2017 seasons for the first and second grazing.

Table 2. Dry matter (DM1) (kg/ha) for wheat, triticale and barley varieties across NSW in 2016. Each varieties rank in the respective trial is shown, 2016. (Note: only released varieties are reported).

Variety	Crop type	Bathurst		Holbrook		Cudal		Purlewaugh		Spicers Creek		Somerton		Wagga		**All sites**	
		DM1	Rank	DM1	Rank	DM1	Rank	DM1	Rank	DM1	Rank	DM1	Rank	DM1	Rank	**DM1**	**Rank**
Urambie	Barley	4290	4	595	47	1751	16	2883	25	3218	4	2301	21	1422	29	**2081**	**10**
Cartwheel	Triticale	3778	18	1463	12	1645	28	2882	26	2634	16	1827	41	1417	30	**1946**	**24**
Crackerjack2	Triticale	4630	1	1498	9	1865	11	2708	36	2379	28	2267	26	1559	12	**2145**	**8**
Endeavour	Triticale	4272	5	1492	10	2112	1	3097	19	2887	10	2318	18	1554	14	**2182**	**6**
Kowari	Triticale	–	–	–	–	–	–	–	–	–	–	–	–	1565	10	**1983**	**18**
Tobruk	Triticale	3293	40	1559	6	1553	33	3293	12	2587	19	1864	39	1438	26	**1911**	**29**
Tuckerbox	Triticale	3478	31	2020	1	1838	13	3766	2	3407	1	3234	1	2042	1	**2385**	**1**
DS Pascal	Wheat	3506	30	1322	22	1565	32	3224	13	2183	36	2180	30	1433	27	**1894**	**30**
EGA Gregory	Wheat	4391	2	1202	26	1692	24	3649	3	3162	6	2553	7	1450	25	**2271**	**3**
EGA Wedgetail	Wheat	3579	24	1368	19	1853	12	3200	15	2710	14	2521	10	1601	6	**2078**	**11**
Longsword	Wheat	4200	6	1426	16	2023	4	3790	1	2627	17	2446	14	1732	3	**2215**	**5**
LRPB Kittyhawk	Wheat	3442	33	1325	21	2029	3	2661	37	2891	9	2313	19	1489	20	**1990**	**17**
Mackellar	Wheat	3079	46	874	43	1448	42	2041	47	1674	46	1838	40	916	47	**1451**	**45**
Manning	Wheat	3813	17	1383	17	1685	25	2861	29	2513	21	2482	12	1323	38	**1951**	**21**
Naparoo	Wheat	3413	34	1184	30	1910	7	3356	9	2699	15	2548	9	1495	19	**2023**	**15**
RGT Accroc	Wheat	3100	45	1202	27	1987	6	3002	23	2354	30	1922	36	1577	7	**1881**	**33**
SF Adagio	Wheat	3459	32	953	40	1575	31	2579	41	2172	37	1907	38	1249	43	**1724**	**41**
SF Scenario	Wheat	4069	9	1052	33	1884	9	3323	11	1989	43	2914	2	1283	39	**1977**	**19**
Sunlamb	Wheat	3283	41	1375	18	1631	29	2575	42	2717	13	2896	3	1431	28	**1889**	**31**
	Wheat	3650	23	1543	7	1551	34	3627	4	3382	2	2426	16	1663	4	**2177**	**7**
Whistler	Wheat	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**–**	**–**
Trial mean		3631		1260		1679		2989		2504		2236		1433		**1933**	
LSD 5%		845		200		441		713		568		475		195		**158**	

Table 3. Dry matter (DM1) (kg/ha) for wheat, triticale and barley varieties across NSW in 2017. Each varieties rank in the respective trial is shown, 2017. (Note: only released varieties are reported).

Variety	Crop type	Holbrook		Purlewaugh		Spicers Creek		Somerton		Wagga		**All sites**	
		DM1	Rank	DM1	Rank	DM1	Rank	DM1	Rank	DM1	Rank	**DM1**	**Rank**
Urambie	Barley	2001	27	1056	28	1798	17	1693	28	1213	22	**1563**	**25**
Cartwheel	Triticale	2219	12	1447	7	1736	19	2016	6	1326	14	**1772**	**11**
Crackerjack2	Triticale	–	–	–	–	–	–	–	–	–	–	**–**	**–**
Endeavour	Triticale	2562	2	1370	10	1962	10	1807	23	1291	18	**1754**	**12**
Kowari	Triticale	2320	6	1167	22	2075	6	1909	12	1388	10	**1750**	**13**
Tobruk	Triticale	2177	15	1450	6	1808	15	2031	5	1360	12	**1775**	**10**
Tuckerbox	Triticale	–	–	–	–	–	–	–	–	–	–	**–**	**–**
DS Pascal	Wheat	1567	36	1205	19	1647	25	1487	35	980	35	**1369**	**35**
EGA Gregory	Wheat	2104	18	1032	30	1682	20	1817	22	1163	24	**1543**	**27**
EGA Wedgetail	Wheat	2510	4	1391	9	1947	11	1712	27	1444	7	**1822**	**4**
Longsword	Wheat	2043	22	1212	18	1907	12	1900	14	1342	13	**1681**	**17**
LRPB Kittyhawk	Wheat	2041	24	1473	5	1657	22	1832	21	1128	27	**1606**	**21**
Mackellar	Wheat	1885	30	1104	26	1128	36	918	36	913	36	**1240**	**36**
Manning	Wheat	1663	35	873	35	1328	35	1860	17	1048	31	**1389**	**34**
Naparoo	Wheat	2028	26	1532	4	1664	21	1838	18	1000	34	**1565**	**24**
RGT Accroc	Wheat	1849	33	905	34	1507	32	1615	31	1305	15	**1525**	**28**
SF Adagio	Wheat	–	–	–	–	–	–	–	–	–	–	**–**	**–**
SF Scenario	Wheat	–	–	–	–	–	–	–	–	–	–	**–**	**–**
Sunlamb	Wheat	2051	21	1045	29	1644	26	1664	30	1088	28	**1523**	**29**
Sunmax	Wheat	2166	16	1713	2	2031	7	1937	10	1386	11	**1822**	**5**
Whistler	Wheat	2318	7	1215	17	1819	14	1882	16	1474	5	**1793**	**9**
Trial mean		2123		1239		1786		1826		1286		1656	
LSD 5%		393		326		384		534		265		**168**	

Table 4. Dry matter (DM2) (kg/ha) for wheat, triticale and barley varieties across NSW in 2016. Each varieties rank in the respective trial is shown, 2016. (Note: only released varieties are reported).

Variety	Crop type	Bathurst		Holbrook		Cudal		Purlewaugh		Spicers Creek		Somerton		Wagga		**All sites**	
		DM2	Rank	DM2	Rank	DM2	Rank	DM2	Rank	DM2	Rank	DM2	Rank	DM2	Rank	**DM2**	**Rank**
Urambieⓓ	Barley	3654	18	373	47	2599	13	2543	14	2237	14	3011	1	1451	24	**2304**	**14**
Cartwheelⓓ	Triticale	3696	17	1101	11	2488	18	2669	12	2769	6	2399	10	1566	9	**2374**	**10**
Crackerjack2	Triticale	3449	25	1027	14	2222	30	2150	34	1735	34	2026	28	1512	19	**2057**	**27**
Endeavourⓓ	Triticale	4058	7	1220	5	2773	6	2406	21	2523	11	2333	14	1558	11	**2400**	**6**
Kowari	Triticale	–	–	–	–	–	–	–	–	–	–	–	–	1391	27	**2163**	**23**
Tobrukⓓ	Triticale	3928	10	1204	6	3165	2	3124	7	2758	8	2128	23	1533	15	**2384**	**8**
Tuckerbox	Triticale	2434	44	1114	8	1174	47	1229	47	1334	45	2449	7	1260	39	**1820**	**45**
DS Pascalⓓ	Wheat	1907	48	714	32	1528	44	1426	45	1293	46	1877	39	1170	45	**1604**	**48**
EGA Gregoryⓓ	Wheat	2092	46	660	37	1439	46	1347	46	1242	47	2179	20	1118	48	**1404**	**50**
EGA Wedgetailⓓ	Wheat	3401	26	1005	15	2604	12	2449	15	1745	33	2115	24	1543	13	**2164**	**22**
Longswordⓓ	Wheat	4246	2	1131	7	2730	9	2419	20	1924	24	1913	36	1674	5	**2380**	**9**
LRPB Kittyhawkⓓ	Wheat	3722	15	907	23	2164	32	2429	17	1896	25	2358	13	1453	23	**2196**	**21**
Mackellar	Wheat	3324	27	617	39	2144	35	2427	18	1660	37	1620	46	1146	46	**1823**	**44**
Manningⓓ	Wheat	3306	28	805	28	2336	22	2256	32	1846	27	1842	40	1342	29	**2047**	**28**
Naparooⓓ	Wheat	3939	9	809	27	2303	25	2323	27	2148	16	2662	4	1787	2	**2354**	**11**
RGT Accroc	Wheat	3132	35	923	20	2451	20	2383	23	2344	13	2271	15	1415	25	**2075**	**26**
SF Adagio	Wheat	2845	38	825	26	2330	24	2281	28	1780	32	1935	33	1319	35	**1914**	**38**
SF Scenario	Wheat	4015	8	613	40	2250	27	2373	24	2047	18	1411	47	1201	43	**1935**	**36**
Sunlambⓓ	Wheat	2753	43	780	30	1915	38	1897	38	1586	39	1798	44	1335	31	**1859**	**41**
Sunmaxⓓ	Wheat	2816	41	897	24	1583	43	1812	39	1484	42	1913	37	1307	36	**1767**	**46**
Whistler	Wheat	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**–**	**–**
Trial mean		3384		885		2284		2379		2026		2136		1424		**2105**	
LSD 5%		640		169		406		450		386		560		258		**146**	

Table 5. Dry matter (DM2) (kg/ha) for wheat, triticale and barley varieties across NSW in 2017. Each varieties rank in the respective trial is shown, 2017. (Note: only released varieties are reported).

Variety	Crop type	Holbrook		Purlewaugh		Spicers Creek		Somerton		Wagga		**All sites**	
		DM2	Rank	DM2	Rank	DM2	Rank	DM2	Rank	DM2	Rank	**DM2**	**Rank**
Urambie	Barley	1214	6	1444	14	1065	16	2181	31	1975	20	**1685**	**15**
Cartwheel	Triticale	1250	4	1588	8	1015	23	3091	7	2137	7	**1753**	**9**
Crackerjack2	Triticale	–	–	–	–	–	–	–	–	–	–	**–**	**–**
Endeavour	Triticale	1013	17	1506	13	1007	24	3111	6	2295	3	**1750**	**11**
Kowari	Triticale	556	33	867	34	922	31	2300	27	2049	18	**1402**	**31**
Tobruk	Triticale	1193	7	1929	3	935	29	2772	14	2040	19	**1755**	**8**
Tuckerbox	Triticale	–	–	–	–	–	–	–	–	–	–	**–**	**–**
DS Pascal	Wheat	450	36	492	36	600	36	1821	36	1588	31	**1091**	**36**
EGA Gregory	Wheat	593	32	640	35	1066	15	2173	32	1766	29	**1310**	**34**
EGA Wedgetail	Wheat	983	21	1432	15	1086	14	2630	21	2089	10	**1657**	**19**
Longsword	Wheat	1087	11	1588	7	1410	2	2422	25	2091	9	**1751**	**10**
LRPB Kittyhawk	Wheat	1009	18	1512	12	1047	18	2225	29	2061	14	**1665**	**17**
Mackellar	Wheat	1029	16	1273	22	986	26	2168	33	1535	33	**1458**	**27**
Manning	Wheat	893	26	1054	29	756	33	3123	5	1541	32	**1360**	**33**
Naparoo	Wheat	998	19	1288	21	1088	13	3148	4	1970	21	**1714**	**13**
RGT Accroc	Wheat	1036	14	1375	17	933	30	2768	15	1598	30	**1486**	**25**
SF Adagio	Wheat	–	–	–	–	–	–	–	–	–	–	**–**	**–**
SF Scenario	Wheat	–	–	–	–	–	–	–	–	–	–	**–**	**–**
Sunlamb	Wheat	706	29	1061	28	1032	20	2299	28	1879	25	**1456**	**28**
Sunmax	Wheat	474	35	1048	30	1190	7	2130	35	1810	27	**1370**	**32**
Whistler	Wheat	1113	10	1390	16	1138	9	2857	12	2223	4	**1760**	**7**
Trial mean		961		1335		1053		2694		1945		**1597**	
LSD 5%		211		333		243		770		278		**173**	

Table 6. Grain yield (GY) (kg/ha) for wheat, triticale and barley varieties across NSW in 2016. Each varieties rank in the respective trial is shown, 2016. (Note: only released varieties are reported).

Variety	Crop type	Bathurst		Holbrook		Cudal		Purlewaugh		Spicers Creek		Somerton		Wagga		**All sites**	
		GY	Rank	GY	Rank	GY	Rank	GY	Rank	GY	Rank	GY	Rank	GY	Rank	**GY**	**Rank**
Urambie	Barley	6400	24	1926	47	7755	17	5770	8	5153	30	3816	45	4802	23	**5190**	**35**
Cartwheel	Triticale	6342	25	6648	10	8864	5	4555	43	6106	7	5449	5	5911	4	**6384**	**5**
Crackerjack2	Triticale	4990	41	4134	42	5525	47	5132	35	2849	47	4367	41	2976	48	**4362**	**47**
Endeavour	Triticale	7016	11	5818	15	7352	26	6045	3	5086	32	5035	14	4516	25	**5769**	**19**
Kowari	Triticale	–	–	–	–	–	–	–	–	–	–	–	–	3544	44	**5355**	**32**
Tobruk	Triticale	5794	32	7775	2	8297	10	5192	26	6638	2	5313	7	5826	5	**6388**	**4**
Tuckerbox	Triticale	6034	28	4923	27	4943	48	4957	37	4519	40	4319	42	3325	47	**4587**	**46**
DS Pascal	Wheat	3690	47	4789	29	7318	29	5464	14	5334	25	4666	32	4414	27	**5064**	**42**
EGA Gregory	Wheat	4110	46	4134	41	6387	46	5779	7	5406	24	4106	44	3859	40	**4816**	**45**
EGA Wedgetail	Wheat	7104	9	5337	21	7524	23	4548	44	5876	10	4885	23	4273	29	**5378**	**29**
Longsword	Wheat	5447	38	4475	35	7708	19	5260	20	5505	22	4861	25	3927	38	**5252**	**33**
LRPB Kittyhawk	Wheat	–	–	4187	40	7201	33	5218	25	5128	31	4959	19	3364	46	**5106**	**39**
Mackellar	Wheat	6414	23	4563	33	7006	37	5176	27	5211	29	4589	37	5100	16	**5564**	**21**
Manning	Wheat	7474	3	6311	14	6634	41	5507	13	4878	36	3673	47	5480	9	**5840**	**18**
Naparoo	Wheat	5750	34	4880	28	6504	45	5373	18	5675	14	4887	22	4250	31	**5388**	**28**
RGT Accroc	Wheat	7283	5	6831	7	8113	13	6000	4	5931	9	5048	12	6356	1	**6468**	**2**
SF Adagio	Wheat	6949	13	5014	26	8348	9	5086	36	5846	11	5030	15	5524	7	**6063**	**13**
SF Scenario	Wheat	7170	7	4606	32	6908	39	5253	21	4908	35	3750	46	5211	14	**5558**	**22**
Sunlamb	Wheat	6449	22	5506	17	6626	43	5560	10	4986	33	4566	38	3835	41	**5361**	**31**
Sunmax	Wheat	5654	37	5488	18	7024	36	5220	24	4817	37	4814	28	4199	33	**5498**	**27**
Whistler	Wheat	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**–**	**–**
Trial mean		6127		5343		7551		5243		5348		4827		4656		**5619**	
LSD 5%		666		951		632		896		414		529		539		**293**	

Table 7. Grain yield (GY) (kg/ha) for wheat, triticale and barley varieties across NSW in 2017. Each varieties rank in the respective trial is shown, 2017. (Note: only released varieties are reported).

Variety	Crop type	Holbrook		Purlewaugh		Spicers Creek		Somerton		Wagga		**All sites**	
		GY	Rank	GY	Rank	GY	Rank	GY	Rank	GY	Rank	**GY**	**Rank**
Urambie	Barley	5034	16	1826	23	1867	18	2636	16	1632	7	**2642**	**13**
Cartwheel	Triticale	6073	9	2604	2	2897	1	3249	3	1637	6	**3357**	**2**
Crackerjack2	Triticale	–	–			–	–	–	–	–	–	**–**	**–**
Endeavour	Triticale	5312	14	2083	12	2453	6	2617	17	1232	29	**2893**	**9**
Kowari	Triticale	4416	31	1984	17	2040	12	2518	22	1499	16	**2712**	**12**
Tobruk	Triticale	6689	3	2550	3	2458	5	2968	7	1568	13	**3123**	**5**
Tuckerbox	Triticale	–	–	–	–	–	–	–	–	–	–	**–**	**–**
DS Pascal	Wheat	4853	21	1963	18	1440	34	2474	24	1009	33	**2305**	**31**
EGA Gregory	Wheat	4225	33	1608	32	1457	33	2386	26	1107	31	**2276**	**32**
EGA Wedgetail	Wheat	4490	28	1950	20	1738	25	2864	10	1321	24	**2599**	**16**
Longsword	Wheat	4431	30	1616	31	1790	20	3148	6	1336	23	**2559**	**21**
LRPB Kittyhawk	Wheat	4292	32	1622	30	1776	22	2862	11	1198	30	**2457**	**26**
Mackellar	Wheat	5556	13	2415	6	1799	19	2592	18	1569	12	**2634**	**14**
Manning	Wheat	6634	4	1652	29	1154	36	2151	33	1452	18	**2174**	**35**
Naparoo	Wheat	4991	17	1926	22	1679	28	2284	29	1310	26	**2431**	**28**
RGT Accroc	Wheat	6937	1	1945	21	1545	31	2075	35	1447	19	**2402**	**30**
SF Adagio	Wheat	–	–	–	–	–	–	–	–	–	–	**–**	**–**
SF Scenario	Wheat	–	–	–	–	–	–	–	–	–	–	**–**	**–**
Sunlamb	Wheat	4490	29	1666	28	1555	30	2077	34	1061	32	**2187**	**34**
Sunmax	Wheat	4615	26	2078	13	1925	17	2277	30	1470	17	**2581**	**19**
Whistler	Wheat	3760	36	1579	33	2002	13	2518	21	1575	10	**2590**	**17**
Trial mean		5220		1987		1942		2628		1452		**2644**	
LSD 5%		433		286		242		324		367		**282**	

Variety flowering time response

Crop flowering time plays an important role in a cereal variety's suitability for use as a dual purpose crop, for grazing and grain recovery (Harrison et al., 2015). The balance between sowing early for adequate forage production and the need to delay reproductive development to avoid physical damage to the plant (grazing damage), have it flower in a period that avoids frost damage and heat (high temperatures >30°C) at grain filling can be challenging.

The main mechanisms used in dual purpose varieties are either a vernalisation requirement or a photoperiod response to delay the shift from the vegetative phase to reproductive development. These are controlled by the presence of vernalisation (Vrn) genes or photoperiod (Ppd) genes, or a combination of both. A series of flowering-time experiments were run at Wagga Wagga to help characterise a variety's flowering time response in relation to EGA Wedgetail⫏ the industry benchmark.

Table 8 shows the days to flowering for a group of varieties tested. There are strong winter types such as Manning⫏ and RGT Accroc, mid-winter types such as EGA Wedgetail⫏ and LRPB Kittyhawk⫏, fast winter types such as the newly released Longsword⫏ and varieties more dependent on a photoperiod response like Sunlamb⫏, a long-season spring wheat. The availability of these varieties allow growers the opportunity to choose a variety that matches their local growing region and provide the best opportunity to maximise grain production after grazing.

Table 8. The number of days to flowering for wheat varieties sown at Wagga Wagga over four years (2014–2017).

Variety	Year	SD1	SD2	SD3	SD4
EGA Gregory⏀	2014	–	–	–	–
	2015	146	150	141	129
	2016	130	136	137	128
	2017	149	153	142	131
EGA Wedgetail⏀	2014	174	157	145	125
	2015	177	162	145	132
	2016	173	161	144	129
	2017	179	163	145	132
Longsword⏀	2014	–	–	–	–
	2015	–	–	–	–
	2016	165	153	142	127
	2017	177	158	143	128
LRPB Kittyhawk⏀	2014	173	158	146	129
	2015	178	165	149	133
	2016	173	162	150	135
	2017	182	164	148	132
Manning⏀	2014	194	177	162	136
	2015	193	176	159	142
	2016	201	186	172	150
	2017	194	176	156	142
Naparoo⏀	2014	181	165	150	131
	2015	185	165	150	135
	2016	186	167	153	139
	2017	184	165	147	134
RGT Accroc	2014	192	171	154	131
	2015	189	171	150	134
	2016	196	175	158	140
	2017	189	173	150	135
Sunlamb⏀	2014	174	161	147	128
	2015	177	165	151	137
	2016	183	170	163	143
	2017	173	160	149	136
Whistler	2014	–	–	–	–
	2015	–	–	–	–
	2016	–	–	–	–
	2017	176	159	143	129
Sowing date (SD)	**Year**	**SD1**	**SD2**	**SD3**	**SD4**
	2014	1-Apr	24-Apr	14-May	11-Jun
	2015	2-Apr	22-Apr	14-May	4-Jun
	2016	4-Apr	26-Apr	17-May	14-Jun
	2017	31-Mar	21-Apr	12-May	2-Jun

When matching a variety's flowering time with the preferred flowering window in a region, consider the delay in flowering caused by grazing. The length of this delay varies depending on when the last grazing occurred and the amount of residual plant biomass left. In experiments in Wagga Wagga in 2016 (Figure 1) and in 2017 defoliation (mechanical grazing) of EGA Wedgetail⏀ through the season, before GS31 delayed flowering by nine and four days respectively compared with an ungrazed treatment.

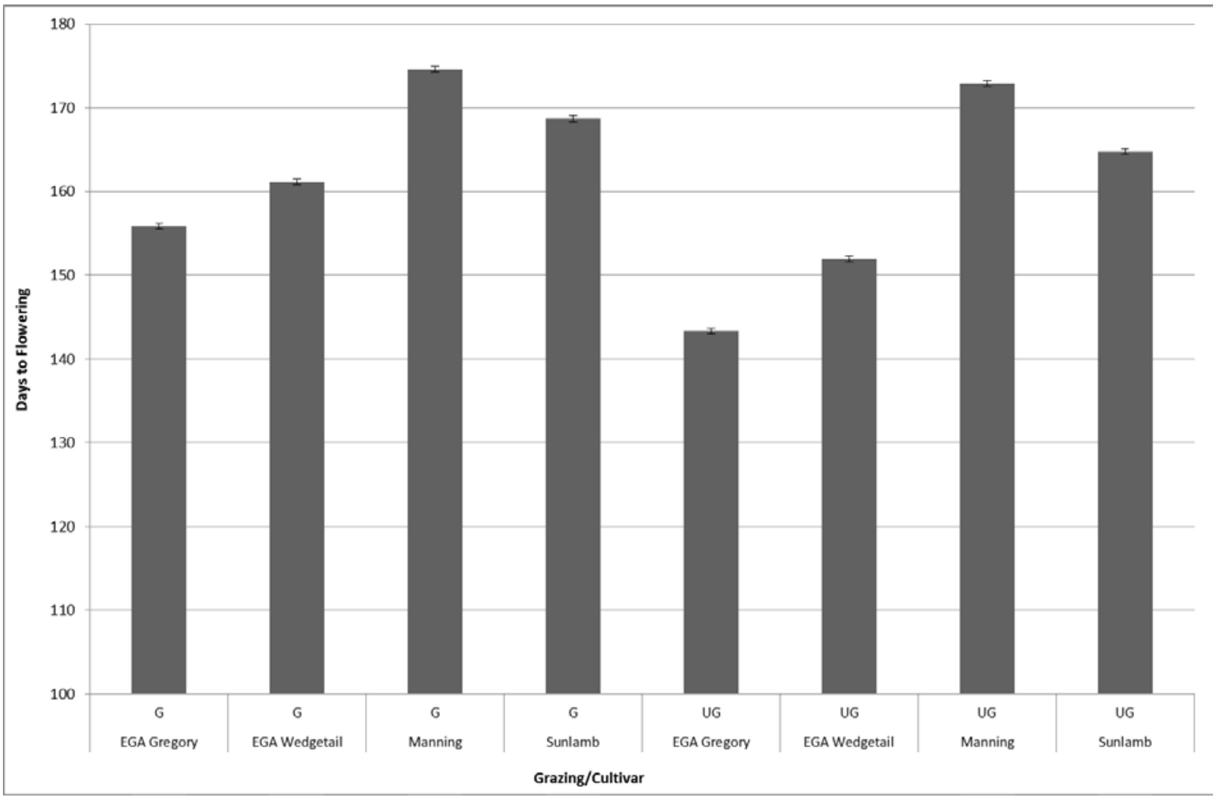

Figure 1. Flowering time for wheat varieties mechanically grazed(G) and non-grazing (UG) treatments, at Wagga Wagga in 2016. (EGA Gregory, EGA Wedgetail, Manning and Sunlamb are protected under the Plant Breeders Rights Act 1994.)

Summary

Varieties differ in forage production and grain yield recovery across the different growing environments in NSW. These differences are influenced by a variety's growth and development phases, which are driven by the different combinations of vernalisation and photoperiod genes each variety has. Matching flowering time to the growing environment is important in dual-purpose varieties to maximise grain recovery. The newly released varieties with their differences in flowering time provide greater opportunity to match a dual-purpose variety to the different growing regions of NSW, maximising grain yield recovery.

Acknowledgements

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⊕ Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.

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Managing risk in mixed livestock and cropping systems

Cam Nicholson, Nicon Rural Services

Key words

enterprise mix, risk, volatility, strategy

GRDC code

SFS00028

Call to action/take home messages

- Managing risk is not about the middle or the average, it is the opposite. It is appreciating what happens at the extremes, the size or value of these extremes and how often they occur.
- Understanding the probability of different yield and price values occurring and if these values are correlated is essential in understanding risk.
- Usually diversification reduces risk (both downside but also upside risk).

Introduction

Risk is a natural and accepted part of farming. Australian agricultural production (based on value of output) is the most volatile in the world and the most volatile sector of the Australian economy (Keogh, 2013). This volatility conveys a level of risk that needs to be managed. Given most farmers are still operating despite two centuries of volatility, suggests they have developed long term strategies and operational tactics to cope with this ongoing challenge.

There are many strategies farmers use to manage production risk. Diversification in crop and pasture type, enterprise mix, targeting multiple markets and property location are common strategies. So is managing input costs, especially when production and prices can be highly variable.

Understanding risk

When we talk about risk, most of us immediately think about the negative consequences if an action goes bad. Dictionary definitions re-inforce this thinking. However this is only one aspect of risk. The word risk is derived from Italian word *risicare,* which means 'to dare'. To manage risk effectively we need to understand both the downside, or the potential harm from taking a risk and also the opportunities that taking a risk can offer.

There is no reward without risk. In farming, risk is a necessary part of making returns. Managing risk is about making decisions that trade some level of acceptable risk for some level of acceptable return for an acceptable amount of effort. Decisions can be made to reduce risk, but it usually comes at a price, namely lower returns.

A common definition of risk is likelihood by consequence. In other words, risk requires knowing how often an event happens (the frequency) and what is the impact (the value) when it does happen. A decision that increases risk will either increase the likelihood of an event happening and/or increase the consequence if it does occur. This increased consequence may be a greater return, not just a greater loss.

We must remember everyone has a different position on risk. Financial security, stage of life, health, family circumstances, business and personal goals can influence the amount of risk an individual is willing to take on. This position can change rapidly, sometime triggered by sudden events. Importantly no position is right or wrong, it is what the individual is comfortable living with.

Average values are commonly used in agricultural extension. We present average yields, average prices and average costs. While these averages convey a value (and are convenient), they rarely present the frequency of this average occurring. This would be fine if we consistently got these average values, but in agriculture we rarely do. The key drivers of profit in agriculture, namely yield, prices and some costs, have a range of values within and between production periods. If we use averages for analysis, it usually over estimates the profits and hides the volatility in those profits (Nicholson, 2013).

Understanding risk is not about the middle or the average, it is the opposite. It is appreciating what happens at the extremes, the size or value of these extremes and how often they occur. Managing risk is knowing what to do when these extremes occur, either by changing things to avoid them or having contingencies when they do occur.

Analysing risk

As described previously the derivation of risk is 'to dare'. This implies there is opportunity but it also implies a choice. As individuals we can influence how much risk we expose ourselves to by making choices.

Insights from the Grain and Graze program would suggest farmers mainly inform their decisions around risk based on past experience and intuition or instinct. Doing the 'sums' to understand the likelihood and consequence is much less common.

Through the Grain and Graze program we have developed a relatively simple way to put some numbers around the risk in a farming business. It is based on Excel with an additional program called @Risk (www.palisade.com). Firstly the risky variables in a business are identified. These are inputs that we have little or no control over at the start of the season and are typically yields, prices and some costs. Graphs are created that show *the amount or value* of this risk and *how often this amount or value occurs*. It includes extreme and more common results and are referred to as distributions or frequency histograms. The broader the range in values the greater the volatility or risk (figure 1).

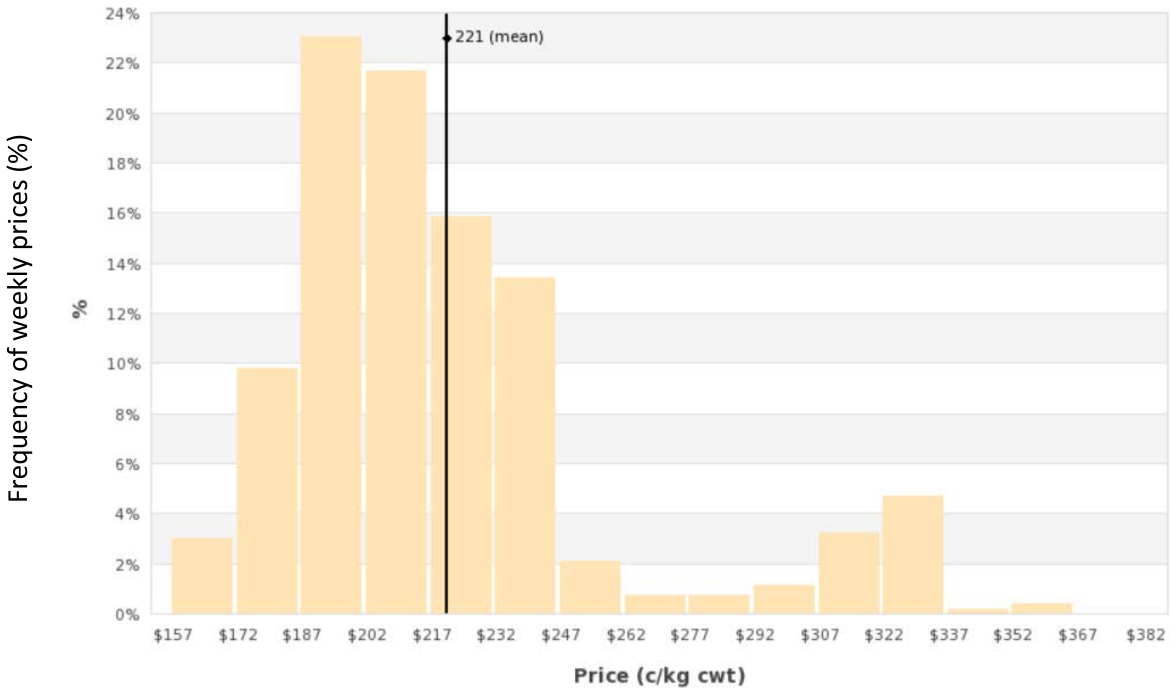

Figure 1. Example of the frequency of weekly prices for feeder steers in NSW from 1 Jan 2006 to 24 June 2016, inflated to June 2016 values. (http://agprice.grainandgraze3.com.au/)

These 'risky' distributions are then substituted for the average values used in calculations. For example we may have used an average price for steers of $2.21/kg Lwt. By substituting this distribution, the program will do some calculations with a price around $2.21/kg, but also do calculations with prices at $1.90/kg, $2.50/kg and even $3.50/kg. However the frequency these prices occur will be different. There will be more calculations around $1.90/kg than around $2.50/kg and many more than around $3.50/kg.

The same can be done for yields (and some costs, although most costs increase in price but are not highly variable throughout the season). When the risky yield, price and cost values are combined, they reflect what happens in real life. For example, we may have a high yield but poor prices, so our gross income is about average. Less often we will have poor yields and poor prices and conversely we occasionally get high yields and high prices. Adjustments can also be made to link events such as often getting higher prices when yields are poor.

We create these distributions through a combination of historic information ('form guides') and gut feel. I call this 'framing the odds'. Each distribution can be customised to suit your location, soil type, frost risk etc.

Not all risks are equal. The computer program enables a comparison between the risky variables. For example we might have a farm with 20 or so distributions but not all of these risks are of equal influence to our final profit. Some create more volatility than others and some are more influential in making or losing large amounts of money. We can identify these and examine the impact if we were able to change them. This scenario analysis is extremely valuable as it enables an understanding of the risk implications of large (and small) changes on the farming business *before* we make the changes.

Correlations

One reason for diversifying enterprises is to 'decouple' price and yield movements. We grow different commodities so if one fails to produce, a different crop or enterprise may still produce something. How strongly yields and prices are linked are referred to as correlations and understanding it is critical in managing risk.

Correlations (co- meaning 'together' + relation) can be calculated mathematically The numeric scale used for correlations is 0 to ±1 and is commonly referred to as the 'r' value[1] (or correlation co-efficient). If there is no connection or dependence between two variables, then it is considered a zero (0) correlation. If one variable exactly follows the size and direction of the fluctuations of the other it is positively correlated and given a value of one (+1). Conversely if one variable exactly follows the size and direction of the fluctuations of the other, *but in opposite direction,* it is negatively correlated and given a value of one (-1).

The r value can be broadly classified into 'strengths'.

- **Strong** with r greater than ±0.8
- **Medium** with an r value between ±0.5 and ±0.8
- **Weak** with an r value less than ±0.5
- **None** with an r value of 0

Knowing a weak r value can be just as useful as knowing a strong r value because the weakness implies there is no connection between the two variables, so they should be considered independent of each other.

Price correlations for common crops and livestock enterprises is provided (tables 1 & 2).

Table 1. Correlation between common crops (July 2003 to June 2016)

	Canola	APW wheat	Malt barley	Feed barley	Lentils
Canola	1				
APW wheat	0.8	1			
Malt barley	0.8	0.8	1		
Feed barley	0.7	0.8	0.9	1	
Lentils	0.3	0.4	0.4	0.2	1

Table 2. Correlation between sheep enterprises (July 2003 to June 2016)

	18u	24u	Trade lambs	Heavy lambs	Mutton	Live sheep
18u	1					
24u	0.5	1				
Trade lambs	0.1	0.2	1			
Heavy lambs	0.2	0.2	1.0	1		
Mutton	0.1	0.0	0.8	0.7	1	
Live sheep	0.5	0.5	0.6	0.6	0.8	1

Correlations can also be easily created between enterprises (http://agprice.grainandgraze3.com.au/).

Enterprise mix

Changing the enterprise mix, both in the type and scale of these enterprises changes the risk profile of a business. The following example is for a 1500 ha farm in the West Wimmera, but is based on a real farm. The key values are;

- 1,000 ha heavy soil, 500 ha light soil
- Typical enterprise mix: 40% wheat, 25% barley, 10% canola, 5% lentils, 5% bean, 15 % vetch hay.
- 1 manager, 0.5 labour
- Cost reduced by 20% if yield is decile 3 or less (less nitrogen use)
- Cost increased by 20% if yield decile 7 or more (greater nitrogen use)
- $0.5M debt, 6.5% interest
- $1.2M in plant and equipment (dep @10%)

In a second scenario the 500 ha of light soil is in pasture and grazed rather than cropped (self-replacing merino ewes at 2.5 ewes/ha).

Distributions around yields, process and costs are created and substituted for average values. This enables a range of values to be generated, based on the frequency distributions of each risky input. So rather than just calculating a single profit (after tax) value, based on averages, a range of profit values are determined and represented based on the frequency in which they occur (figure 2).

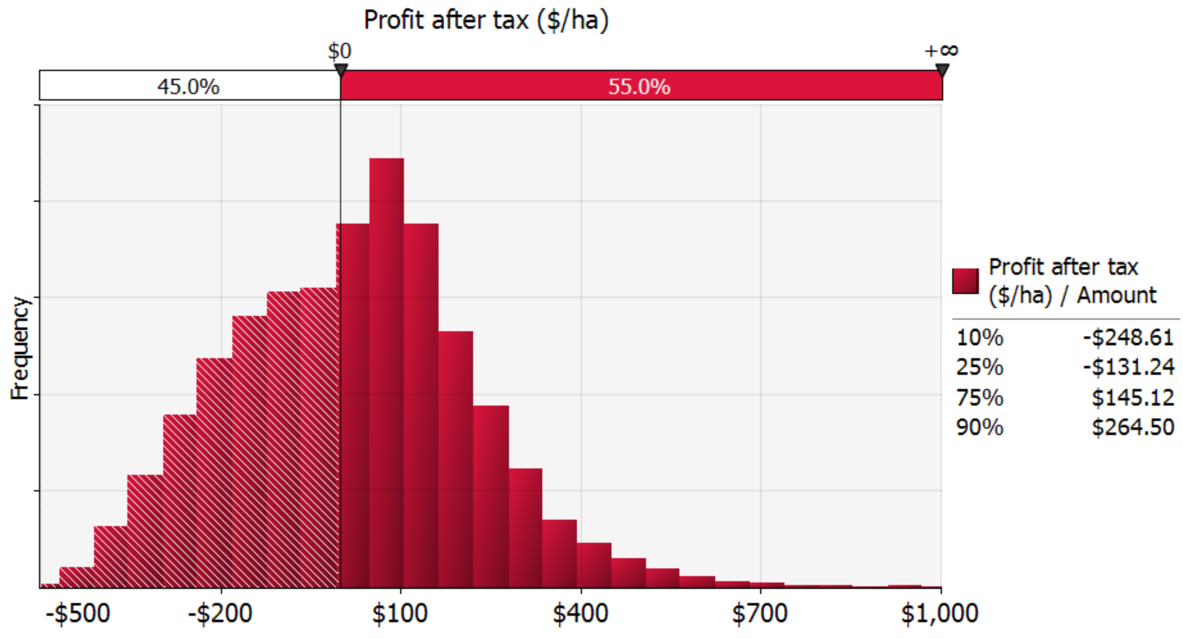

Figure 2. Profit after tax for a 1500 ha west cropping Wimmera farm

Figure 2 shows the chances of not making a profit are 45.0% (the average profit is $33.10/ha).

While every farm is different some generalisations on the risk of different enterprise mixes can be made (based on analysis of approximately 40 mixed farms across Southern Australia).

Cropping is usually more risky than livestock

This is usually true, however risk also includes upside as well as downside risk. If the 500 ha of light soil was taken out of cropping and livestock run on this area instead, then the risk profiles of the two enterprises can be compared (figure 3).

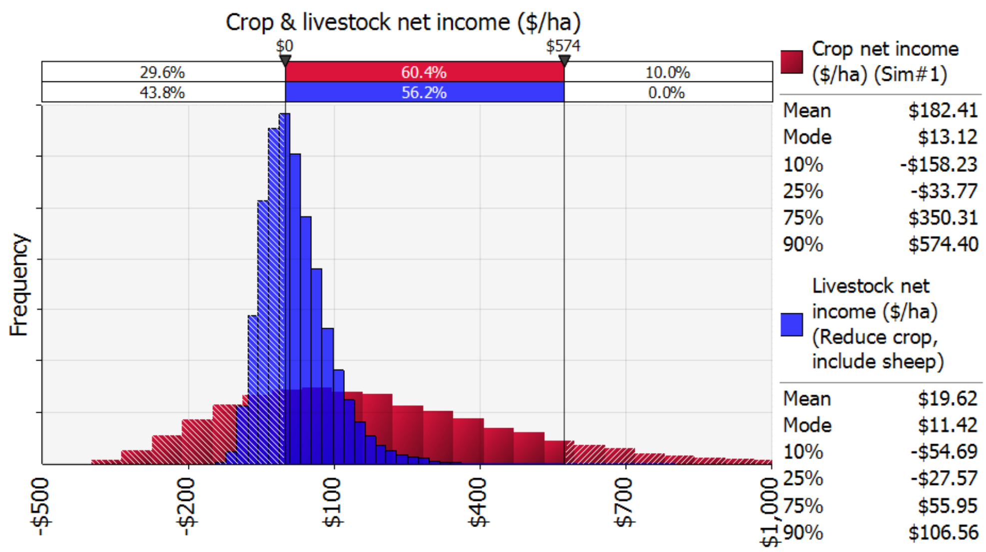

Figure 3. Net farm income from cropping the heavy soil (red distribution) and livestock on the light soil (blue distribution)

This example clearly illustrates the contrasting net income distributions for the cropping enterprise compared to livestock. The cropping enterprise is flatter and wider compared with the sheep enterprise, indicating greater volatility in possible profits with the cropping enterprise.

When the two are combined the addition of livestock reduce the volatility in farm profits, although the average income stays roughly the same (figure 4).

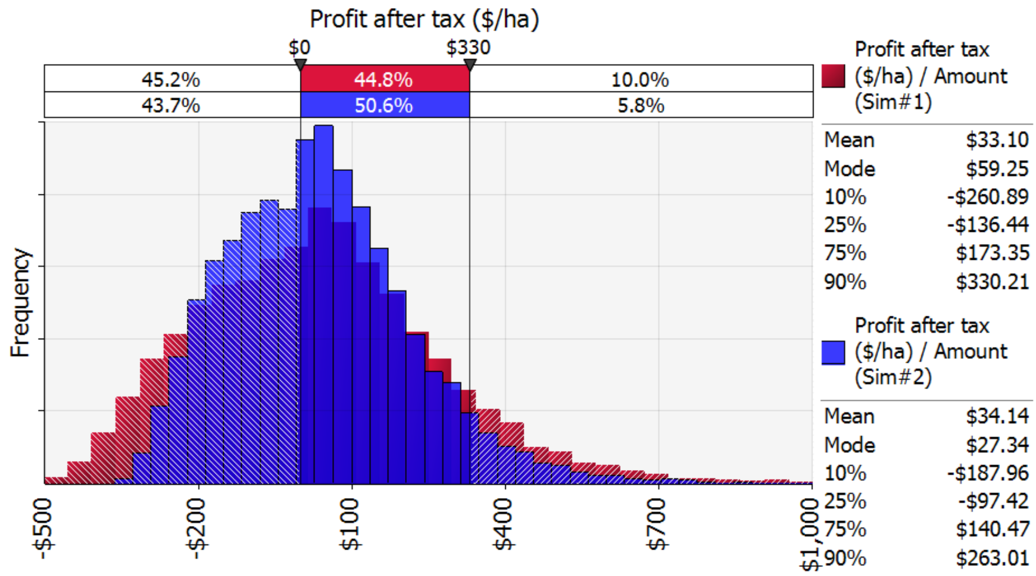

Figure 4. Profit after tax for all cropping (red distribution) compared to 1000 ha of cropping and 500 ha of sheep (blue distribution)

Other conclusions from the enterprise mix include:

- Intensification (say increasing stocking rate) generally increases risk
- Enterprise diversity usually decreases risk
- Sheep are usually more risky than cattle.

Conclusion

There is no single way to manage production risk. Many 'levers' influence the ultimate risk profile of a business and it is up to the individuals in that business to determine and feel comfortable with a level of risk that matches the rewards they seek.

Having said this, managing risk requires making decisions. The type of analysis used in Grain and Graze provides a very useful platform to inform discussion and decisions around risk.

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Useful resources

Grain and Graze 3 website (www.grainandgraze3.com.au)

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Widen sowing window to improve reliability of dual purpose crops: a central west NSW case study

Robert Freebairn, Agricultural Consultant and David Freebairn, Soil Scientist

Key words

dual purpose winter crops, timely sowing critical, CliMate App for assessing sowing time risks, quality agronomy fundamental to high profit, understanding soil type implications critical

Call to action/take home messages

Dual purpose crops are a vital part of many mixed farming operations, being especially critical for reliable supply of winter feed and grain potential recovery. Reliable and timely sowing is vital for profitability of both grazing and grain recovery crop phases. To reliably sow in an appropriate sowing window, several factors are vital: sowing on a minimal rainfall event; stored sub soil moisture; stubble cover to maximise duration of surface moisture; a renewed view of what is a desirable sowing time window; and where possible, choosing lighter soil for dual purpose crops. The CliMate App is a valuable tool for exploring probabilities of sowing success in a multitude of scenarios.

Role of dual purpose cereals on our property

Dual purpose winter crops or grazing only can reliably gross $1000 -$1500/ha with costs typically $350/ha. Additionally, dual purpose crops take pressure off the property's grazing base (pastures), giving them a chance to get away and be a more valuable supply of quality grazing after dual purpose crops are locked up for grain. Research also shows that in addition to proving valuable winter grazing, dual purpose crops can produce yields similar to a grain only crop.

Dual purpose crops supply quality feed in good quantities when other pastures are growing slowly, especially in years with dry autumns (six of the last seven years in our Purlewaugh property example). For our property, 30 km east of Coonabarabran (625mm average annual rainfall), 20 percent of the area is sown to dual purpose crops in late summer - early autumn, 36 percent is tropical grass based (aim for 50 percent) and 44 percent is improved native grass based. In both native and tropical grass pastures, winter legumes (serradella, biserrula, gland, sub and arrowleaf clover) are an important part of these pastures. Figure 1 shows typical production patterns for these three pasture types. Lucerne is not included here as it is less suited to acidic surface and sub soils in this case study.

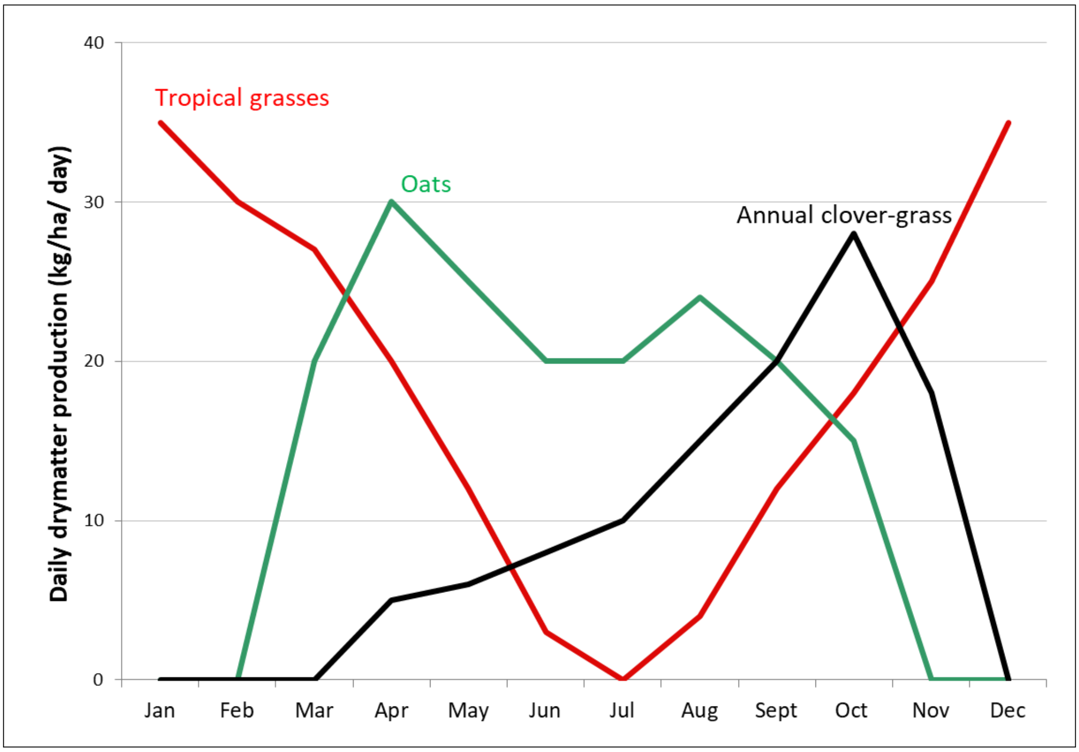

Figure 1. Typical seasonal dry matter production patterns for tropical grass, oats and annual clover-grass based pastures on lighter soils of N NSW

Early sowing is critical

Often missing an early sowing opportunity is the difference between a good or poor winter feed supply. Early sown crops sown onto good subsoil moisture can survive for months if no follow up rain occurs and provide reliable winter feed despite little follow-up rain. This was the case in 2017 at Purlewaugh, with the second driest period from April 1st – September 30th since 1900. Being able to sow early, often much earlier than the accepted norm for a district, and reliably (high probability of successful establishment), is critical for securing a high quality and reliable winter feed supply. For our region, this can mean sowing as early as 20th February, as was the case in 2014. In many years it will be too hot for a reliable establishment that early. Good subsoil moisture and stubble cover also support reliable early establishment.

Late summer and autumn rains are unreliable. Probabilities of achieving reliable establishment in a desirable sowing window is closely related to being able to successfully establish a crop or pasture on a minimal rainfall event.

Sowing rainfall probability - CliMate provides a useful guide

Based on long term rainfall data at Purlewaugh in central western NSW, the “CliMate” App tells us that we have a 94% chance of getting 10mm over 3 days between 20th February to the end of April (our nominally desirably sowing window) (Figure 2). CliMate is well suited to exploring options as it is easy to adjust dates and rainfall amounts.

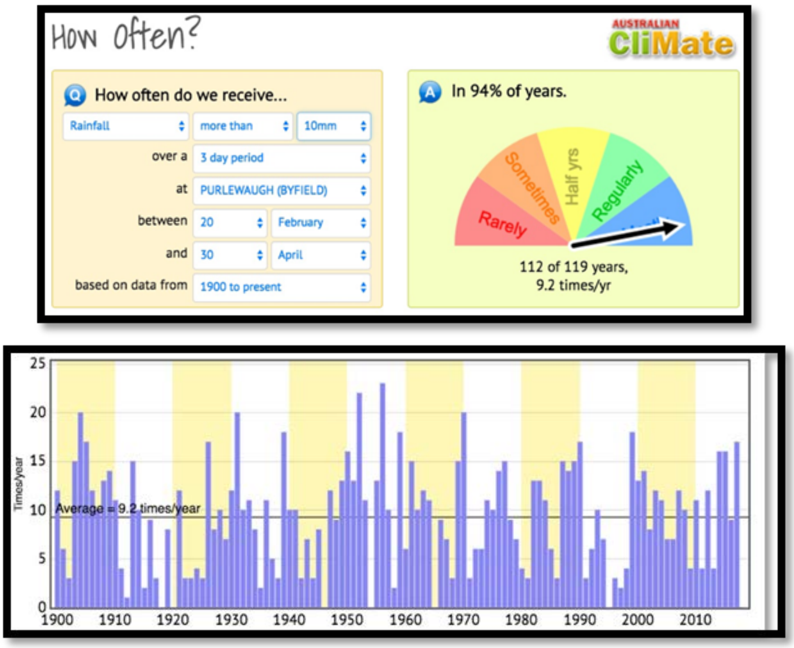

Figure 2. Screens from the Australian CliMate app showing inputs and outputs for an analysis exploring sowing opportunities. The bottom graph shows the number of times each year the condition is met, emphasising the variable nature of rainfall

If 25mm of rain is required, for example on a heavier soil type or little sub soil moisture, this probability drops to 74% over the same sowing window. If we delayed the sowing window to 15th March (a common judgement), the probability of being able to sow drops to 59%, or missing out on good winter feed from the dual-purpose crop in four of every 10 crops. Hardly a dependable strategy.

"CliMate" can provide these estimates for any cropping area across Australia, exploring any sowing window and designated rainfall event.

Factors affecting success of early sowing, other than soil moisture

Temperature and temperature forecast

Data is unclear as to what is a "safe" temperature to successfully sow dual purpose winter crops. Based on various sowing date guides (from an internet search), we base our decisions on mean daily temperature (average of maximum and minimum). If it is 23°C or less and unlikely to rise, it is a reasonable bet to sow if soil moisture is reasonable (little hard data to support this claim). Some farmers have successfully established dual purpose winter crops above this temperature. Clearly there is scope for future research dealing with temperature, sowing dates and varieties. Prevailing and forecast temperature is a better guide to sowing time than choosing a fixed date (such as early March for our area), as each season is different and we need to adapt to the conditions we have been given. Sometimes we sow as early as 20th of February, while in other years with hotter late summers, we delay until around 10th March onwards. If heatwaves are forecast (rare but can occur at this time of the year) then clearly sowing will be delayed.

Soil type

Generally, it is possible to successfully establish crops on much smaller rain events on light textured soils, compared to heavier textured clays. For example, we have established crops on an eight-mm rain event on a sandy loam with good sub soil moisture, whereas a minimum of 25mm (and commonly more) would have been required for successful establishment on a clay loam or clay.

Where properties have a mix of soil types, using light soil paddocks for dual purpose crops dramatically increases the probability of being able to be sow on time.

Sub soil moisture

Stored soil water is not only important for keeping crops growing during dry periods over autumn, winter and spring, but also maximises the probability of being able to establish them on time. If there is a good stored soil water at sowing time, the probability of being able to sow on time also increases dramatically.

Evidence from GRDC funded research notes that for every extra mm of stored soil moisture, crop yields can increase by 15 -30 kg/ha of grain. Dry matter for grazing will exceed these increases.

It is neither logical nor supported by research to sow crops directly into pastures without storing soil water, especially if reliable grain yields and grazing are the aim. Even in lighter soils that can't conserve as much soil water, an extra 40 -100mm of stored soil water is vital for early sowing and achieving a high probability of good winter growth.

Direct drilling crops into active summer pastures, even poor ones where weeds generally replace pastures for water use has significant downsides. In addition to not accumulating soil water prior to sowing, such crops commonly face higher levels of nitrogen deficiency. NSW DPI research has shown differences of 40 kg/ha or more in available soil nitrogen where fallow weeds were not controlled in a timely manner.

Fallow water capture

Maximising stored soil moisture, as well as having moisture as close to the surface as possible, depends on efficient capture and storage of fallow rainfall. Early control of weeds over the fallow is critical, even if it means additional fallow sprays. For example, on our farm, it is not uncommon for us to spray our fallows five times over the fallow period. Preparation for a crop or pasture requires early planning for water storage.

Zero till and stubble retention is part of the story

Reasonable levels of stubble cover (old pasture if coming from a pasture phase or crop residues in a cropping sequence) helps with fallow moisture capture as well as maintaining moisture storage closer to the surface. Zero till with stubble is generally a vital part of a reliable early dual-purpose crop.

Narrow points and press wheels

Sowing with minimal soil disturbance (narrow points or disc seeders) plus press wheels, improves the probability of early sowing success on small rainfall events. The ability to moisture seek with narrow points and press wheels also enhances the length of the sowing window after larger rainfall events.

Profitability

On our light acid soil farm in a 625mm rainfall area, the gross margin for 2017/18 is projected to be similar to the previous two years ($350/ha), despite one of the driest winter seasons on record. Dual purpose winter crop has been especially vital to success this past season and would not have been possible had it not been sown on time and into good sub soil moisture.

Variety choice is critical

"Spring habit" winter cereal varieties (oats, wheat, barley, triticale, cereal rye) or other crops like canola sown in February or March commonly head in May, June or July (depending on sowing time and maturity type). These crops commonly recover slowly and poorly after grazing – in large part as they have to form new growing points. Compare this with “winter habit” types, that stay largely vegetative and continually regrow from existing leaves until their “winter habit” has been satisfied by a sufficient level of cold weather.

“Winter habit” is a characteristic where the growing point remains at ground level until a sufficient amount of cold weather triggers plants to change to “spring habit”, which means the head begins rising up the stem. Spring habit varieties have no such delay, with heads growing up the stem as soon as tillering occurs.

Soil fertility and other agronomy issues

Nitrogen deficiency remains a more than common yield limiting factor in dual purpose crops. A typical dual-purpose cereal crop, may provide 4.0 t/ha of drymatter for grazing and yield 4.0 t/ha of grain. The amount of nitrogen utilised in this example is typically 150 kg/ha for grazing and a further 84 kg/ha for grain, a total of 234 kg/ha.

While not a lot of the nitrogen needed for grazing is removed from the paddock in animal product, it takes time to be re-released to the soil via urine and faeces and trampled plant material. Such nitrogen recycling is not distributed evenly across paddocks.

A major risk with early sowing of cereal crops is barley yellow dwarf virus (BYDV), a major disease threat to most varieties of oats, barley and wheat. BYDV risk can be minimised by treating seed with a registered insecticide to reduce risk of aphid attacks and transmission of BYDV. Note that many insecticides have a grazing withholding period, commonly around nine weeks post sowing. When spraying or treating seed with insecticide, always read the product label prior to use to ensure that the product you are using is compatible with your desired grazing schedule.

Rust can also be a greater risk in early sown crops, especially if autumns are humid. There are few resistant oat and barley varieties and some popular “winter habit” wheats are not resistant to some rusts. Again seed treatment with an appropriate fungicide, or fungicide treated fertiliser applied with seed, can help reduce risk of early rust outbreaks.

Good in-crop weed control is another important aspect of productive dual-purpose winter crops.

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Chickpea concurrent session

The impact of wheat residue on air temperature in the canopy and phenology of chickpea in 2017

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Key words

stubble, frost, temperature, radiant, phenology

GRDC code

DAN00965 - Thermal responses of winter pulses

Call to action/take home messages

- Surface wheat residue increases the incidence and severity of radiant frosts.
- The average minimum surface temperature declines by -0.10^{0}C/ tonne of residue.
- High residue loads can change the thermal profile of the crop and lead to delays in the onset of flowering, podding and maturity in chickpeas.
- Inter-row sowing into standing residue (>30cm) led to less frosts and higher minimum temperatures in chickpeas.
- Some chilling tolerant chickpea lines flowered 3 to 11 days earlier than PBA HatTrick⦶ but this did not translate into earlier 1st pod dates.

Introduction

Chickpea productivity in the northern grains region (NGR) is constrained by several abiotic stresses (Whish *et al.* 2007) and temperature is one of the most important determinants of crop growth over a range of environments (Summerfield *et al.* 1980) and may limit chickpea yield (Basu *et al.* 2009).

The potential evaporative demand for water usually exceeds the water available to the crop and represents the greatest limitation to crop production in the northern grains region (NGR). Low-disturbance direct seeding into standing or flattened cereal stubble is the most effective practice to reduce the impact of water stress on chickpea crops. However, surface residues can cause an increase in radiant frost risk and may also affect the micro-climate of the crop canopy, with impact on floral initiation, pod set and seed development.

The impact of surface residue on air temperature in the canopy, phenology, biomass and grain yield of chickpea was explored in a series of experiments across the NGR in 2017.

Stubble effects on soil and air temperature

During the day, stubble reflects solar radiation. A bare, darker soil absorbs more solar radiation than a stubble-covered soil and warms up more readily. The stubble also acts as insulation as it contains a lot of air which is a poor conductor of heat. Finally, the stubble affects the moisture content of the soil. It takes more heat to warm up moist, stubble covered soil than dry, bare soil.

This causes soil temperature of a bare soil to be higher than stubble covered soil during the day (especially in the afternoon). At night, however, the bare soil loses more heat than stubble covered soil due to the lack of insulation (the air-filled stubble being a poorer heat conductor). This is especially noticeable when skies are clear. The air above the bare soil is therefore warmer during the night than the stubble covered soil, while the soil temperature differences become negligible. Therefore stubble cover may lead to a higher incidence of frost than bare soil.

Methods

A range of experiments were conducted at Rowena and Tamworth in 2017 (Table 1).

Table 1. Experiments, treatments and locations for 2017

Experiment	Tamworth	Rowena
Row orientation	North - South	East - West
Stubble loading	0, 3, 6, 12, 24 t/ha residue Chickpea, faba bean, field pea	0, 3, 6, 9, 12 t/ha residue 4 x chickpea genotypes
Stubble height	0, 10, 30, 50 cm Chickpea, faba bean, field pea	0, 5, 10, 17 cm 4 x chickpea genotypes
Chilling tolerance	Plus and minus residue 16 chilling tolerant chickpeas	Plus and minus residue 16 chilling tolerant chickpeas
Genotype screening	Plus and minus residue 20 selected chickpea lines	

In all of the stubble experiments, treatments were not invoked until just prior to sowing. This ensured there was no treatment effect on soil stored water at sowing. In the stubble loading experiments, residue was removed, bulked and weighed into treatment amounts and re-applied to the plots immediately post-sowing. In the stubble height experiments, treatments were cut using a small plot header the day before sowing. Stubble was stripped and captured at the back of the header for removal.

In all experiments, tiny tag temperature data loggers were used in selected treatments and plots. Sensors were placed at 0cm and 50cm above ground in-crop. Temperature was logged at 15minute intervals. Another Tiny Tag sensor was placed outside the crop area at 150cm above the ground to record ambient temperature at similar time intervals.

Detailed phenology was recorded on a daily basis. At physiological maturity, whole plant samples were taken for detailed plant component analysis and whole plots were harvested for grain yield.

Results

The 2017 growing season

The 2017 growing season has been one of the most difficult and extreme on record equivalent to the 1994 and 1982 seasons with record frost events and below average in-crop rain.

The Rowena site failed due to lack of soil moisture exacerbated by the high frost incidence. Nothing was recoverable. Table 2 shows the long term average (LTA) monthly rainfall and minimum screen temperatures and the monthly rainfall and average minimum temperature for Tamworth in 2016 and 2017.

Table 2. Long term average (LTA) monthly rainfall and minimum temperature and monthly rainfall and mean minimum temperature for 2016 and 2017 at Tamworth

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall 2017 mm	125	19	124	22	61	49	20	21	10	90	64	39
Rainfall 2016 mm	100	1	22	5	61	169	29	83	133	76	12	97
LTA rainfall mm	85	67	49	42	44	49	46	46	48	58	66	72
Mean Min 2017 (°C)	19.6	18.5	15.3	9.2	6.3	3.5	-0.1	1.2	4.5	11.4	11.9	16.5
Mean Min 2016 (°C)	17.0	16.1	15.7	12.2	6.6	6.1	3.7	3.2	7.2	7.1	10.1	16.9
LTA min temp (°C)	17.4	17.1	14.8	10.6	6.7	4.1	2.9	3.7	6.1	9.9	13.1	16.0

Rainfall leading into the 2017 growing season was on par for the LTA, but July-September was below the cumulative LTA by 88mm. Rainfall in October saved these crops and resulted in average yields (Table 2).

The mean minimum temperatures started to dip below the LTA from April right through to September, with mean minimums for July, August and September being, -3.05, -2.52 and -1.58^{0}C colder than the LTA, respectively. The frost incidence at Tamworth in 2017 was unprecedented, with 49 screen frosts compared to 22 in 2016. Rowena experienced 26 screen frosts up to the 1st week in September when the crop failed.

At Tamworth, the extreme weather events led to complete death of ALL field pea blocks. This was through frost events followed by a wipe out due to bacterial blight infection.

Elevation and air temperature

Figure 1 shows the effect of slope on average minimum air temperature at ground level at the Tamworth site. Minimum temperature declined by - 0.22^{0}C per m drop in elevation measured on bare soil.

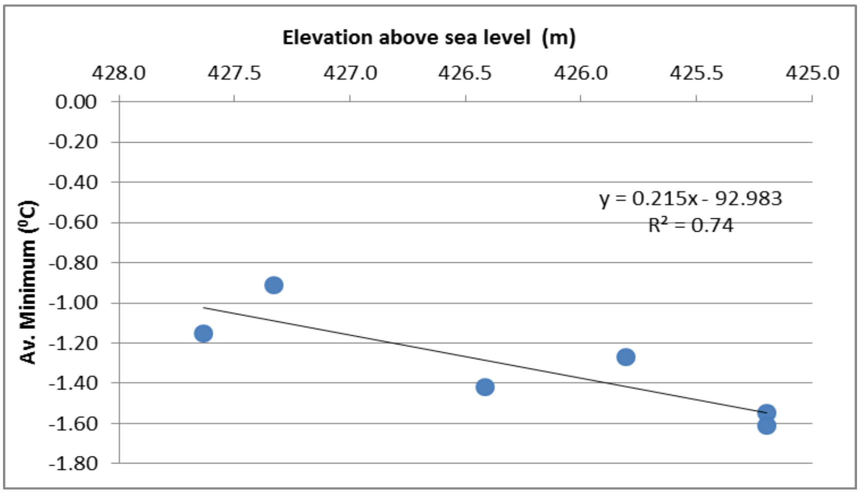

Figure 1. Effect of slope on average minimum temperature (7/7 – 8/8/2017) at ground level at the Tamworth Agricultural Institute (TAI)

Stubble loading effects on in-crop temperature

The effect of different amounts of wheat residue, flat on the ground, and its impact on the temperature profile of different pulse species was examined.

Table 3 shows the effect of residue loading on minimum temperature at the residue surface in chickpea at TAI.

The bare soil surface was on average, -1.0^{0}C colder than the minimum screen temperature. Both the average minimum and absolute minimum declined as the amount of surface residue increased, with the high residue loading (24 t/ha) -1.4^{0}C colder on average than bare soil. Frost incidence was similar across all residue level loadings, but there were 5 more ground frosts recorded compared to the screen temperature. The absolute minimum decreased with increasing residue load, with the high residue treatment reaching -7.5^{0}C compared to -6.4^{0}C on bare soil (see Table 3).

Table 3. The average minimum, absolute minimum and number of frosts (<0^{0}C) for a range of stubble loadings at the residue surface in chickpea compared to the screen temperatures at TAI (7th July to 8th August).

		Residue loading				
	Screen	Bare soil	3 tonne	6 tonne	12 tonne	24 tonne
Av. Min	0.5	-1.5	-1.9	-2.1	-2.2	-2.9
Abs. Min	-5.2	-6.4	-6.7	-6.9	-6.9	-7.5
No. Frosts	20	25	25	25	25	26

Table 4 contains data from the Rowena site prior to it succumbing to terminal drought. The temperature response to residue loading is the same here as at TAI. Average minimum temperature declined with increasing residue load, with a -1.2^{0}C difference between bare soil and 12 t/ha of residue.

Table 4. The average maximum and minimum, absolute minimum and number of frosts (<0^{0}C) for a range of stubble loadings at the residue surface in chickpea at Rowena (1st June to 10th August).

	0 tonne	3 tonne	6 tonne	9 tonne	12 tonne
Av. Max	10.3	10.5	10.4	10.4	10.3
Av. Min	0.4	0.1	-0.3	-0.4	-0.8
Abs. Min	-6.5	-7.2	-7.9	-7.6	-8.9
No. frosts	36	42	42	43	43

At Rowena, frost incidence rose with the addition of residue compared to bare soil, but was similar across residue loading treatments. Maximum temperatures did not vary across treatments.

Figure 2 shows the linear relationship between residue loading and average minimum surface temperature in chickpea.

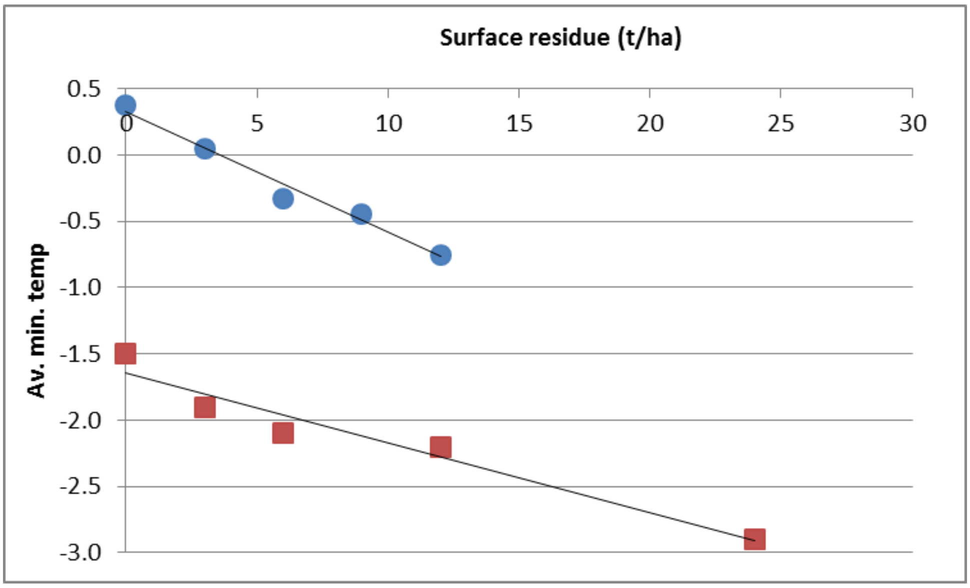

Figure 2. The effect of surface residue loading on average minimum temperature at the residue surface at Rowena (●) and TAI (■) in the chickpea crop

Both responses are linear but the steeper slope at Rowena would suggest that residue amount had a more significant impact on minimum temperature and frosting in 2017 than at TAI. Minimum temperature declined by -0.10 and -0.05 ^{0}C, per tonne of residue at Rowena and TAI, respectively.

Stubble height effects on in-crop temperature

Table 5 shows the effect of stubble height on temperature parameters at the soil surface on inter-row sown chickpea at TAI.

Table 5. The effect of residue height on absolute and average maximum and minimum temperature and number of frosts in chickpea at the soil surface at TAI (7th July to 20th September)

Parameter	Bare soil	10cm	30cm	50cm
Abs. Max	37.1	37.0	36.7	35.0
Av Max	25.5	25.3	24.9	23.5
Av Min	-0.8	-0.7	0.2	0.0
Abs. Min	-5.6	-5.4	-4.3	-4.9
No. frosts	51	51	41	42

There was no change in temperature parameters between the bare soil and 10cm high residue. Changes started occurring once residue reached 30cm high, with the average and absolute minimums rising 0.4^{0}C and 1.3^{0}C, respectively. There were 10 less frosts in the 30 and 50cm high residue treatments compared to bare soil. Average and absolute maximums were 2.0^{0}C cooler in the tall 50cm stubble treatment compared to bare soil (see table 5).

Stubble loading effects on phenology

The effect of surface residue loading on the time taken, recorded as days after sowing (DAS), to reach 20% flower, 1st pod, 50% pod and flowering cessation are shown in figure 3.

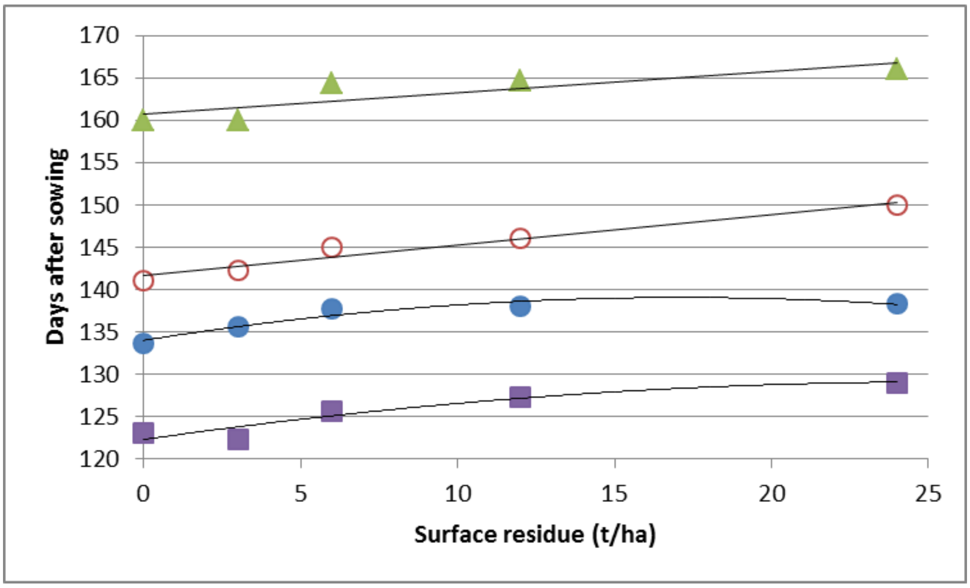

Figure 3. The effect of surface residue loading on the time taken (days after sowing) to reach 20% flower (■), 1st pod (●), 50% pod (○) and flowering cessation (Δ).

Across all parameters the time taken to reach these increased with increasing residue load on the surface. This effect was even more pronounced for 50% pod set and development and flowering cessation (Figure 3).

Assessment of chilling tolerant lines

Table 6 contains phenology data for selected lines from the chilling tolerance experiment at TAI.

Table 6. The effect of surface residue treatment on the time taken (days after sowing) to reach 1st flower, 50% flower and 1st pod for selected genotypes

		Days after sowing		
Stubble	Variety	1st Flower	50% Flower	1st Pod
Bare	CICA-1521	101	124	132
Flat residue	CICA-1521	104	126	132
Bare	PBA HatTrick⏀	110	126	132
Flat residue	PBA HatTrick⏀	115	126	137
Bare	CT-3	97	126	132
Flat residue	CT-3	118	129	137

In the bare soil treatment, genotypes reached 1st flower 3 to 11 days earlier than in the flat residue treatments. The residue treatments delayed 50% flowering in the numbered lines, but not in PBA HatTrick⏀, while the bare soil treatments led to earlier 1st podding. CICA1521, a fixed line, is substantially earlier at flowering than PBA HatTrick⏀, but similar in time to 1st pod set. CT-3 is a new line with enhanced chilling tolerance which is evident from its earlier time to 1st flowering, but this didn't translate into earlier pod set when compared to PBA HatTrick⏀.

Conclusion

The 2017 season was unprecedented with record frost events coupled with below average in crop rainfall. The severe weather conditions led to the complete death of the field pea blocks at TAI, due to frost and bacterial blight. Terminal drought led to the eventual loss of the Rowena site.

The slope of cropping country can contribute to spatial variability in soil surface temperatures, with minimum temperatures declining by - 0.22^{0}C per m drop in elevation measured on bare soil.

Surface residue loading increased the severity of radiant frosts which impacted on all species. Field peas are the most susceptible, while faba bean and chickpea can tolerate some vegetative frosting. The number of frosts increased with residue loading, while the average minimum surface temperature declined by -0.10 ^{0}C, per tonne of residue.

Standing stubble led to changes in air temperature at the inter-row soil surface. There was no difference in temperature parameters between bare soil and 10cm high residue. Once residue was above 30cm average, absolute minimums rose by 0.4 to 1.3^{0}C and there were fewer frosts. Maximum temperatures were cooler by up to 2.0^{0}C.

Numbered lines assessed for chilling tolerance showed that they could flower 3 to 11 days earlier than PBA HatTrick⏀, but this did not translate into earlier pod set. Post-harvest assessment will determine whether earlier flowering has led to more viable flowering and podding sites compared to PBA HatTrick⏀.

In all cases, sowing chickpeas between standing wheat residue gave equivalent grain yield outcomes to the bare soil treatment.

This remains the preferred strategy to maximise fallow efficiency and grain yield.

Acknowledgements

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⊕ Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994

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Preliminary data on phenology of Australian chickpea cultivars in the northern grain belt and prebreeding for heat avoidance traits

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Key words

chickpea, phenology, heat, chilling, prebreeding

GRDC code

US00083

Call to action/take home messages

- This research aims to identify chickpea traits and germplasm with superior tolerance to high temperatures and produce pre-breeding lines with improved productivity for the northern region. Results from this project will be published over the next few years.
- Results from contrasting 2016 and 2017 seasons in delayed sowing experiments were used to benchmark the phenological response of current and older cultivars to temperatures during flowering and podset.
- Approximately 1250 internationally-sourced lines (including both *Cicer arientinum* and wild relatives) are being screened for performance in the northern grain belt to select appropriate parents for pre-breeding for high yield under terminal heat stress. Earlier podding is one of several traits being targeted.

Introduction

Chickpea is rapidly growing in its importance as a winter legume crop in Australia. Research and pre-breeding in Australia is expanding in the areas of abiotic stress tolerance to build on gains in disease control over the past 40 years.

Terminal heat stress is one of the most widespread abiotic stressors in Australian cropping regions. There are several ways in which heat can reduce yield, which include death/sterility of reproductive tissues (Devasirvatham *et al.* 2013), reduced pod set, a reduction in the duration of developmental stages (Devasirvatham *et al.* 2012) and investment in heat-shock proteins (Jha *et al.* 2014). These factors are controlled by different genes and require different breeding strategies, but relevant traits could potentially be 'pyramided' into new pre-breeding lines to enhance the performance of chickpea in hot and dry seasons.

Compared to most other winter legumes, chickpea has a reputation as relatively tolerant to hot, dry conditions (Sadras *et al*. 2015). The temperatures required to sterilise flowers are relatively high (sustained >33^{o}C daytime temperatures in sensitive genotypes – Devasirvatham *et al.* 2013) and are not usually persistent during the key weeks of pollination in September and October in the Australian grain belt. Conversely, temperatures which delay the onset of podding (average daily temperature of 15^{o}C, termed "chilling temperatures" – Croser *et al.* 2003) are quite common, and delays in the commencement of podding of up to 35 days post flowering have been recorded in Mediteranean-type climates in Australia due to long periods of chilling temperatures (Berger *et al* 2004). Reduced pod set has been observed in mean temperatures up to 21^{o}C (Berger *et al.* 2011). This has been attributed to a reduced ability of the pollen to grow through the style and fertilise the ovule under low temperatures, despite both pollen and ovule being fertile (Srinivasan *et al.* 1999; Clarke and Siddique 2004).

It has been argued that greater yield gains for Australian growers are possible by bringing the podding period earlier by a week in September (heat avoidance) rather than extending the podding period a week into November (heat tolerance), when moisture availability is usually also a significant constraint (Clarke *et al.* 2004). Several approaches to breeding for improved chilling tolerance have been attempted in Australia, including pollen screening utilising internationally-sourced *Cicer arientinum* germplasm, which resulted in early-podding cultivars Sonali and Rupali (Clarke *et al.* 2004), and screening wild relatives for chilling tolerance (Berger *et al.* 2011). It has been suggested that little genetic variation exists amongst domesticated chickpea to breed for chilling tolerance (Berger *et al.* 2011), however a difference of a few days in the onset of podding, though scientifically small when compared to wild *Cicer* species or other crops, can be economically large to a grower, particularly in seasons of terminal heat or drought stress (Berger *et al.* 2004).

The aim of this research is to investigate mechanisms for heat tolerance and avoidance, screen Australian and international germplasm for genetic sources of relevant traits, and incorporate these traits into pre-breeding lines which can be used for development of future Australian cultivars by breeders. The data presented in this paper are preliminary phenological results from a subset of lines to illustrate the potential to breed for chilling tolerance as a mechanism to increase the time available for podding in seasons/environments which experience terminal heat and drought stress.

Methods for preliminary results

A field experiment was conducted at the I. A. Watson Grains Research Institute, Narrabri (30.34°S; 149.76°E) in 2016 and 2017. Up to 76 chickpea genotypes were planted in two replicated plots (each plot 1.8 x 4 m). Data presented here is from a subset of lines representing released cultivars or publically available genotypes.

The experiment consisted of two sowing dates - a sowing date typical for the northern region and a later sowing when plants would be exposed to higher temperatures. Planting dates were 14 June and 29 July in 2016, and 31 May and 25 July in 2017. The experimental years provided two contrasting seasons: 2016 was dominated by high rainfall (529 mm Jun – Oct) and relatively cool September daytime temperatures, with large amounts of cloud associated with precipitation in the first few months of growth. In contrast, 2017 started with good stored moisture, but had less in-crop rainfall (135 mm Jun-Nov), with concurrent warmer days and cooler nights. Temperature profiles for the period before and during the reproductive phase are given in Figure 1.

Plots damaged by severe ascochyta infection in 2016 were excluded from the analysis and hence, the results for some cultivars represent data from single plots.

Phenology for the time of sowing (TOS) trial was recorded as the days after planting (DAP) that 50% of plants in the plot had produced its first flower or first pod. Growing degree days (GDD) was calculated by

$$[(T_{max} + T_{Min}) / 2] - T_{base}$$

Where T_{max} is the daily max temperature and T_{Min} is the daily minimum, unless the minimum dropped below T_{base} in which case T_{base} was used. A T_{base} of 0°C was assumed (Soltani *et al*. 2006). Daily temperatures were measured by an on-site weather station.

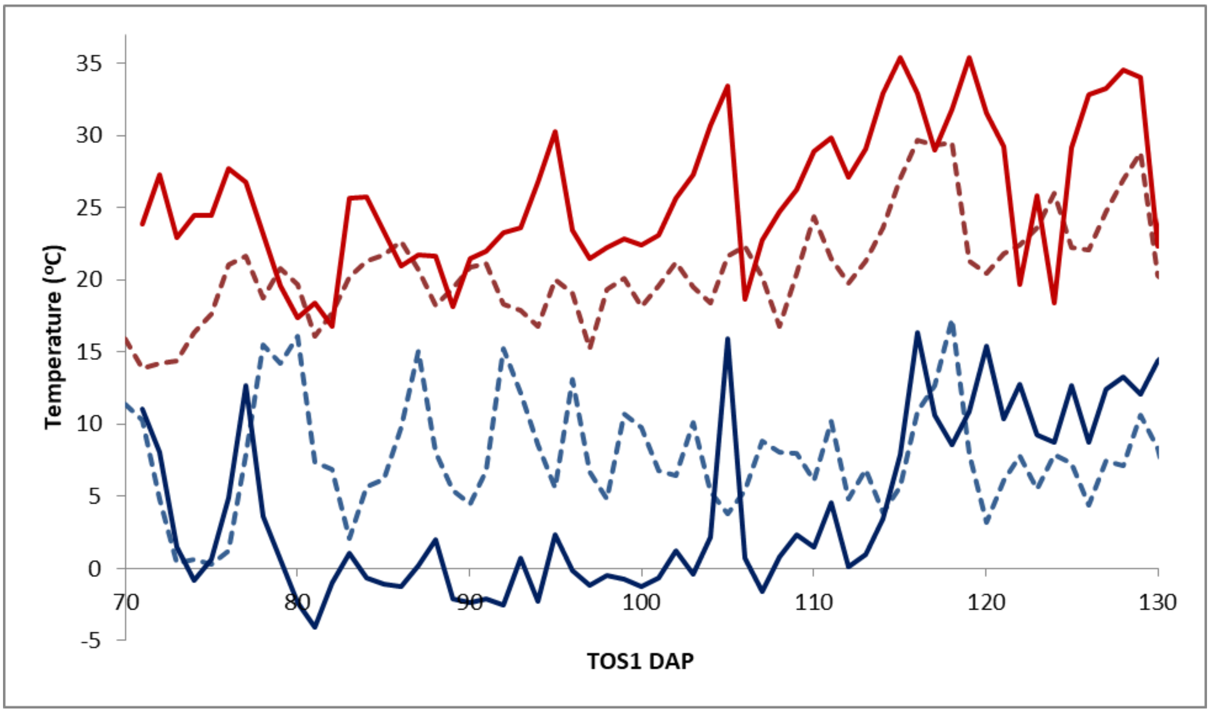

Figure 1. Temperature profiles for the two experimental seasons before and during the reproductive phase. Dotted lines = 2016 daily minimum and maximum temperatures; solid lines = 2017 daily minimum and maximum temperatures.

In addition, over 1000 genetically-diverse chickpea genotypes were obtained from the Australian Grains Genebank (AGG), plus a subset of 241 lines from the ICRISAT reference set were obtained via the Australian Centre for Plant Functional Genomics (Adelaide, South Australia). These sets included wild relatives of domesticated chickpea, wild-collected accessions of *Cicer arientinum*, and breeding lines/cultivars from a diverse range of growing environments around the world. All genotypes were sown in single 1.5m rows in 2016 in a netted bird-exclusion cage at Narrabri between the 18th and 27th July, with the late and long sowing period being due to high rainfall, which continued for most of the growing season. PBA HatTrick⦶ and PBA Slasher⦶ were included as comparators. Phenology was determined for plants within each 1.5m row as per TOS trial.

The data were analysed using the REML function I Genstat (version 17). Years, sowing dates and genotypes were considered fixed effects and row-column coordinates within sowing dates and seasons as random effects.

Preliminary results and discussion

The contrasting seasons provided interesting study years for the influence of temperature on phenology. DAP for flowering, podding and the flower-pod interval exhibited a significant interaction between genotype, year and TOS (P=0.036, P<0.001 and P<0.001 respectively). The range in flowering dates between genotypes for TOS1 was greater than the range in podding dates (Table 1). However, the range in flowering and podding dates within TOS2 were similar (approximately 12 days), but much narrower than TOS1. This suggests that either the warmer temperatures in TOS2 induced earlier pod set, or that cooler temperatures in TOS1 delayed pod set.

This data shows clear relationship between flowering and podding date, with 58-63% of the variance in podding date being explained by flowering date in regular sowings. Hence, selecting for earlier flowering will result in earlier podding. However, based on this data and considering only this set of genotypes, selecting for 1 day earlier podding will only bring forward podding by 0.31 days. Hence the economic value of selecting for earlier flowering/podding amongst this set of germplasm is quite low, considering that the range in flowering dates from which to select is only a couple of weeks.

Cultivars which had a flower-pod interval which was more than 2 weeks greater in TOS1 compared with TOS2 were Genesis 079, PBA Monarch⊕, PBA Pistol⊕, PBA Slasher⊕, PBA Striker⊕ and Sonali. These cultivars tended to have both earlier flowering and earlier podding times than other cultivars, and were the earliest in both TOS1 and TOS2.

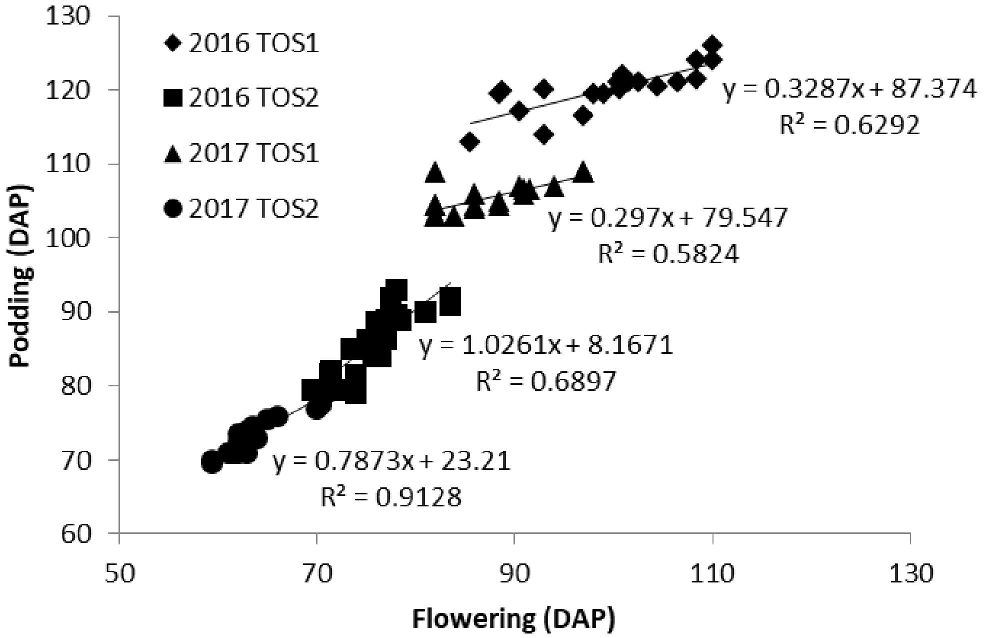

Figure 2. Correlations between the flowering and podding dates of genotypes in two contrasting seasons

The thermal time requirements to the commencement of the flowering and podding periods are given in Table 2. Earlier commencement of podding in 2017 cannot be explained by faster accumulation in thermal time. Commencement of podding in TOS1 was 207 GDD later in 2016 than 2017. This trend was also evident in TOS2, albeit to a lesser extent. Whilst the average daily temperatures (essentially what is used to calculate GDD where T_{base} = 0°C) in both seasons were similar during the commencement and early reproductive stage (Figure 1), the daily maximums and minimums were quite different, and the amount of cloud was much higher in 2016 due to the large number of rainy days. It is possible that lower light intensity due to cloud cover had a significant influence on chickpea development. Note that irrigation was used to top up stored soil moisture in 2017 such that there was minimal to zero water stress during flowering and podding (no irrigation was required in 2016).

The shorter intervals between flowering and podding in TOS2 compared to TOS1 are also not explained by differences in GDD alone, with podding commencing 330 GDD earlier in TOS2 than TOS1 in 2016 and 246 GDD earlier in 2017. This lends support to the importance of considering daylength as well as temperature in delayed sowing trials (Sadras *et al*. 2015).

Table 1. Number of days between flowering and podding in heat stress trials at Narrabri in 2016 and 2017

	Flowering		Podding		Flower-pod interval	
	TOS1	**TOS2**	**TOS1**	**TOS2**	**TOS1**	**TOS2**
2016						
Amethyst	102	79	121	89	20	11
Flipper⟨PBR⟩	105	77	121	89	16	12
Genesis 079	89	71	120	82	31	11
Genesis 090	101	76	120	84	19	8
Genesis Kalkee	107	77	121	87	15	10
Howzat	99	77	120	84	21	8
ICCV 05112	101	74	121	85	21	12
ICCV 05301	109	81	122	90	13	9
ICCV 05314	110	78	124	90	14	12
ICCV 06109	98	78	120	91	22	14
ICCV 98818	97	76	117	89	20	13
Jimbour	109	84	124	91	13	9
Kyabra⟨PBR⟩	110	84	126	92	16	12
PBA HatTrick⟨PBR⟩	98	75	120	86	22	11
PBA Monarch⟨PBR⟩	93	72	120	82	27	11
PBA Pistol⟨PBR⟩	93	74	114	79	21	5
PBA Slasher⟨PBR⟩	91	72	117	80	27	8
PBA Striker⟨PBR⟩	89	74	120	82	31	8
Sonali	86	70	113	80	28	10
Tyson⟨PBR⟩	103	78	121	93	19	15
Yorker	101	78	122	92	21	15
Range	*25*	*14*	*13*	*14*	*18*	*10*
Mean	*99*	*76*	*120*	*86*	*21*	*10*
2017						
Ambar⟨PBR⟩	84	64	103	75	19	11
Amethyst	89	64	105	73	17	9
Genesis 079	82	62	103	73	21	11
Genesis 090	91	65	107	76	16	11
Genesis Kalkee	92	66	107	76	15	10
ICCV 05112	97	71	109	79	12	8
ICCV 05301	89	71	105	78	16	7
ICCV 05314	91	70	106	77	15	7
ICCV 06109	97	71	109	80	12	9
ICCV 98818	97	71	109	80	12	9
Jimbour	86	62	104	74	18	12
Kimberly Large	82	63	109	71	27	8
Kyabra⟨PBR⟩	86	63	106	74	20	11
Neelam⟨PBR⟩	91	63	107	73	17	10
PBA Boundary⟨PBR⟩	94	62	107	71	13	10

PBA HatTrick⦸	86	63	105	72	19	10
PBA Monarch⦸	82	64	105	74	23	11
PBA Pistol⦸	82	60	103	70	21	10
PBA Seamer⦸	82	62	103	71	21	9
PBA Slasher⦸	82	62	105	71	23	10
PBA Striker⦸	82	60	103	70	21	11
Sonali	82	61	105	71	23	10
Range	*15*	*12*	*6*	*11*	*15*	*5*
Mean	*87*	*64*	*106*	*74*	*18*	*10*
s.e.	*4.384*		*2.079*		*2.880*	

Podding for all genotypes in TOS2 began between 80 and 92 DAP in 2016 and 71 and 76 DAP in 2017. The mean flower-pod interval was 10 days in both 2016 and 2017 for this treatment, which was between 9 and 14 days shorter than TOS1. Given that it is not GDD alone which causes shorter flower-pod intervals in TOS2, two possible factors are proposed: longer daylength/greater incidence of solar radiation (Soltani and Sinclair, 2011), and/or a critical minimum temperature under which sporogenesis or pollenation cannot occur (Clarke and Siddique 2004). The large number of cloudy days in 2016 likely played a role in alteration of phenology.

Further field trials over the next few years will quantify the influence of these various factors, as well as growth rate, changes in canopy temperature using aerial remote sensing, model phenology relative to canopy temperature rather than weather station data, and quantify photothermal time rather than simply GDD. Another factor that warrants further research is that average daily temperature is not the best measure of chilling but rather temperatures after dawn (when pollen is released).

Table 2. Accumulated GDD up to the commencement of flowering and podding for the earliest genotypes in each treatment

	Flowering		**Podding**	
	TOS1	**TOS2**	**TOS1**	**TOS2**
2016	999	892	1374	1044
2017	940	729	1167	921

Of most value to prebreeding is that differences existed between genotypes, even amongst the fairly narrow genetic diversity found in current Australian cultivars. To expand this genetic range and seek lines with earlier podding capacity (and suitability to other climatic features of the Northern Grain Belt), the phenology and yield potential of a diverse range of chickpea genotypes were quantified at Narrabri (Figure 3). Heavy rains in June and July caused significant planting delays, such that the planting date was closer to TOS2 in 2016 and thus the discrimination between podding dates was anticipated to be small. Nevertheless, up to 6 days difference in podding date between PBA HatTrick⦸ and the earliest podding lines, and 7 days difference in the flower-pod interval, were observed. Podding dates of PBA Slasher⦸ and PBA HatTrick⦸ standards were 91 DAP and 85 DAP respectively, and flower-pod intervals were 15 days and 12 days respectively. This placed these lines (and by deduction most Australian cultivars) well within, but slightly earlier than average, the range of podding dates found in the diverse lines. It is anticipated that when sown within the optimum sowing window for chickpea there would be greater variation in podding dates and flower-pod interval, as experienced in the TOS1 trials.

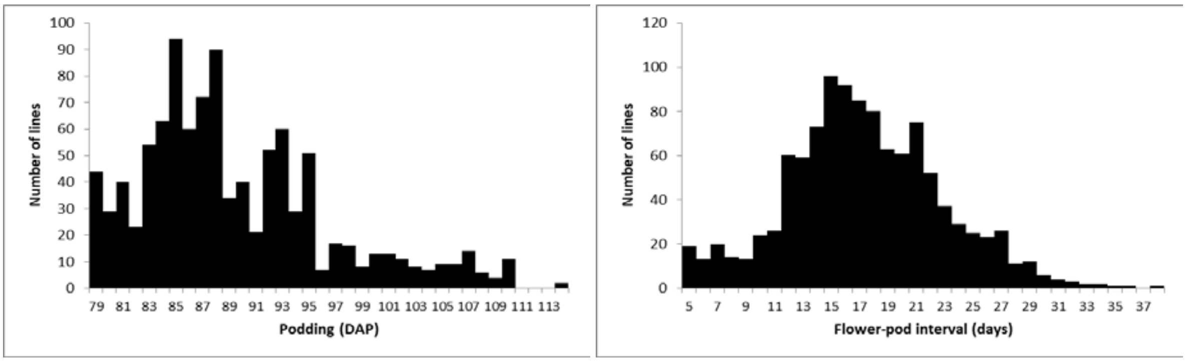

Figure 3. Histograms showing distribution of podding and flower-pod intervals amongst a range of >1000 diverse genotypes including closely related *Cicer* species and wild lines.

A subset of approximately 200 of the diverse lines from 2016 were increased in 2017 and will undergo field-based screening in 2018. Selection amongst diverse genotypes will be made for earlier podset as well as a host of other traits likely to lead to yield gains in the northern grain belt. The most promising lines will be crossed with high-yielding Australian cultivars and sent to the PBA chickpea breeding program at Tamworth for incorporation into future chickpea cultivars.

Acknowledgements

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Chickpea agronomy and water use with neutron moisture meters

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Key words

chickpea, agronomy, row spacing, harvest index, water use

GRDC code

UQ00067

Call to action/take home messages

- Chickpea yields are maximised when planted on narrow rows (50cm and below).
- Avoid planting early and excessive biomass production.
- Aim to establish 20-30 plants/m^2 .
- Chickpeas will extract water from soils to 1.2m and below.
- Water Use Efficiency is improved by narrow rows; more water extracted and higher yields.

Background

The Queensland Pulse Agronomy Initiative planted its first chickpea trial in the 2013 winter, and with the next 2 years of trials our understanding of what drives yield improved, but also left many unanswered questions regarding crop physiology and how to best manage the crop to maximise yield.

The initial trials across southern Queensland confirmed that the latest release varieties such as PBA HatTrick⦸, PBA Boundary⦸ and the now released PBA Seamer⦸ (formerly CICA 0912) responded similarly to several agronomic factors:

- All maximised yields when planted at narrow row spacings with peak yields obtained when planted at row spacing of 25cm, however across several sites and years yields at 50cm were statistically the same as 25cm; yields then dropped when planted at wider spacings of 75cm and 100cm. This was observed in both low and high yielding environments (Figure).
- Plant population had less effect than did row spacing on final yields, with a flat response curve across 20, 30 and 40 plants/m^2, with a slight drop in yield at 10 plants/m^2. Hence it is recommended that planting rates remain at the current recommended rate of 20-30 plants established/m^2 for dryland plantings.
- There were no interactions that suggest any variety be planted at different populations for different row spacings. Planting early in the planting window had no grain yield benefit, however early plantings generated more biomass.
- Later plantings have mixed results for yield and biomass. It has been observed that harvest index (HI) improves with later plantings due to lower dry matter production (Figure 2) & (Table 1).

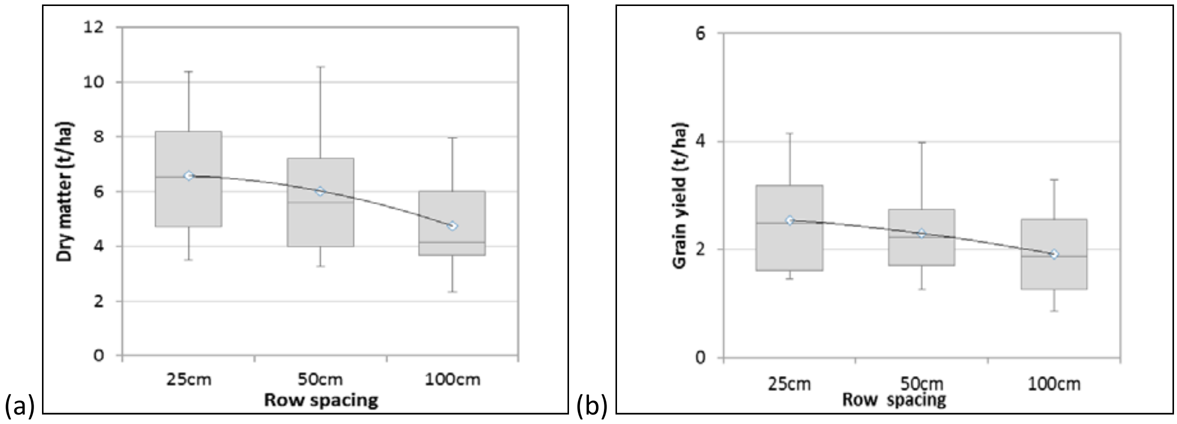

Figure 1. Summary of 12 chickpea sites from 2014 and 2015 [diamond marker indicates average across all sites and the trend line for the 3 row spacings]. (a) shows the effect of row spacing on dry matter production and (b) final grain yield. Row spacing has a larger effect on dry matter production than grain yield, however both trend lower as row spacing increases.

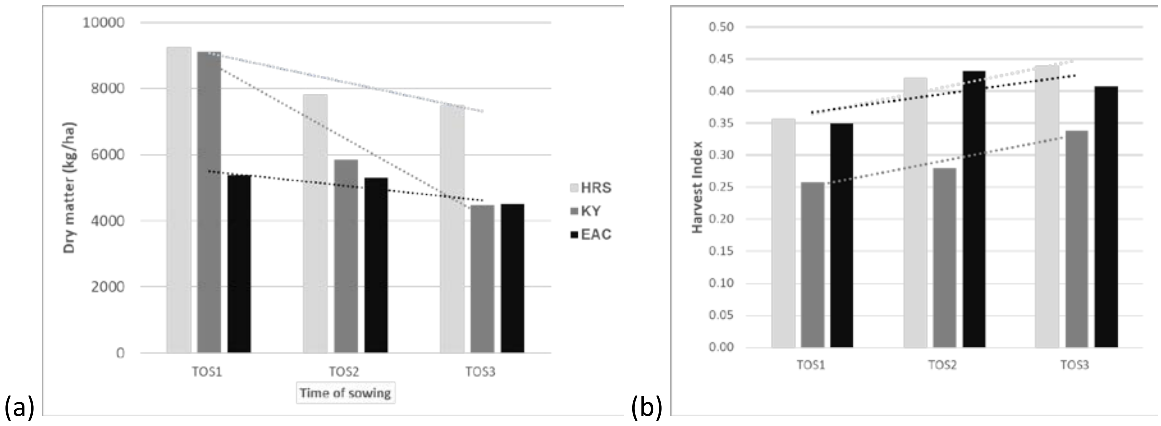

Figure 2. Time of Sowing (TOS) trials in 2015 at 3 sites; Hermitage [HRS], Kingaroy [KY] and Emerald [EAC]. All sites had a decreasing trend for dry matter production when planted later in the season (a). Harvest Index (HI) improves with later sowing dates as dry matter is reduced (b).

Table 1. Dry matter production and grain yield at Hermitage 2015 (relates to Figure 2).

Hermitage	TOS 1 20/5	TOS 2 12/6	TOS 3 3/7
Dry matter (t/ha)	9.250a	7.825b	7.492b
Grain Yield (t/ha)	3.3d	3.3d	3.3d

* Note that grain production in this trial was the same for all TOS even with high biomass in the early sowing

Combining dry matter and yield data across 10 sites over 3 years which includes trials sites at Emerald, Kingaroy, Warra, Dalby, Goondiwindi and Hermitage in Figure 3, indicates that chickpeas do not convert biomass to grain with the same efficiency as the production of dry matter increases. There is a very good straight line relationship up to 8t/ha dry matter and it plateaus after this, i.e. the highest yield potential crops do not fully meet their grain production potential. There could be many reasons for this including terminal droughts as a consequence of growing large biomass crops.

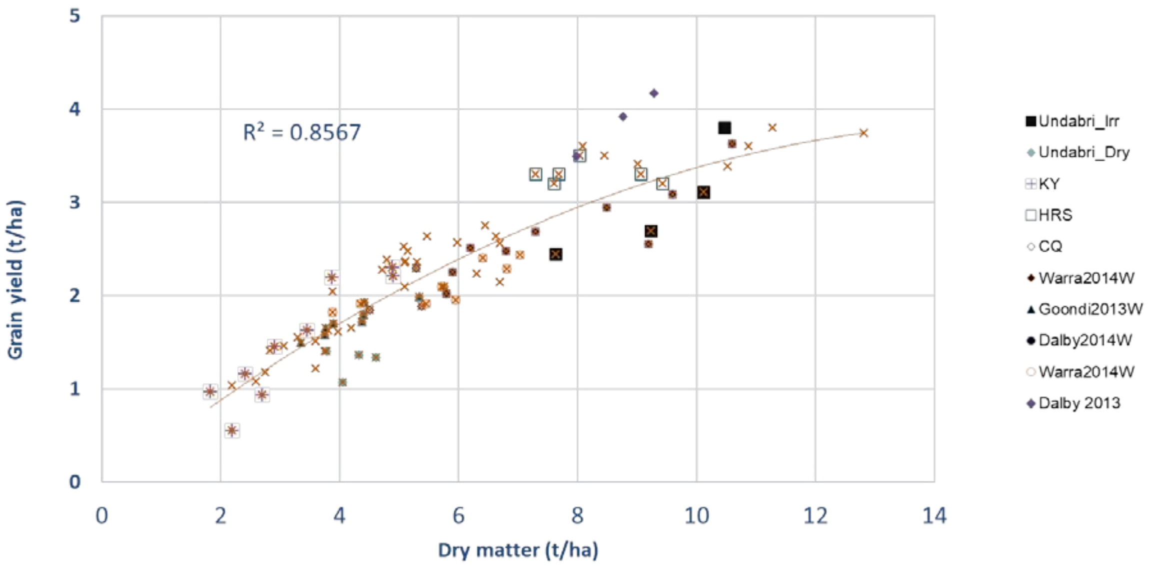

Figure 3. The relationship ship between dry matter production and grain for chickpea trials at 10 sites over 3 years

New directions

These findings have directed subsequent research questions in the Queensland Pulse Agronomy Initiative. The questions to be answered include; can harvest index be manipulated in chickpeas? How best to manage high biomass crops? Can early biomass production be reduced to conserve soil moisture for later in the season?

Trials with many plant growth regulators (PGRs) and other chemicals were conducted in 2016. While there were some products that did have a minimal effect on harvest index (HI), no products improved yields. Work with PGR's has many seasonal, rate and timing variabilities that make consistent results difficult to obtain. Due to this and that currently there are no PGR products registered for use on chickpeas, this aspect of the research was not pursued further.

In other trials, the water use of chickpeas was monitored with neutron moisture meters (NMM) to determine when and where the crop was accessing soil water and to explain why narrower row spacings were able to access more water and convert it more efficiently to grain.

Water use

To monitor soil moisture and where chickpeas are drawing moisture from using the neutron moisture meter (NMM), plots were planted at 2 different row spacings of 50 and 75 cm. Within the plot 2 access tubes were installed, one in the planted row and the other between the 2 rows. In 2016 the variety was PBA HatTrick ⒟ planted at 30 plants/m^2. Access tubes were in all 3 replicated plots and measurements averaged.

This chickpea trial at Hermitage in 2016, had an unusually wet late winter and spring with close to 500 mm of in-crop rain for the main season planting time and 350mm for the later sowing. This led to a very late January harvest and a badly lodged crop. Grain yield results from this trial had no statistical differences across variety and row spacing, with a trend for higher yields at the later sowing time.

For the earlier sowing time, flowering commenced by mid-September. The critical 15°C average temperature for pod retention was not consistent until well into October, with below 5°C minimum temperatures recorded on the 25th of October.

Due to the very wet season, NMM data shows that the crop grew from August to mid-October on rainfall, with soil moisture depletion only starting to occur after this time. This soil draw down coincided with the warmer temperatures and pod retention of the crop. The NMM data shows that even with the high rainfall, soil moisture was removed from the profile to the deepest measuring point of 125 cm (Figure 4). We can only assume the chickpea crop was the cause of this as roots were not assessed.

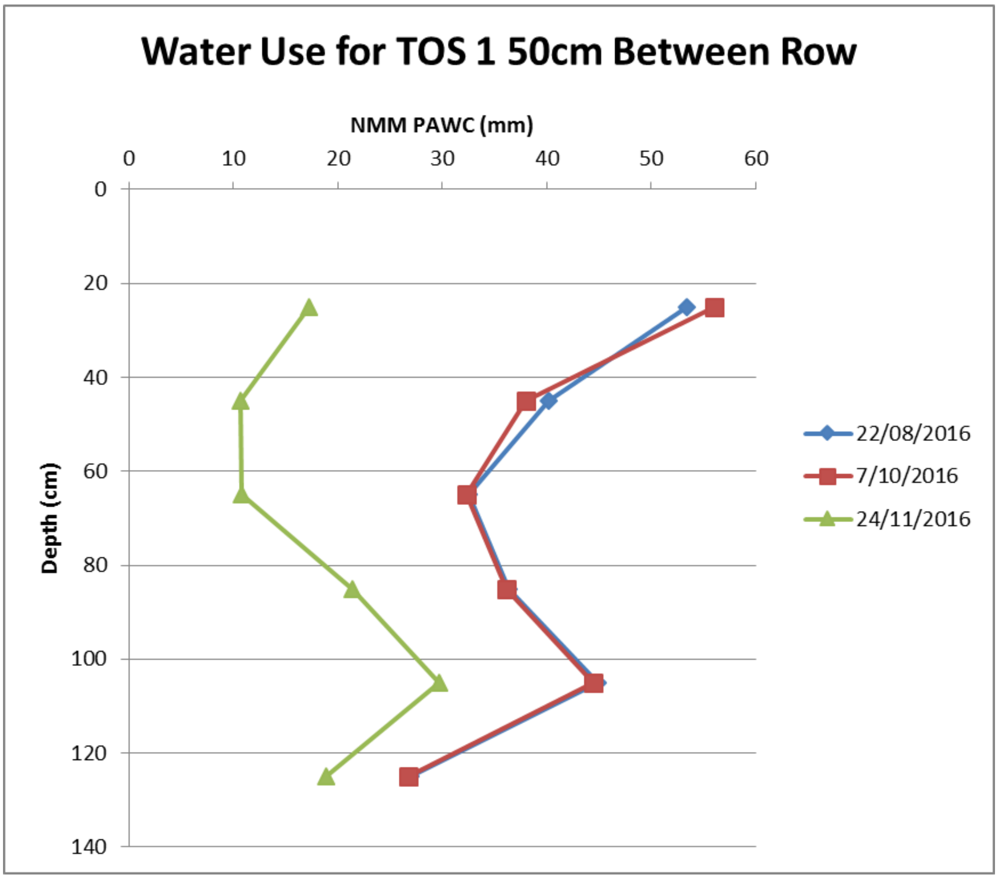

Figure 4. Soil water use as measured by neutron moisture meter at Hermitage Qld. at 3 times during the growing season. Access tube was in the middle of 2 rows planted 50 cm apart.

A further point of interest was from where water was extracted in the different row spacings of 50 cm and 75 cm. In the 50 cm, plots water extraction patterns were virtually the same where measured in the planted row or between the row. In the wider spaced rows at 75 cm, as the season progressed, more water was extracted in the between row space and this occurred in the top 65 cm of the profile. The difference over the season was 30 mm of additional PAWC removed in the inter row space as compared to the on row readings. If you averaged the 2 tubes it would mean an additional 15mm of water extracted in 75cm plot for no additional yield benefit.

In previous trials within the Pulse Agronomy project where starting and ending gravimetric assessments of soil water were taken, the results show that crops planted on narrow row spacing access up to 20mm more of the stored soil water, and due to higher yields convert this moisture more efficiently to grain.

The trial data for chickpeas grown in 2017 which will provide additional NMM data were unavailable at the time of publishing.

Discussion

Chickpeas have the potential for yields approaching 5 t/ha given the right environment/season (this project's best small plot yield 4.7 t/ha dryland). Dry matter production of above 10t/ha and up to 13 t/ha have been produced, and results have seen harvest index of 0.45, however the crop seems unable to maintain a constant harvest index above 8 t/ha dry matter and it is difficult to get the combination of high dry matter and HI.

The results suggest several management options to give the crop the greatest potential; starting with narrow rows. The farming system also needs to be considered, as well as any associated risk with disease for the coming season. Improved yields from narrow rows are evidenced in high and low yield scenarios, with disease pressure high 1 in 7 – 10 years.

Planting early produces large biomass that has a higher disease risk potential. The bigger risk however, is using up stored soil moisture and adding to the possibility of terminal drought and being unable to maintain this yield potential through pod fill.

Chickpeas should be sown into paddocks with good soil depth and minimal soil constraints. It has long been known that chickpeas are very adept at chasing deep moisture and NMM suggests extraction to 125 cm in a soft year. Choosing paddocks with the biggest bucket is highly adventitious for high yields.

Continue with best management crop scouting for pests and diseases and utilise preventative fungicide applications as appropriate.

Management options once the crop is growing, apart from the usual crop protection/good agronomy, have been elusive and work will continue to manipulate the crop to improve harvest index particularly for high biomass crops but also for lower biomass situations.

Current farming systems aim to store rainfall and fill the soil profile between crops. Good management enable the crop to withdraw more from this bank of stored soil water.

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A special thanks to the generous farmer co-operators who have hosted field trials.

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Rules-of-thumb for calculating additional soil N availability and wheat N uptake in pulse-cereal sequences

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Key words

N uptake, pulses, canola, cereals, rotation, sequence

GRDC code

CSP00146

Call to action/take home messages

- Nitrogen (N) contributed by legumes is an important component of N supply to subsequent cereal crops, yet few Australian grain-growers routinely monitor soil mineral N before applying N fertiliser.
- Data collected from 16 dryland experiments conducted in eastern Australia from 1989–2016, showed soil mineral N (nitrate and ammonium) measured in autumn following legumes in the expected rooting zone (1.2m) of a subsequent wheat crop, was on average 35± 20 kg N/ha (n = 26) higher than after a previous wheat, barley or canola crop.
- The additional soil N availability was calculated to be equivalent to 0.15 ± 0.09 kg N/ha per mm summer fallow rainfall, 9 ± 5 kg N/ha per t residual legume shoot dry matter/ha and 18 ± 9 kg N/ha per t/ha grain harvested, representing 28 ± 11% total legume residue N. It was proposed that these 4 measures could be used as potential rules-of-thumb by grain-growers and their advisors to bench-mark the likely additional soil mineral N provided by pulse crops.
- The apparent recovery of legume residue N by wheat averaged 30 ± 11% for 16 legume treatments in a subset of eight experiments, which could be considered as a further rule-of-thumb to indicate the relative value of legume N to a following wheat crop.
- By comparison, the apparent recovery of fertiliser N in the absence of legumes in two of these experiments represented 64 ± 16% of the 51–75 kg fertiliser-N/ha supplied as top-dressing applications at stem elongation just prior to peak crop N demand.

Introduction

The concentrations of soil mineral (i.e. nitrate+ammonium) nitrogen (N) measured prior to sowing a cereal in dryland farming systems depends upon the relative balance between factors that either favour the build-up, or result in a reduction, of available soil N.

An accumulation of soil N can arise from the combined contribution of:

(i) the carry-over of any mineral N not utilised by the previous crop (spared N; Herridge et al. 1995), and

(ii) the total N mineralised from above- or below-ground plant residues and the soil organic N pool by soil microbes (total N released).

Factors that reduce soil mineral N on the other hand include:

(i) the extent to which crop residues or management influences the use of available soil N by soil microbes for growth (*N immobilised*),

(ii) assimilation of available N by weeds (*weed N-uptake*), and

(iii) leaching, erosion and gaseous losses (*N lost*; see papers cited by Peoples *et al.* 2017).

Consequently, the concentrations of soil mineral N observed at the beginning of a growing season represent the net effect of all these variables according to the following conceptual Equation [1]:

Soil mineral N = [(spared N)+(total N released)] – [(N immobilised)+(weed N-uptake)+(N lost)]

Each of these processes can be influenced by:

(i) the duration of the period of fallow between the end of one cropping season and the beginning of the next since this defines the time available for weed growth, and mineralisation or loss processes to occur,

(ii) rainfall amount and distribution during the fallow period, as soil moisture regulates soil microbial activity, determines the risk of N losses, and affects weed germination and growth, and

(iii) the quantity of plant residues remaining at the end of the previous growing season and the N content (or C:N ratio "quality" attributes) of those residues. Residue N content determines the amount of N potentially available for mineralisation, and C:N ratio influences whether a net release or immobilisation of mineral N occurs.

Many researchers have observed improved grain yields and/or N uptake by cereal crops grown after legumes compared to cereal-after-cereal sequences (Angus *et al.* 2015). This is usually attributed to elevated availability of soil mineral N and healthier crops recovering more soil N following legumes. However, few Australian dryland grain-growers routinely conduct pre-season soil testing, or monitor soil N fertility in all the cropping paddocks across their farms.

Computer models have been developed that can simulate the complex soil N and water dynamics in rainfed cropping systems, which have been used to investigate N and water use efficiency in different environments and soil types in response to agronomic practice. Grain-growers can now access the outputs from these sophisticated research tools through subscriptions to internet-based decision support services to predict soil N availability and grain yield prospects in response to different N fertilisation scenarios and seasonal conditions (Hochman *et al.* 2009). However, the costs associated with obtaining useful input data (including soil mineral N) to parametrise the model, and the soil characterisation required to improve the accuracy of predictions, remain major barriers to the widespread adoption of such technologies. Apart from an Excel spreadsheet N budgeting approach recently proposed by Herridge (2017), there have been few convenient or simple ways by which farmers and their advisors can benchmark the expected net effect of including a legume in a cropping sequence on the accumulation of soil mineral N prior to sowing the next crop in the absence of soil tests, or to assess how much N from the preceding legume might subsequently be assimilated by a following wheat crop (*Triticum aestivum*).

This paper presents crop production and soil N data from 16 dryland cropping experiments undertaken at different locations across eastern Australia between 1989 and 2016 which aimed to quantify the N benefits derived from including pulses in cereal dominated cropping sequences. In these investigations soil mineral N concentrations immediately prior to sowing wheat for the next growing season were compared for soils after legumes and after various non-legume control treatments such as wheat, barley (*Hordeum vulgare*), or canola (*Brassica napus*). The productivity and N accumulated by the following wheat crop was also quantified. These studies differ from many previous investigations, as the majority of the experiments where conducted in farmers' fields in partnership with individual grain-growers and local grower associations.

The collated crop and soil data from these experiments were used to assess the potential of different approaches to develop simple 'rules-of-thumb' that could be used by farmers and their advisors as guides to the anticipated soil mineral N benefits derived from legumes harvested for grain (28 comparisons). The apparent recoveries of the legume N by a following wheat crop were calculated for eight experiments (16 estimates), and the recoveries of legume N were directly compared to the apparent uptake of fertiliser N applied to wheat when grown after a preceding wheat or canola crop in two experiments (three estimates).

Materials and methods

Full experimental details are described in Peoples *et al.* (2017), but briefly the studies described here were undertaken in partnership with FarmLink, Riverine Plains, Birchip Cropping Group (BCG), Mackillop Farm Management Group (MFMG), Mallee Sustainable Farming (MSF), or Eyre Peninsula Farming Systems grower groups, and/or in collaboration with the NSW Department of Primary Industries (NSW DPI), Victorian Department of Economic Development, Jobs, Transport and Resources (formerly Vic DPI), or the South Australian Research and Development Institute (SARDI). The experimental sites were located on different soil types across northern and southern New South Wales (NSW), Victoria (Vic), and South Australia (SA; Table 1).

Legume treatments included field pea (*Pisum sativum*), chickpea (*Cicer arietinum*), lupin (*Lupinus angustifolius*), faba bean (*Vicia faba*), lentil (*Lens culinaris*), and vetch (*Vicia sativa*). The non-legume control was wheat in nine experiments, barley in one (Breeza 1997), and canola in two studies (Tamworth 2009 and Loxton 2015). Three experiments included both wheat and canola as non-legume controls (Hopetoun 2009, Junee Reefs 2011, and Naracoorte 2011), but only the wheat data were used for subsequent calculations of soil mineral N benefits. During the 25 years, the various cropping treatments experienced both above- and below-average rainfall during the growing season (April-October) and in the post-harvest summer-autumn fallow (Table 1). Most experimental plots consisted of at least six crop rows of plants sown 0.2–0.3 m apart in a randomized complete block design in plots 10 – 35 m long with three or four replicates sown in either late-April to early-May (legume crops and canola) or mid to late-May (wheat). In all cases weeds were controlled with registered herbicides using recommended commercial practices during the summer-autumn fallow between crops and during the growth of the following wheat so neither the accumulation of soil mineral N nor the subsequent uptake of N by wheat were confounded by the presence of weeds.

While wheat was subsequently sown into all legume and non-legume plots in May of the following growing season to quantify the impact of legumes for all 16 experiments, full N analyses of the wheat grain and stubble were only undertaken for 11 studies. In three of these experiments (one at Tamworth 2010 and two at Culcairn 2011), wheat growth was not constrained by N availability and there were no responses to either legume pre-treatments or applications of fertiliser N. The N uptake data presented in the current paper come from the remaining eight experiments and represented 16 pulse crops where significant wheat responses were observed (North Star 1990 and 1993, Breeza 1998, Gundibindjal 2001 and 2002, Junee Reefs 2012, Wagga Wagga 2012, and Loxton 2016).

The application of fertiliser N to wheat after wheat was included as an additional treatment to allow direct comparisons of the apparent recoveries of legume and fertiliser N in only two of these experiments (Junee Reefs and Wagga Wagga 2012). At Junee Reefs the wheat sown into the 2011 legume treatment plots received starter fertiliser of 25 kg/ha mono-ammonium phosphate (2.5 kg N/ha), and was top-dressed with 46 kg/ha urea-N at stem elongation. The 2011 wheat and canola plots were each split into 2 × 10 m sub-plots with one half receiving exactly the same N fertiliser treatment as the legume plots, and the other half being top-dressed with an additional 51 kg urea-N/ha (i.e. supplied with a total 97 kg urea-N/ha) just prior to stem elongation. At Wagga Wagga the wheat sown into the 2011 legume plots received no N fertiliser while the 2011 wheat plots received either no fertiliser or 75 kg fertiliser-N/ha (25 kg urea-N/ha at sowing with a further 50 kg N/ha at stem elongation).

Measurements

Soil mineral N - Treatment plots were sampled for soil mineral N immediately before sowing wheat in the following growing season. The soil mineral N data presented here, and the values subsequently used for calculations, were normalised for the anticipated rooting depth of wheat. At Mildura, Naracoorte, Minnipa and Loxton this represented 0-0.6 m since inhospitable subsoils (high salinity, sodicity or alkalinity), or rocks at these locations effectively restricted root exploration and/or prevented soil sampling deeper in the profile. At all other sites soil mineral N data were calculated to 1.2 m which approximates the average rooting depth of wheat in most eastern Australian soil types where there aren't major subsoil constraints to root growth (average maximum rooting depth of wheat = 1.29 m ± a standard deviation of 0.3 m, n=36; Kirkegaard and Lilley 2007). Examination of the distribution of soil mineral N in the soil profiles of treatments at eight of the experimental sites indicated that mineral N in the top 0.6 m was on average 68±9% of the total mineral N to 1.2 m (n=27), which in turn represented 88±5% of the soil mineral N detected to 1.5 m depth (data not shown). The distribution of soil mineral N in soil profiles following legumes (0-0.6 m equivalent to 66±8% of soil mineral N 0-1.2 m, n=17) was found to be similar to that observed after non-legumes (0-0.6 m equivalent to 71±9% of soil mineral N 0-1.2 m, n=9; data not shown).

Calculations

Total plant N - Since N associated with, or derived from, nodules and roots can represent a significant source of N for subsequent mineralisation and can play a major role in determining the N-balances of cropping systems (Peoples *et al.* 2009), below-ground N was estimated for each experimental treatment. For example, it was assumed that 25% of the whole plant N was below-ground for lupin and therefore a root-factor of 1.33 was used to convert shoot N to total plant N as described by Unkovich *et al.* (2010). Root factors used for the other crops were 1.47 for both field pea and vetch, 1.52 for faba bean, 1.56 for lentil, and 1.82 for chickpea. Below-ground N was also estimated for non-legume treatments using root-factors of 1.43 for canola and 1.52 for wheat, respectively.

The N accumulated in shoot and roots of grain crops at the end of the growing season was calculated as:

$$\text{Total crop-N} = [(\text{vegetative DM}) \times \%\text{N}/100]+[(\text{grain DM}) \times \%\text{N}/100] \times \text{root-factor} \qquad \text{Equation [2]}$$

Residue N - The total amounts of N remaining in crop vegetative residues and roots following grain harvest at the end of the growing season was calculated as:

$$\text{Total residue N} = (\text{total crop N}) - (\text{grain N removed}) \qquad \text{Equation [3]}$$

Soil mineral N benefits of legumes - The net effect of growing legumes on available soil N (i.e. the integrated effect of all the factors described in Equation [1]) were determined from the differences in soil mineral N data after legumes and non-legume controls measured just prior to sowing wheat across all treatments in autumn the following year. The observed soil mineral N benefits derived from legumes were expressed in four different ways (Equations [4] to [7]) as the basis of developing simple predictive relationships that potentially could be used by grain-growers to assist decision-making about fertiliser N applications following legumes in their cropping sequence:

(a) Mineral N benefit per mm fallow rainfall (kg N/ha per mm)

$$= [(\text{mineral } N_{\text{after legume}}) - (\text{mineral } N_{\text{after non-legume}})]/(\text{fallow rain}) \qquad \text{Equation [4]}$$

Where fallow rainfall (mm) represented the cumulative total between legume grain or BM harvest and sowing of the following wheat crop. In most studies where legume grain crops were grown, the fallow period began in late November or early December and finished in May.

(b) Mineral N benefit per t shoot residue DM (kg N/t shoot residue DM)

$$= [(\text{mineral } N_{\text{after legume}}) - (\text{mineral } N_{\text{after non-legume}})]/(\text{legume shoot residue DM}) \qquad \text{Equation [5]}$$

Where shoot residue DM = (peak biomass DM) – (grain yield)

(c) Mineral N benefit per t legume grain yield (kg N/t legume grain yield)

$$= [(\text{mineral } N_{\text{after legume}}) - (\text{mineral } N_{\text{after non-legume}})] /(\text{legume grain yield}) \qquad \text{Equation [6]}$$

(d) Soil mineral N benefit expressed as % total residue N

$$= 100\times [(\text{mineral } N_{\text{after legume}}) - (\text{mineral } N_{\text{after non-legume}})] /(\text{total legume residue N}) \qquad \text{Equation [7]}$$

Where total legume residue N was determined from Equation [3]

Apparent recovery of legume and fertiliser N - The apparent recoveries of legume or fertiliser N by the first wheat crop grown after the legume and non-legume (wheat, barley or canola) treatments were calculated as:

Apparent recovery of legume N (% total residue N)

$$= 100\times [(\text{wheat } N_{\text{after legume}}) - (\text{wheat } N_{\text{after non-legume}})] /(\text{total legume residue N}) \qquad \text{Equation [8]}$$

Where wheat N represented an estimate of total N in the shoots + roots calculated as described in Equation [2].

Apparent recovery of fertiliser N (% additional N applied)

$$= 100\times [(\text{wheat N uptake } N_{R2}) - (\text{wheat N uptake } N_{R1})] /(N_{R2} - N_{R1}) \qquad \text{Equation [9]}$$

Where wheat N represented an estimate of the total N present in shoots + roots, and N_{R1} or N_{R2} represent two different rates of fertiliser N applied to wheat grown after a non-legume. In the case of the Junee Reefs experiment N_{R1} = 49 kg N/ha, and N_{R2} = 100 kg N/ha, so the recovery of N referred to just the additional top-dressed 51 kg fertiliser-N/ha. At Wagga Wagga N_{R1} = 0 kg N/ha and N_{R2} = 75 kg N/ha.

Statistical analyses - Throughout the paper mean values are presented along with ± standard deviations to provide measures of variability. Analysis of variance was undertaken of the soil mineral N, crop DM and N data for each experimental site/year to provide least significant difference (LSD) determinations ($P<0.05$). Regression analysis was used to evaluate the potential value of different prospective relationships to predict soil mineral N benefits, and to explore the relationship between legume grain yield and total legume residue N.

Results

Legume growth and N accumulation

Data for shoot residue and grain DM, N accumulation, and calculations of net inputs of total residue N collated from all 16 experiments conducted in different locations, years, soil types and environments across the eastern Australian dryland cropping zone are presented in Table 2. Field pea was the most frequently used legume treatment (included in eight experiments), while vetch grown for grain was used the least (only once).

Large differences in growing season rainfall (GSR, 92–447 mm; Table 1) for the different experiments resulted in the accumulation of a wide range of legume shoot residue DM (1.4–9.8 t/ha), and grain yields (0.5–3.9 t/ha; Table 2). The harvest index (i.e. grain yield as a proportion of total above-ground DM calculated from Table 2) for the different legume crops grown for grain ranged from 0.17–0.20 (field pea and chickpea at Loxton in 2015 which experienced a heat wave during grain-filling) to 0.56–0.58 (lentil at Junee Reefs 2011 and faba bean at Breeza in 1997), and were 0.26–0.40 for the remaining 20 of the 24 crops (mean 0.34±0.09 across all 28 crops), values within the range commonly observed for Australian legume crops.

The N contents of the legume shoot residues remaining after grain harvest was higher, and C:N ratios were typically lower (0.9–1.4% N, C:N ratios 33–56), than either canola (0.7–0.8% N, C:N ratio 50–60), or wheat and barley stubble (0.3–0.6% N, C:N ratio 75–160). The estimates of net inputs of legume N associated with the vegetative residues and nodulated roots at the end of the growing season ranged 52–330 kg N/ha (Table 2). Comparisons of the contributions by individual grain crops in different experiments suggested that the largest net inputs of total residue N were often achieved by faba bean and lupin (Table 2).

Trends in available soil N

Soil mineral N concentrations measured after the non-legume controls in autumn varied widely from 36–141 kg N/ha, which presumably reflected key differences in inherent background fertility at the various study sites and rainfall during the preceding fallow period, but were on average 68±25 kg N/ha after wheat (n=13), 59 kg N/ha after barley (n=1) and 90±30 kg N/ha canola (n=5; Table 3).

Soil mineral N was significantly greater ($P<0.05$) after legumes than the non-legume controls for 26 of the 28 legume crops (non-significant data occurred following field pea and lentil at Loxton in 2015; Table 3). The difference in autumn soil mineral N after legume crops and non-legume treatments ranged from 11–89 kg N/ha (mean 35±20 kg N/ha, n=26; Table 4).

Soil mineral N benefits

The soil mineral N benefits calculated for the 31 legume treatments where autumn measures of soil mineral N were significantly different from non-legume controls, were equivalent to 0.03–0.36 kg N/ha per mm fallow rainfall (mean 0.15±0.08), 3–20 kg N/t above-ground residue DM (mean 9±4), representing 13–48% of the N remaining in vegetative and below-ground legume residue at the end of the previous growing season (mean 27±10%; Table 4). Despite large differences in crop performance, inputs of residue N, GSR and fallow rainfall across the 16 experiments (Tables 1 and 2), the average relationships derived for soil mineral N benefits calculated on the basis of either fallow rainfall, residue DM or N were remarkedly similar between legume species (Table 4).

In recognition of a previous observation that the size of the effects of lupin on subsequent wheat in Western Australia was related to the grain yield by the lupin crop (Seymour *et al.* 2012), our data were further examined to ascertain whether there might also be a useful relationship between legume grain yield and subsequent soil mineral N benefit. Values ranged from 7–46 kg additional soil mineral N/t legume grain harvested, with estimates for 17 of the 26 grain crops of between 11 and 26 kg N/t grain. The mean relationship between soil mineral N benefit and grain yield across all 28 grain crops was 18±9 kg mineral N/t legume grain (Table 4).

In the absence of an independent data set to test the relative value of the mean relationships between soil mineral N benefits and either fallow rainfall, residue biomass, residue N, or grain yield calculated above as prospective predictive tools, the different approaches were evaluated by using each mean relationship to estimate soil mineral N from the original experimental biophysical data. Those predictions were then compared to the actual mineral N benefits measured across the 16 experiments. The proportion of the variance explained by the various simple relationships were determined from r^2 assessments obtained from regression analyses of predicted soil mineral N benefits *vs* actual data. On the basis of such analyses it was suggested that:

- 0.15 × mm fallow rainfall explained 24% of the variance,
- 9 × t shoot residue explained 35% of the variance,
- 18 × t grain explained 27% of the variance, and
- 28% × total legume residue N explained 57% of the variance.

Other relationships based on fallow rainfall combined with either grain yield, shoot DM or residue N were also examined, but in all instances comparisons of predicted vs actual indicated that the ability to calculate subsequent soil mineral N was not improved. Indeed regression analysis of all approaches that combined more than one parameter suggested that less than 10% of the variance was explained by the process.

It was concluded that as a decision-making tool the individual relationships could only provide a rough approximation of the expected additional soil mineral N after a legume. Of the four different expressions, predictions based on legume residue N were likely to be the most reliable because it explained the largest fraction (i.e. 57%) of the observed variation. Unfortunately, residue N is a particularly difficult parameter for farmers to measure directly. Since grain yield is usually related to above-ground residue biomass, the data were examined to ascertain whether grain yield might also provide a guide to the amount of total residue N remaining at the end of the legume growing season. Analyses of the experimental data were confounded by the clustering of yield below 1.5 t/ha and above 2.5 t/ha (solid circles; Fig. 1), and an apparent outlier (faba bean at Culcairn 2010, solid triangle; Fig. 1), so data for a further 20 legume crops obtained from previously published and unpublished sources for another 16 experimental studies conducted in Victoria and NSW between 1995 and 2014 (open circles; Fig. 1) were included to improve the prospects of devising a relationship between grain yield and residue N. These additional data exhibited a degree of variation in residue N across similar yield values, presumably reflecting differences in seasonal conditions and harvest index. This was despite restricting the selection of data to legume crops with a similar range in harvest index to that measured for the majority of treatments in the original 16 experiments (i.e. between 0.26 and 0.40). Regression analysis of the combined data in Figure 1 indicated that total residue N = [54 + (30 × legume grain yield)] (r^2 = 0.56). Therefore, another more slightly complex rule-of-thumb for estimating the additional soil mineral N derived from crop legumes would be: 0.28 × [54 + (30 × t legume grain harvested)].

Apparent recovery of legume N by the following wheat crop

Pre-sowing soil mineral N following all legume and non-legume treatments, and subsequent measures of wheat total N uptake from eight of the 16 experiments are presented in Figure 2 and Table 5. Wheat N at harvest failed to exceed soil mineral N at sowing (i.e. fell below the 1 : 1 line depicted in Fig. 2) at only two locations, North Star 1993 and Breeza 1998. The lower than expected wheat uptake at Breeza could have been associated with potential denitrification losses of N from the soil as a result of waterlogging due to the record high rainfall experienced during the growing season (866 mm compared to 334 mm long-term average, Tables 1 and 5). Examination of the data across all trials and treatments except Junee Reefs (where applications of fertiliser N would have confounded the calculations), indicated that on average wheat accumulated 1.34±0.67 kg N/ha for every 1 kg/ha of soil mineral N present at sowing. Given that the ratio of wheat N uptake : pre-sowing soil mineral N exceeded 2.5 : 1 at one location (Gundibindjal 2001), and fell between 1.1–1.7 : 1 across all other experiments and treatments, it was concluded that soil N mineralisation during crop growth play an important role in contributing N for wheat uptake at most locations in most years (Fig. 2).

All legume treatments significantly increased ($P<0.05$) above-ground wheat biomass (by 0.6–4.5 t/ha mean 2.4±1.2 t/ha) and total N uptake (by 8–86 kg N/ha, mean 38±23 kg N/ha), but grain yield was significantly greater ($P<0.05$) than measured in the neighbouring wheat crops grown after wheat, barley, or canola following 12 of the 16 legume pre-cropping treatments (Table 5). The increased N uptake represented apparent recoveries of legume N by wheat equivalent to 12–48% of the residue N estimated to be remaining at the end of the previous growing season (mean 30±10%; Table 5).

Comparisons of recoveries of legume N with fertiliser N

The effect of legumes on wheat N uptake could only be directly compared to fertiliser N in two experiments. In these, applications of fertiliser N increased total N uptake by wheat grown after canola or wheat by 25 and 31 kg N/ha, respectively at Junee Reefs, or by 61 kg N/ha, at the Wagga Wagga site (Table 6). The apparent recoveries of the fertiliser N were calculated to be equivalent to 49–81% of the fertiliser N supplied (mean 64±16%; Table 6). While these determinations of apparent recoveries of fertiliser N by wheat were somewhat higher than the recovery of legume N in the same experiments (mean recovery of 30±5% of residue N from nine legume treatments), the additional quantity of N accumulated by wheat in response to fertiliser N was lower than observed after all legume treatments (38–84 kg N/ha) at Junee Reefs.

Discussion

Effect of legumes on soil mineral N

In keeping with the findings of other previous studies undertaken in Australia and elsewhere in the world, concentrations of soil mineral N were significantly greater following legumes compared to after non-legumes. In absolute terms the magnitude of the effect of legumes varied across locations and years (Tables 3–5) reflecting the influence of rainfall within the growing season on biomass production, and rainfall during the subsequent fallow. Improvements in soil N availability tended to be lowest after lentil and vetch, and highest after faba bean (Table 4), which was consistent with faba bean's reputation as a species with a capacity for the accumulation of high biomass and the symbiotic fixation of large amounts of atmospheric N_2 (Peoples *et al.* 2009).

Reasons for the unusually high soil mineral N following the chickpea crop at Junee Reefs, compared to the lupin or lentil (see Tables 3 and 5), remains unresolved. Some of the additional soil mineral N could have arisen from chickpea's tendency to be less efficient at recovering soil mineral N during growth than wheat (Herridge *et al.* 1995). Unfortunately, soil mineral N was not determined following chickpea grain harvest so the presence of unutilised 'spared' mineral N cannot be confirmed in the Junee Reefs experiment. Chickpea is also known to partition a larger proportion of the plant N below-ground in nodules than most other legume species. Nodules tend to have high N contents (4–7% N) and low C:N ratios which is conducive to rapid decomposition rates, so it is possible that the observed effect of chickpea on soil N dynamics could have reflected a higher nodule load combined with high rainfall during the summer-autumn fallow period to stimulate microbial activity and mineralisation processes (Tables 1 and 2).

Soil mineral N benefits derived from legumes

Pre-season deep soil testing for soil mineral N (0-60cm) is considered to be the most accurate data that grain-growers and their advisors can utilise for decision-making about fertiliser N applications before or at sowing. Similarly deep soil sampling in-crop could be used to better inform further top-dressing decisions in light of weather forecasts for the remainder of growing season and grain prices. Unfortunately, few Australian farmers routinely monitor soil N availability in all their fields prior to cropping, and the logistics and cost of in-crop soil sampling and analysis for soil mineral generally precludes adoption of this practice by most growers.

In the absence of pre-season soil testing, the most valuable information that could be provided to farmers would be some means of predicting the soil mineral N prior to sowing wheat which could be used as a basis for decisions about rates of N fertiliser to apply to meet target yields and grain quality. The large location and year variability in the soil mineral N data observed following the non-legume control treatments in all 16 experiments (Table 3) exemplifies the underlying influence that different soil types, soil organic N contents, and preceding rainfall can have on the end result, and emphasises the challenge in devising such a tool. However, it was hoped that through the interrogation of data collated from 25 years of cropping systems studies that it might be possible to identify some simple relationships that could be utilised to benchmark the likely incremental improvement in soil mineral N as a result of growing a N_2-fixing legume rather than a non-legume.

Two key parameters used in the calculations of soil mineral N benefits of legumes (Table 4) that all farmers routinely monitor or measure are rainfall and grain yield. Therefore, of the four potential measures of mineral N benefits examined here, relationships described as 0.15 kg N per mm fallow rainfall, and 18 $\times$ t legume grain yield, are the ones that could most easily be applied by farmers. Given the relationship between grain yield and shoot DM reported here (i.e. average harvest index = 0.34±0.09), growers might also be able to estimate shoot residue biomass by assuming grain yield generally represents around one-third of above-ground biomass (i.e. shoot residue DM = 2 $\times$ t legume grain yield). By combining this knowledge with the estimate of 9 kg additional mineral N/t shoot residue DM the added contribution of crop legumes to soil mineral N could also be calculated to approximate: 18 $\times$ t legume grain harvested. However, the most reliable estimate of soil mineral N benefit is likely to be calculated on the basis of net inputs of total residue N after legume cropping (28% residue N; Table 4). By utilising the relationship between grain yield and legume residue N presented in Figure 1, soil mineral N benefit calculated on a % N residue basis could also be re-expressed in a form that farmers can extrapolate from grain yield as: 0.28 $\times$ [54 + (30 $\times$ t legume grain harvested)].

Apparent recoveries of legume and fertiliser N by wheat

While the observed range of estimates of the apparent recovery of legume N by wheat was large (12–48%), 16 of the 20 determinations fell between 19-39%, and the mean represented 30±10% across all legume treatments (Table 5). This provides new insights into the value of including legumes in a cropping sequence in the rainfed grains belt of eastern Australia. Applying a similar approach to the one described above to estimate total residue N from grain yield, farmers could also calculate the likely recovery of legume N by a following wheat crop as representing: 0.30 $\times$ [54 + (30 $\times$ t legume grain harvested)]. The data strongly suggested that for most crops wheat's enhanced N uptake reflected improvements in N availability both prior to sowing wheat and during crop growth. A reduced incidence of cereal root disease following a legume break crop was also likely to have assisted wheat's ability to more fully exploit the soil mineral N pool.

The mean apparent total recovery of fertiliser N by wheat calculated from two experiments conducted in southern NSW (64%; Table 6) was comparable to the mean value previously reported for wheat in Australia (38% on a shoot basis, which is equivalent to 58% when re-calculated as total shoot + root N, n=42; Krupnik *et al.* 2004). That the apparent recoveries of fertiliser N were higher than calculated for legume residue N in the same studies (30%, Table 5) was not surprising given that either two-thirds (Wagga Wagga), or >90% of the fertiliser N applied (Junee Reefs) was supplied at the stem elongation phase of crop development immediately prior to a period of high plant demand for N, and that only a fraction of the organic legume N would have become available for crop uptake (Peoples *et al.* 2009). However, it should be noted that the soil mineral N generated after legume cropping should be just as effective a source of N to support wheat growth as N released from fertiliser, and that legumes contribute a large pool of organic N that becomes available for the benefit of more than one subsequent crop and sustains to the long-term fertility of the soil.

Conclusions

In the absence of any direct measures of soil mineral N, the four predictive relationships reported here could be used by grain-growers and their advisors in the dryland cropping areas of eastern Australia to estimate the additional pre-sowing soil mineral N following legume grain crops as they can be calculated directly or indirectly from readily-available information such as rainfall and legume grain yield. Growers could also potentially apply the relationship developed in the current paper to estimate N remaining in legume residues from grain yield to benchmark the subsequent recovery of legume N by a wheat crop. Recognising that none of the relationships will provide perfect predictions, and acknowledging that there are potential consequences in over- or under-estimating available N and wheat N uptake, it is recommended that all five expressions be used as a means of providing some measure of uncertainty. The risks of either under-fertilising in a wet growing season and not realising yield potential, or over-supplying fertiliser N to wheat when there is a prolonged period of drought during spring which can lead to yield reductions due to haying-off, would also be lowered, and the efficiency of fertiliser N uptake improved, if decisions on applications of N fertiliser can be delayed until later in the growing season when there is more confidence about anticipated rainfall.

More experimentation following the accumulation of soil mineral N and crop recovery of N after legumes still needs to be undertaken across different soil types, farming practices and years to evaluate and validate the preliminary simple predictive relationships proposed here and to further refine them. Studies should also be initiated to explore whether similar approaches to those described in the current paper might usefully deployed in dryland grain production systems beyond eastern Australia.

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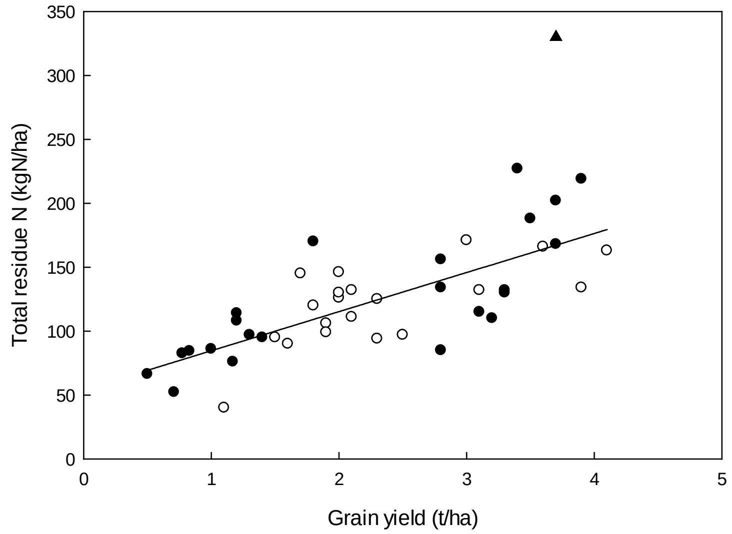

Figure 1. Relationship between grain yield of various legume crops and total (above- + below-ground) legume residue N remaining at the end of the growing season using data from the 16 cropping systems experiments presented in Table 2 (●), together with additional published and unpublished data for 20 legume crops from 16 other studies conducted in Victoria and NSW between 1995 and 2014 (○). The line of best fit calculated without the apparent outlier (faba bean at Culcairn; ▲) was described by: Total residue N = [54 + (30 $\times$ legume grain yield)] (r^2 = 0.56)

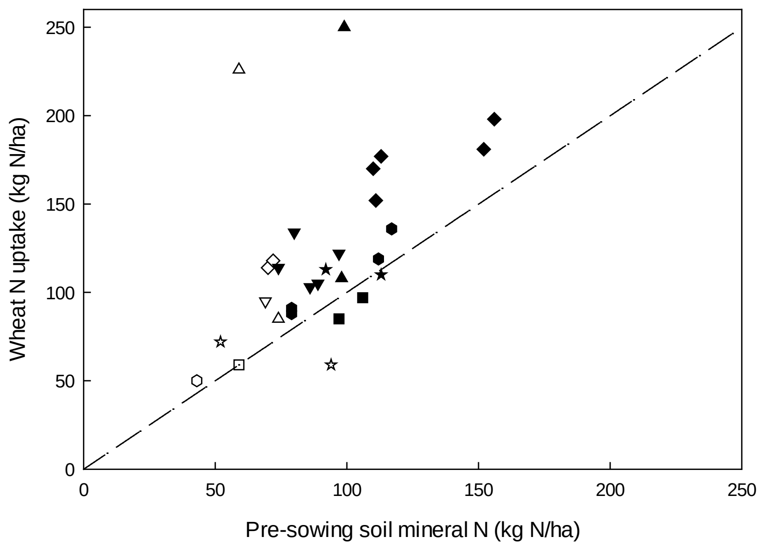

Figure 2. Relationship between pre-sowing soil mineral N and wheat total N uptake across eight different experiments conducted at two locations in northern NSW (North Star 1990 and 1993, ★; Breeza 1998,■), three in southern NSW (Gundibindjal 2001 and 2002,▲; Junee Reefs 2011, ◆; Wagga Wagga 2011, ⬢) and one site in SA (Loxton 2016,▼). The symbols represent data for non-legumes (open) and legumes (closed) grown prior to sowing wheat.
The dashed line indicates the 1 : 1 line.

Table 1. Experimental site locations and soil details, year of study, growing season rainfall (GSR) and post-crop summer-autumn fallow rainfall for the first year of various cropping sequences across eastern Australia where either non-legume crops, or legumes were grown.

Site location	Latitude, longitude	Soil type and pH (0-0.1 m)[a]	Year	Rainfall (mm)			
				GSR		Post-crop fallow	
				Year of study	Long-term average	Year of study	Long-term average
North Star, NSW	29° 01'S, 150° 20'E	Black Vertosol 7.5	1989 1992	170 158	271	628 316	350
Breeza, NSW	31° 11'S, 150° 25'E	Grey Vertosol 7.6	1997	267	306	272	334
Gundibindjal, NSW	34° 29'S, 147° 47'E	Kandosol 5.8	2000 2001	448 222	375	181 140	235
Tamworth, NSW	31° 15'S, 150° 98'E	Black Vertosol 8.0	2009	208	296	508	348
Hopetoun, Vic	35° 46'S, 142° 29'E	Hypocalcic Chromosol 7.9	2009	196	176	224	122
Culcairn, NSW	35° 39'S, 147° 05'E	Sodosol 4.8	2010	253	379	588	212
Junee Reefs, NSW	34° 71'S, 147° 55'E	Red Chromosol 5.5	2011	216	311	386	214
Wagga Wagga, NSW	35° 13'S, 147° 31'E	Red Kandosol 5.4	2011	318	331	390	195
Naracoorte, SA	36° 84'S, 140° 68'E	Brown Chromosol 6.1	2011	447	353	123	139
Minnipa, SA	32° 84'S, 135° 15'E	Endohypersodic Calcarosol 8.8	2011 2012	252 185	204	96 96	84
Mildura, Vic	34° 18'S, 142° 20'E	Calcareous Tenosol 7.9	2012	92	175	94	116
Loxton, SA	34° 45'S, 140° 57'E	Sodic Calcarosol 7.8	2015	137	178	102	96

[a] Soil type as described by Isbell (2016). Soil pH below 6.0 were determined 1:5 in $CaCl_2$ and above 6.0 were determined 1:5 in water.

Table 2. Mean shoot and grain dry matter (DM) production, N accumulation, and estimates of the amounts of residue N remaining at the end of the growing season for legume crops grown in different years and locations in NSW, Vic and SA.

Location	Year	Legume grown	Shoot residue DM (t/ha)	Grain yield (t/ha)	Total plant N[a] (kg N/ha)	Grain N (kg N/ha)	Total residue N[b] (kgN/ha)
North Star, NSW	1989	Chickpea	3.6	2.8	200	105	85
	1992	Chickpea	3.5	1.2	153	45	108
Breeza, NSW	1997	Chickpea	3.3	1.2	157	43	114
		Faba bean	2.4	3.3	255	123	132
Gundibinjal, NSW	2000	Lupin	4.6	3.1	289	174	115
	2001	Lupin	3.3	1.4	165	70	95
Tamworth, NSW	2009	Chickpea	1.9	1.0	127	41	86
		Field pea	2.6	1.3	156	59	97
		Faba bean	9.2	3.9	398	179	219
Hopetoun, Vic	2009	Field pea	6.3	3.4	363	136	227
Culcairn, NSW	2010	Lupin	5.5	3.7	381	179	202
		Faba bean	7.9	3.7	492	162	330
Junee Reefs, NSW	2011	Lupin	6.4	3.5	398	210	188
		Chickpea	4.6	1.8	247	77	170
		Lentil	2.5	3.2	248	138	110
Wagga Wagga, NSW	2011	Field pea	6.3	3.7	299	131	168
		Lupin	5.9	2.8	273	117	156
Naracoorte, SA	2011	Field pea	4.0	3.3	262	132	130
		Faba bean	5.0	2.8	257	123	134
Minnipa, SA	2011	Field pea	3.2	1.6	Nd	Nd	Nd
	2012	Field pea	1.4	0.7	Nd	Nd	Nd
Mildura, Vic	2012	Field pea	1.9	1.2	127	50	76
Loxton, SA	2015	Lupin	1.9	0.7	92	40	52
		Chickpea	2.0	0.5	85	19	66
		Field pea	3.0	0.6	104	25	79
		Faba bean	2.2	0.8	120	36	84
		Lentil	2.3	1.0	111	43	68
		Vetch	2.6	0.8	121	39	82

[a] Above-ground data adjusted to include an estimate of below-ground N using Equation [2].
[b] Calculated using Equation [3].
[c] Nd indicates no data available.

Table 3. The effect of previous non-legume and legume crops on soil mineral N measured in autumn the following year immediately prior to sowing wheat at different locations in NSW, Vic and SA.

Location	Sowing Year[a]	Soil mineral N (kg N/ha) detected following different crop species[a]									
		Wheat	Barley	Canola	Field pea	Lupin	Chickpea	Faba bean	Lentil	Vetch	LSD[c] (P<0.05)
North Star, NSW	1990	52					92				21
	1993	94					113				11
Breeza, NSW	1998		59				97	106			14
Gundibinjal, NSW	2001	59				99					
	2002	74				98					
Tamworth, NSW	2010			141	157		161	170			12
Hopetoun, Vic	2010	86		77	131						18
Culcairn, NSW	2011	75[d]				170					
		121[d]						210			
Junee Reefs, NSW	2012	70		72		110	152		111		11
Wagga, NSW	2012	55			79	79					22
Naracoorte, SA	2012	83		93	111			125			15
Minnipa, SA	2012	36			55						
	2013	39			64						
Mildura, Vic	2013	37			66						
Loxton, SA	2016			69	74	89	86	97	74	80	10
Number (n)		13	1	5	8	6	6	5	2	1	
Mean±SD		68±25	59	90±30	92±34	114±35	108±34	142±47	93±26	80	

[a] Year in which the crop was sown, which followed the fallow period after the legume or non-legume crops were harvested.
[b] Autumn measures of soil mineral N detected to a depth of either 0-0.6 m (Naracoorte, Minnipa, Mildura and Loxton), or 0-1.2 m (all other sites).
[c] LSD = Least significant difference.
[d] There are two sets of data for wheat at Culcairn as both the lupin and faba bean experimental plots, which were located in separate parts of the same field, included wheat controls.

Table 4. Comparisons of mean estimates of shoot residue dry matter (DM) and total residue N remaining after individual legume species, the subsequent additional soil mineral N in autumn the following year compared to non-legume controls, and determinations of the soil mineral N benefits derived from legumes.

Legume			Additional mineral N detected[a]	Soil mineral N benefits derived from legumes			
Species and number of studies	Shoot residue (t DM/ha)	Total residue N (kgN/ha)	(kg N/ha)	(kg N/ha · mm fallow rain)	(kg N/t shoot residue)	(kg N/t grain)	(% residue N)
Field pea (n=7)	3.7	140	23	0.16	8	14	22
Chickpea (n=6)	3.2	105	35	0.11	10	25	31
Lupin (n=6)	4.6	135	37	0.15	8	16	29
Faba bean (n=5)	5.3	180	47	0.20	11	19	28
Lentil/vetch (n=2)[b]	2.6	96	26	0.11	10	14	25
Mean all grain crops (n=26)[c]	4.0±2.2	134±64	35±20	0.15±0.09	9±5	18±9	28±11

[a] Additional soil mineral N detected to a depth of either 0-0.6 m (Naracoorte, Minnipa, Mildura and Loxton), or 0-1.2 m (all other sites) following legumes compared to wheat, barley or canola treatments calculated from data shown in Table 3.

[b] For convenience data from one lentil crop and a single vetch crop grown for grain were pooled for analysis.

[c] The data from field pea and lentil crops grown at Loxton in 2015 were not included as soil mineral N measured in 2016 following these two treatments were not significantly different from the non-legume control.

Table 5. Pre-sowing soil mineral N, total above-ground biomass, grain yield and total N uptake by wheat grown following legume crops, wheat, barley, or canola, and calculations of the apparent recovery by wheat of N from legume residues in different years and locations in NSW, Vic and SA.

Location, year & GSR	Preceding crop	Pre-sowing soil mineral N[a] (kg N/ha)	Wheat biomass (t DM/ha)	Wheat grain yield (t/ha)	Wheat total N uptake[a] (kg N/ha)	Apparent recovery of legume N[a] (%)
North Star, NSW 1990	Chickpea	92	9.6	2.8	113	48
(GSR = 208 mm)[b]	Wheat	52	5.8	1.5	72	
North Star, NSW 1993	Chickpea	113	8.1	3.8	110	47
(GSR = 294 mm)	Wheat	94	5.8	2.7	59	
Breeza, NSW 1998	Chickpea	97	5.4	2.3	85	23
(GSR = 866 mm)	Faba bean	106	5.8	2.0	97	29
	Barley	59	3.5	1.4	59	
Gundibindjal, NSW 2001	Lupin	99	12.7	5.1	250	21
(GSR = 222 mm)	Wheat	59	12.0	5.1	226	
Gundibindjal, NSW 2002	Lupin	98	4.8	1.5	108	24
(GSR = 169 mm)	Wheat	74	4.0	1.2	85	
Junee Reefs, NSW 2012	Lupin	110	10.8	3.9	170	30
(GSR = 168 mm)	Chickpea	152	12.2	4.0	181	39
	Lentil	111	11.2	4.0	152	35
	Wheat	70	9.4	3.4	114	
	Canola	72	10.2	3.4	118	
Wagga Wagga, NSW 2012	Field pea	79	9.4	3.6	88	23
(GSR = 188 mm)	Lupin	79	9.2	3.5	91	26
	Wheat	43	6.3	2.4	50	
Loxton, SA 2016	Lupin	89	7.8	3.0	105	19
(GSR = 322 mm)	Chickpea	86	7.9	3.0	103	12
	Field pea	74	8.5	3.3	114	24
	Faba bean	97	8.4	3.3	122	32
	Vetch	80	9.1	3.7	134	48
	Canola	69	7.2	2.7	95	
Mean±SD legumes (n=16)		98±19	8.8±2.3	3.3±0.9	126±43	30±11
Mean±SD non-legumes (n=9)		65±15	6.8±2.8	2.6±1.3	95±57	

[a] Soil mineral N data from Table 3. Estimates of total wheat N uptake were calculated using Equation [2], and apparent recovery of legume N using Equation [8].
[b] Data in brackets represent cumulative growing season rainfall (GSR) experienced by the wheat crop.

Table 6. Total above-ground biomass, grain yield, total N uptake and calculations of the apparent recoveries of fertiliser N by wheat grown in 2012 following either canola and/or wheat grown at Junee Reefs or Wagga Wagga, NSW in 2011.

Location and preceding crop grown in 2011	Rate of N fertiliser applied in 2012 (kg N/ha)	Wheat biomass (t DM/ha)	Wheat grain yield (t/ha)	Wheat total N uptake[a] (kg N/ha)	Apparent recovery of fertiliser N[b] (%)
Junee Reefs, NSW					
Wheat	N_{R1} = 49	9.4	3.4	114	
Wheat	N_{R2} = 100	9.9	3.8	145	61
Canola	N_{R1} = 49	10.2	3.4	118	
Canola	N_{R2} = 100	10.3	3.8	143	49
Wagga Wagga, NSW					
Wheat	N_{R1} = 0	6.3	2.4	50	
Wheat	N_{R2} = 75	10.2	3.7	111	81
Mean±SD N_{R1}		8.6±2.1	3.1±0.6	94±38	
Mean±SD N_{R2}		10.1±0.2	3.8±0.1	133±19	64±16

[a] Total wheat N uptake derived from above-ground N data assuming 34% of the total crop N was below-ground using Equation [2].

[b] Calculated using Equation [9]. Note there was no nil N fertiliser control at Junee Reefs so it was not possible to estimate N recovery for the 49 kgN/ha treatment.

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How much nitrogen is fixed by pulse crops and what factors affect fixation?

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Key words

nitrogen fixation, chickpea, fababean, soybean, mungbean

GRDC code

DAQ00181

Call to action/take home messages

- The amount of nitrogen (N) fixed by pulses varies widely (from 0 to 400 kg N/ha) and is impacted by crop species, soil nitrate at planting, effective nodulation and agronomic factors such as time of sowing, row spacing, plant population and variety.
- Narrower row spacing in pulses not only improves crop biomass and yield but also the proportion of N in that biomass that is fixed from the atmosphere and hence free for crop use. This allows crops to be produced on lower levels of soil nitrate and gives more opportunity for crop residues to be higher in N that can mineralise for the following crop.
- Time of sowing should be optimised for maximum biomass production and longer time to accumulate fixed N. The proportion of N in plants that is derived from the atmosphere (%Ndfa), i.e. fixed, is significantly greater when crops are sown earlier in the planting window rather than late, particularly in soybean and fababean crops. If growers are planting late, more N will be fixed if plant populations are significantly increased.
- Some minor varietal differences in N fixing potential do exist and growers can aim for higher biomass varieties to fix more N.

Background

Average amounts of nitrogen (N) fixed annually by crop and pasture legumes are around 110 kg N/ha (ranging from close to zero to more than 400 kg N/ha). The actual amount fixed depends on the species of legume grown, the site and the seasonal conditions as well as agronomic management of the crop or pasture. The legume crop uses this N for its own growth and may fix significantly more than needed, leaving a positive N balance in the soil for proceeding crops.

Average estimates of N fixation for the major crop legumes grown in Australia (derived from many research trial studies) are given in Drew et al (2012) (Table 1), however, huge variations around these figures exist in practice. Actual percent N fixed and amounts of N fixed by individual crops are influenced by environment and management effects, including soil nitrate levels at planting. Importantly, both root and shoot N must be considered when calculating the total amount of N that was fixed and used by the plant for growth. Root N is substantial for all crops but does vary with species, for example chickpea have equal portions of N in their roots as they do in their shoots wheareas faba bean and mungbean have approximately half as much N in their roots as their shoots (Unkovich et al. 2010). N remaining in residues of shoots and roots of the pulse crop after harvest is a slow release form of N for the subsequent crop. In this form, less is likely to be moved through the loss pathways that lead to loss of inorganic N fertiliser in the short term.

Table 1. Estimates of amounts of N fixed annually by crop legumes in Australia from Drew et al. (2012).

Legume	%N fixed	Shoot dry matter (t/ha)	Total crop N[1] (kg/ha)	Total N fixed[2] (kg/ha)
Lupin	75	5.0	176	130
Pea	66	4.8	162	105
Faba bean	65	4.3	172	110
Lentil	60	2.6	96	58
Soybean	48	10.8	373	180
Chickpea	41	5.0	170	70
Peanut	36	6.8	268	95
Mungbean	31	3.5	109	34
Navy bean	20	4.2	148	30

[1] Total crop N = shoot + root N
[2] Total N fixed = %N fixed x total crop N; Data sourced primarily from Unkovich et al. 2010

Results

Improving the amount of N fixed in a farming system by changing agronomic practices has been a focus in a recent northern region project. Our results show that altering management practices such as row spacing, time of sowing and variety used can have large implications for the amount of N fixed by that crop. This means better N nutrition for the pulse crop and also potentially for the crop following that pulse

Row spacing

Field trials with chickpea, mungbean, soybean and fababean have shown that significant increases in %Ndfa (percentage of nitrogen derived from the atmosphere) occurred when plants were grown on a narrower row spacing (i.e. 25 or 50 cm rows compared to 75 or 100 cm rows), keeping plant population the same. This then translated into higher amounts of N (kg/ha) fixed by the plants as biomass was also greater and ultimately more N was left behind post-harvest for the following crop. Figure 1 below demonstrates this higher amount of N fixed with narrower row spacing for two chickpea trials; one at Billa Billa near Goondiwindi and one near Dalby. After accounting for the N removed in the grain at harvest, an estimated 59 kg N/ha was added to the soil by the chickpeas at the Dalby site when grown on 0.25m rows, while only 23 kg N/ha was added at the 1.0 m row spacing. In the trial at Goondiwindi, N fixation and biomass were much lower overall. Just 6 kg N/ha was added through N fixation at 0.25 m row spacing however if grown at on 1.0m rows, the crop actually depleted soil N by 6 kg/ha

Reducing rows from 90 down to 30 cm in mungbean also significantly increased both %Ndfa and total amount of N fixed. Differences in varieties in their potential to fix N also was evident (Figure 2).

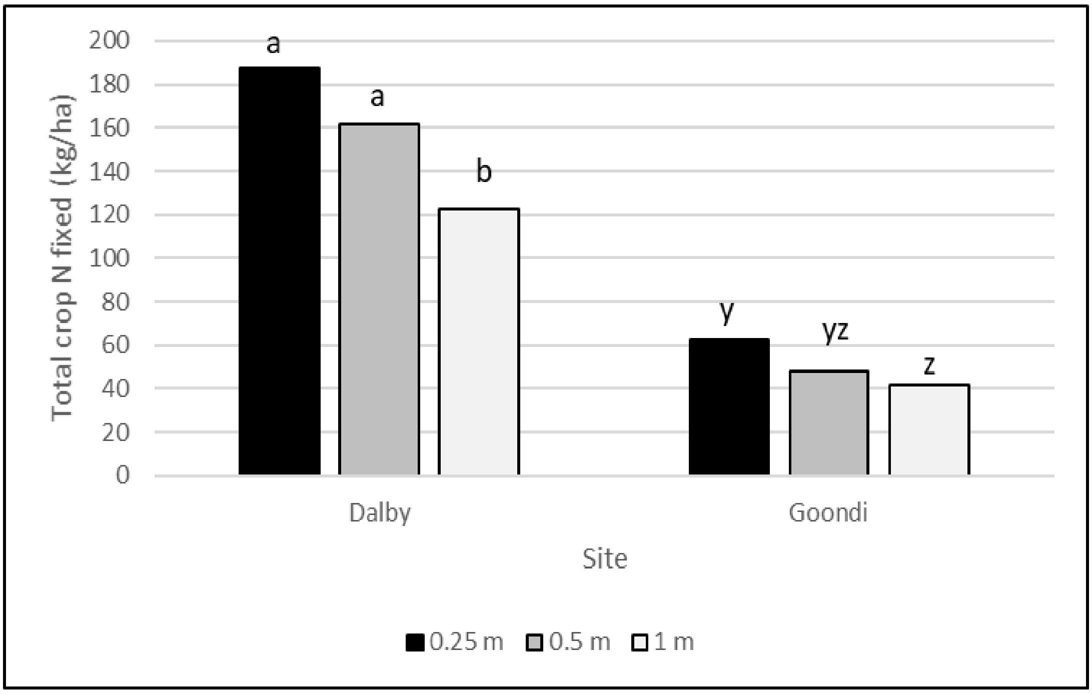

Figure 1. Total N fixed in chickpeas (shoots and roots) when grown at 3 different row spacings but keeping plant population the same at 30 plant/m^2.

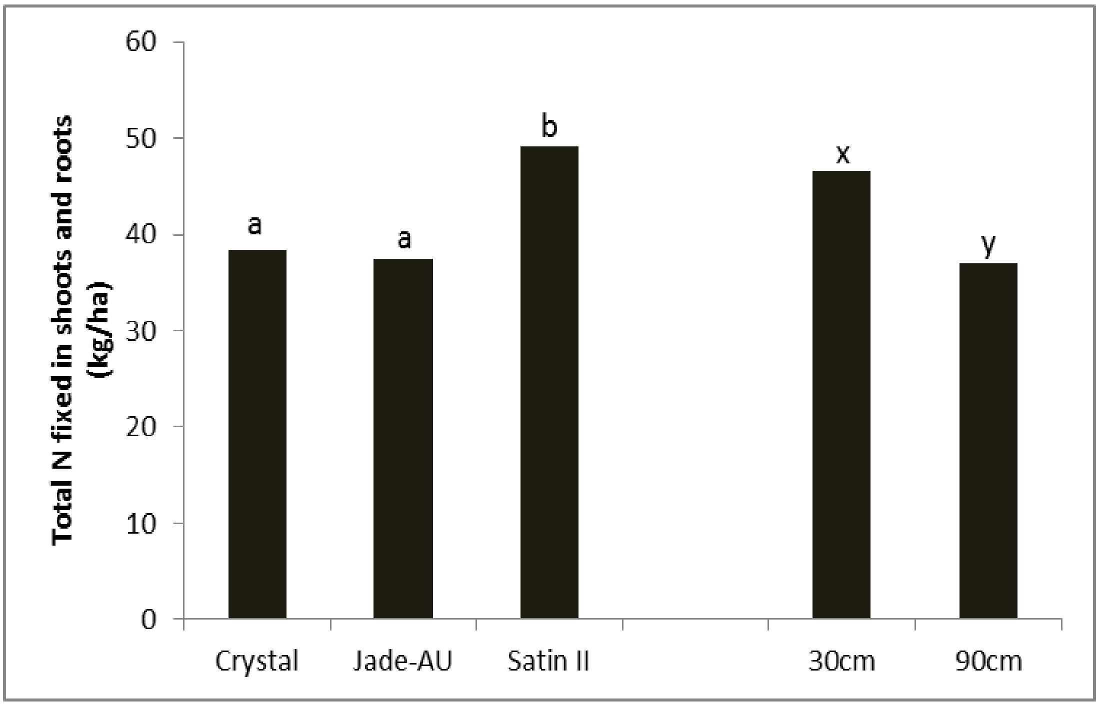

Figure 2. Differences in total shoot and root nitrogen for 3 mungbean varieties, Crystal⦶, Jade-AU ⦶ and Satin II⦶ (LSD 5% = 7.65) and for two row spacings of 30 and 90cm (LSD 5% = 6.24).

Time of sowing

Mungbean, soybean and faba bean have all shown significant impacts of time of sowing on N fixation. Not only is biomass of the crop reduced in a late planting for all three crops, so too is the proportion of the N in the plants that is fixed by the rhizobia (%Ndfa). Higher plant populations are therefore required to try to compensate for this loss in production and reduced amount of free N.

Faba bean varieties PBA Nasma⍉ and PBA Warda⍉ both showed that sowing late decreased %Ndfa by more than half and this combined with the reduced amount of biomass produced by the plants from this late May sowing date, meant much less N was fixed by the plants (Figure 3). Increasing plant population partially compensated but did not completely overcome this loss.

Soybean planted in late January rather than December also was negatively impacted, with much lower %Ndfa and N fixed. One variety from the Australian Soybean Breeding Program, 'Richmond'⍉ fixed half the amount of N (81 kg N/ha less) in shoots when planted later (15 January 2014 compared 20 December 2013). The variety PR443 fixed only a third as much N (163 kg/ha less) when sown at the later planting time.

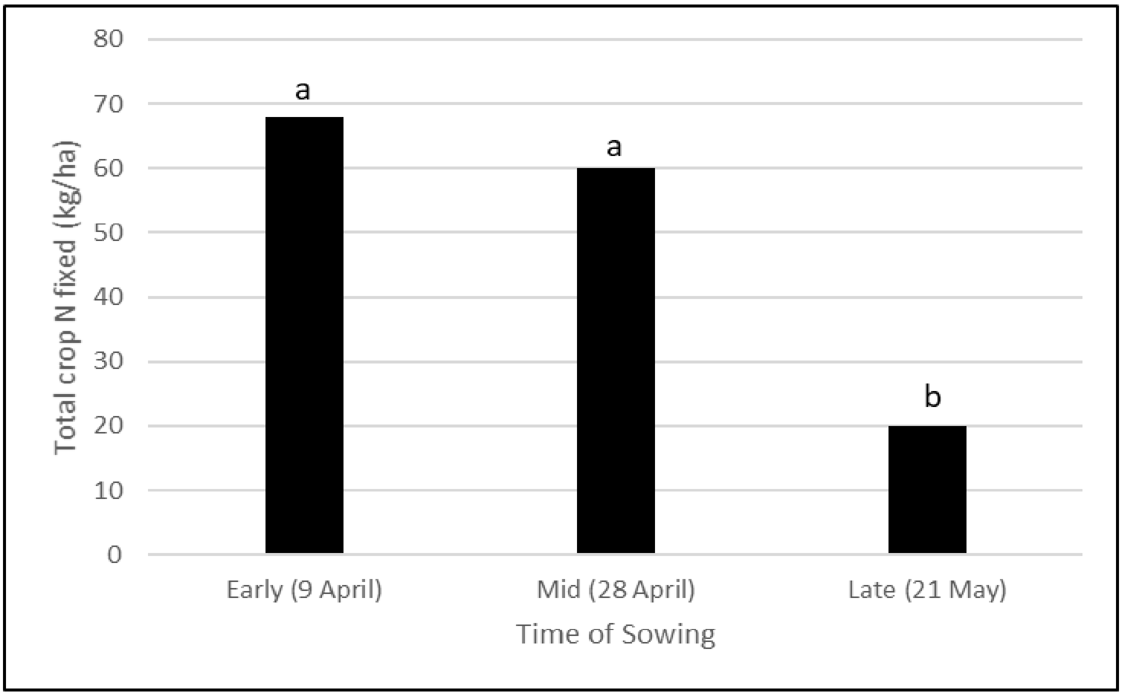

Figure 3. Total amount of N fixed by fababean (mean of two varieties PBA Nasma⍉ and PBA Warda⍉) was much lower when the crop was planted late. (N.B. Figures are for total N in shoots and roots assuming 40% of N in roots).

Inoculation

Trials focussing on the best form of inoculum for soybean and peanut in particular have shown little differences between peat, freeze-dried and granular inoculum forms. Growers should be able to use either form with confidence depending on available equipment. The use of liquid Zn fertilisers at recommended application rates and mixed with the chickpea inoculum strain CC1192 did not significantly impact the rhizobia or nodulation. Mixing of inoculum with concentrated forms of any fertiliser however is not recommended and extreme caution must be taken at all times to protect the live bacteria in the inoculum which are extremely sensitive to heavy metals and low or high pH levels. Further research with rhizobia strain compatibility for soybean, mungbean and fababean strains is required.

Establishment of good nodulation is vital for N fixation and hence good inoculation practices are crucial for survival of the rhizobia on the seed or in the soil at planting. Manufacturer guidelines as given on the packets should be followed and the correct rhizobia strain must be used.

Conclusions

Improving the amount of N fixed in a farming system by changing agronomic practices has been a focus in this project. Our results show that altering management practices such as row spacing, time of sowing and variety used can have large implications for the amount of N fixed by that crop. This can mean better N nutrition for the pulse but also for the crop following that pulse. Field trials have compared the impact of different row spacing, plant population, time of sowing and variety on effective nodulation and N fixation in pulse crops. This work has shown that narrower row spacing (for example 25 and 50cm rather than 75 or 100cm) in pulses can lead to higher levels of N fixed by the crop. This has correlated well with growth of the tops (biomass) and in some cases yield. Also, importantly, it has translated to greater amounts of N left in the soil.

Acknowledgements

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

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Phytophthora in chickpea varieties 2016 and 2017 trials –resistance and yield loss

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Key words

Phytophthora root rot, variety, risk management

GRDC codes

DAN00176, DAN00212, DAQ00186, DAS00137

Call to action/take home messages

- Two seasons of trials (2016 and 2017) under high Phytophthora root rot (PRR) pressure showed the importance of varieties with good PRR resistance.
- Under heavy PRR pressure in 2016, of the three MR rated varieties, YorkerⒹ (1.29 t/ha) performed significantly better than PBA HatTrickⒹ (0.40 t/ha), while PBA SeamerⒹ had yields intermediate (0.95 t/ha) between the two.
- The 2016 trial showed that the best PRR resistance occurred in two breeding lines that are crosses with a wild relative of chickpea.
- The 2017 trial which had extensive PRR losses (minimum loss 78%), was also affected by frosts and cool temperatures delaying podset. In addition, hotter than average conditions in September also led to early plant death. The 2017 results showed that a lines PRR yield loss can be confounded by the lines ability to set and retain pods under sub-optimal conditions.

Varietal resistance to Phytophthora root rot

Phytophthora medicaginis, the cause of Phytophthora root rot (PRR) of chickpea is endemic and widespread in southern QLD and northern NSW, where it carries over from season to season on infected chickpea volunteers, lucerne, native medics and as resistant structures (oospores) in the soil. Although registered for use on chickpeas, metalaxyl seed treatment is expensive, does not provide season-long protection and is not recommended. There are no in-crop control measures for PRR and reducing losses from the disease are based on avoiding risky paddocks and choosing the right variety.

Detailed information on control of PRR in chickpea is available at:
http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot

Current commercial varieties differ in their resistance to *P. medicaginis*, with YorkerⒹ, PBA HatTrickⒹ and PBA SeamerⒹ having the best resistance and are rated MR (historically YorkerⒹ has been slightly better than PBA HatTrickⒹ), while Jimbour is MS - MR, FlipperⒹ and KyabraⒹ are MS and PBA BoundaryⒹ has the lowest resistance (S). PBA BoundaryⒹ should not be grown in paddocks with a history of PRR, lucerne, medics or other known hosts such as sulla.

From 2007 to 2017, PRR resistance trials at the DAF Q Hermitage Research Facility, Warwick QLD have evaluated a range of varieties and advanced PBA breeding lines. Each year the trial is inoculated with *P. medicaginis* at planting. There are two treatments, (i) seed treatment with thiram

+thiabendazole and metalaxyl plus regular soil drenches with metalaxyl* and (ii) seed treatment with thiram + thiabendazole only and no soil drenches. The first treatment has prevented infection by the PRR pathogen in all of these trials. The difference in yield between the metalaxyl-treated plots and non metalaxyl treated plots is used to calculate the yield loss caused by PRR.

**Soil drenching with metalaxyl is not a registered or legal practice for use in chickpeas and has been used purely as a research tool to provide a PRR protected treatment.*

The trials were irrigated during extended periods of low rainfall with dripper tape once or twice per season to provide adequate soil moisture for PRR disease development.

Varietal resistance in 2016 and 2017 trials

Yield losses were high across all entries in the 2016 trial, with only two entries (CICA1328 and D06344>F3BREE2AB027) sustaining less than 50% yield loss.

In the 2016 trial, there were significant effects (P < 0.001) for the PRR protected treatment, variety effects and the interaction between the PRR protected and variety treatments. For the interaction, yields amongst varieties that were PRR protected did not differ, but there were large differences among varieties not protected for PRR (Table 1). Especially for CICA1328 and D06344>F3BREE2AB027 which had higher yields than all other varieties, there were several different levels separating the yields of groups of varieties (group 1 CICA1328 & D344, group 2 CICA1007 & Yorkerⓑ, group3 CICA1521 & PBA Seamerⓑ, group 4 PBA HatTrickⓑ & PBA Boundaryⓑ) in this treatment. The 2016 trial again confirmed the superior PRR resistance of the PBA breeding line CICA1328 and D344 which are both crosses between a chickpea (*Cicer arietinum*) line and a wild *Cicer* species.

Table 1. Yields of chickpea varieties and breeding lines protected from Phytophthora root rot, and % yield losses from PRR in a 2016 trial at Warwick QLD. (P yield <0.001; lsd yield = 0.63 kg/ha)

Variety/line[A]	Yield (t/ha) in absence of *Phytophthora* infection	Yield (t/ha) in presence of *Phytophthora* infection	% yield loss due to *Phytophthora* infection
CICA1007-077	4.20	1.76	58.1
CICA1328[A]	4.11	2.94	28.5
CICA1521[A]	4.06	1.01	75.1
D06344>F3BREE2AB027[A]	4.00	2.37	40.8
PBA Boundaryⓑ	3.98	0.19	95.2
PBA HatTrickⓑ	4.02	0.40	90.0
PBA Seamerⓑ	4.08	0.95	76.7
Yorkerⓑ	4.06	1.29	68.3

[A] These lines are crosses between chickpea (*C. arietinum*) and a wild *Cicer* species

The extent of yield losses to PRR across entries in 2017 was unprecedented with the minimum yield loss of 83% for CICA1328. The 2017 season had an unusual combination of climatic conditions including heavy frosts affecting flowering and podset (see following section for more details). These conditions had a large effect on the performance of material in the 2017 trial, which may reflect the effect of these conditions on performance rather than direct effects of PRR on yields. Therefore we recommend caution in the interpretation of the 2017 PRR varietal resistance results.

For the 2017 trial, protecting for PRR significantly increased yields (P < 0.001) and there were also significant differences amongst varieties, although there was no significant interaction between the PRR protected and variety treatments (Table 2). For the variety effect (P yield < 0.05; lsd yield = 0.38 kg/ha) CICA 1328, 1624 and 1713 had higher yields than CICA 1521, and CICA 1328, 1424, 1624, 1718, 1713, PBA Seamer⊕ and Yorker⊕, those seven entries also had higher yields than PBA Boundary⊕.

Table 2. Yields of chickpea varieties and breeding lines protected from Phytophthora root rot, and % yield losses from PRR in a 2017 trial at Warwick QLD. (interaction, P yield = 0.57; lsd yield = 0.54 kg/ha)

Variety/line[A]	**Yield (t/ha) in absence of *Phytophthora* infection**	**Yield (t/ha) in presence of *Phytophthora* infection**	**% yield loss due to *Phytophthora* infection**
CICA1328[A]	3.29	0.57	82.7
CICA1424	3.37	0.13	96.1
CICA1521[A]	2.74	0.18	93.4
CICA1624	3.81	0.76	80.1
CICA1713[A]	3.59	0.26	92.8
CICA1718[A]	3.30	0.36	89.1
PBA Boundary⊕	2.63	0.46	82.5
PBA HatTrick⊕	3.31	0.72	78.2
PBA Seamer⊕	3.23	0.31	90.4
Yorker⊕	3.50	0.10	97.1

[A] These lines are crosses between chickpea (*C. arietinum*) and a wild *Cicer* species

Seasonal effects on yields and varietal resistance rankings

It is well known that Phytophthora requires periods of soil saturation for disease development. In addition, a range of seasonal factors also affect the performance and yield of chickpeas. Using the last four seasons, we sought to identify factors affecting PRR disease and yields, and especially factors that could explain the unprecedented PRR losses in the 2017 trial.

The yield of PRR protected PBA HatTrick⊕ was used to indicate the yield potential of a season, and the % yield loss from PRR for key entries used to compare the extent of PRR development in differing material across seasons (Table 3). Yield results for PBA HatTrick⊕ show that the 2016 season had the highest yield potential (yields for PBA Boundary⊕ support this) and the 2015 season the lowest yield potential. The most PRR susceptible material is PBA Boundary⊕ with high % losses every season; the most resistant material is CICA1328 with consistently the lowest losses each season. Results for these two entries clearly show that the 2014 season had the lowest PRR disease pressure.

The 2014-2017 results for PBA HatTrick⊕ and PBA Boundary⊕ show the 2016 season was the most PRR conducive of the four seasons, however for CICA1328, 2015 was more conducive than 2016, and that 2017 was more conducive than 2015.

Data from the BOM station at Hermitage was used to identify associations between differing PRR trial seasons (Table 4). For the 2014 season, PBA Boundary⊕, PBA HatTrick⊕ and CICA1328 had the lowest % yield losses, and rainfall across the four seasons was lowest in June and July 2016. These conditions may have limited the extent of early PRR infection. In contrast in 2016, PBA Boundary⒫ and PBA HatTrick⒫ had the largest % yield losses and 2016 rainfall was very high in June, August and September (> 300mm). These conditions may have supported both early infection events and later disease development in spring.

The 2017 season which saw very high % yield losses across all entries also had the lowest August and September rainfall of the four seasons, so the extent of spring rainfall does not explain the 2017 % yield losses and therefore suggests the role of other factors. For the 2017 season, mean minimum temperatures were below the 1994-2013 average temperatures for July, August and September (Table 4). The number of days in 2017 with minimum temperatures below 0°C and 2°C was higher than average in July, August and September (data not presented). September 2017 was also unusual as it had the highest average maximum temperature of the four seasons and was higher than the long term average.

Table 3. Results from the 2014, 2015, 2016 and 2017 seasons for yields of PBA HatTrick⒫ and PBA Boundary⒫, and PRR % yield losses for PBA HatTrick⒫, PBA Boundary⒫ and CICA1328.

Season	PBA HatTrick⒫ Yield (t/ha) in absence of PRR infection	PBA HatTrick⒫ % yield loss due to PRR infection	PBA Boundary⒫ Yield (t/ha) in absence of PRR infection	PBA Boundary⒫ % yield loss due to PRR infection	CICA1328 Yield (t/ha) in absence of PRR infection	CICA1328 % yield loss due to PRR infection
2014	2.94	33	2.79	74	2.76	2
2015	2.50	68	2.88	94	2.64	42
2016	4.02	90	3.98	95	4.01	29
2017	3.31	78	2.63	83	3.29	83

Table 4. Average minimum and maximum monthly air temperatures and monthly rainfall totals for four chickpeas seasons at Hermitage (BOM station 41525) including longer term (1994-2013) average data for these measurements.

Mean min.°C

Season	June	July	Aug	Sept	Oct	Nov
2014	5.1	0.4	6	6.6	10.9	16.2
2015	5.4	3	3.1	5.3	10.3	15.2
2016	7.4	5.4	4.6	9.1	8.6	12.1
2017	5.3	1.7	1.4	6.2	14.1	12.5
1994-2013.	4.8	3.3	3.2	7.1	10.5	13.6

Mean max°C

Season	June	July	Aug	Sept	Oct	Nov
2014	19.5	18.5	19.1	23	29	32.1
2015	18.1	17.3	20.3	22.3	27.9	30
2016	17.7	18.8	19.1	20.8	24.2	29.7
2017	19	19.6	21.8	26.6	25.6	26.5
1994-2013	18.3	17.9	20	23.6	25.8	27.5

Rain mm

Season	June	July	Aug	Sept	Oct	Nov
2014	13	6.8	46.3	23.2	14.4	33
2015	19.4	21.8	24.8	10.8	20.2	97.4
2016	109.8	18	108.6	90.6	67.8	56
2017	30.8	21.5	5.6	0.6	59.8	41.4
1994-2013	35.9	23.3	22.4	33.1	75.2	90.8

The 2017 season was unusual in that in many of the non PRR protected plots, plants were observed to die before setting pods. Unsuccessful and delayed flowering and podset was a key feature of the 2017 season, with temperature data showing that conditions unsuitable for successful flowering and podset occurred very late in the 2017 season. In addition, the combination of low minimum temperatures in September 2017 limiting podset and high maximum temperatures which increased the evaporative demand and so stress on PPR infected plants with compromised root systems, may explain the high yield losses due to PRR infection in 2017. If these conclusions are valid, then the yields of non PRR protected treatments may reflect both the ability of an entry to successfully set pods under sub-optimal conditions and the entry's PRR resistance. For example, this may explain why non PRR protected PBA HatTrick in the 2017 season had for the first time in four seasons a higher (although not significantly higher) yield that CICA1328.

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Early risers panel session

ExtensionAUS™: answers at your fingertips

Johanna Couchman[1], Tony Cox[2], Kellyanne Harris[1] and Fleur Muller[2]

[1]Agriculture Victoria
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Key words

extensionAUS™, crop nutrition, field crop disease, online extension

GRDC code

DAV00146, DAN00209

Call to action/take home messages

ExtensionAUS™ is a national online network that allows two-way dialogue and provision of information and advice on crop disease and nutrition issues - 24 hours a day, 7 days a week, 365 days a year - when and where you need it.

ExtensionAUS™ gathers experts in crop nutrition and diseases and offers:

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- Timely, relevant, peer-reviewed and up-to-date information; and
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When making on-farm decisions, time spent searching for information can mean the difference between acting in the right window for a bumper crop or pouring profits down the drain. Since its inception in 2014, collaboration and responsiveness have become synonymous with extensionAUS™. ExtensionAUS™ uses the latest technology such as online meetings and collaboration tools to connect industry experts across Australia to share knowledge easily and efficiently. This information is then delivered to growers and advisers via web content including articles, YouTube videos, webinars, eBooks, social media and more.

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ExtensionAUS™ brings together the experts into 'communities of practice' in crop nutrition and field crop diseases. A 'community of practice' is a wide range of experts from around Australia, who are willing to formally network together to share knowledge and information to support farmers, their advisers and grains researchers. ExtensionAUS™ communities have members from state government, private industry, universities, industry organisations, grower groups and agronomists.

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"Searched up further information on and found other links to an issue then discussed it with other agronomists"

"[I] used a warning on Septoria in wheat, assessing crops, was preparing to control, season dried up. Looking at altering fungicides used as a result of info read."

ExtensionAUS™ has also become a key tool for industry experts who engage in communities of practice, not only to exchange knowledge, but to provide information for their clients. Rob Norton, Regional director, International Plant Nutrition Institute (IPNI) and chair of the crop nutrition community of practice said:

"This – to me – is the first time that a coordinated multi-state and multi-stakeholder approach has been undertaken to provide regular updates to growers"

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2. Check out our top 5 from 2017 by visiting our website
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        i. When do retained stubbles increase the need for nitrogen?
        ii. Micronutrient deficiencies - real but unpredictable
        iii. How effective are high nitrogen rates for canola-wheat rotations?
        iv. Focus on nitrogen and biomass for better canola
        v. Save the best grain for seed - know your zinc levels
    b. Field crop diseases – www.extensionaus.com.au/field-crop-diseases/top-five-of-2017/
        i. The northern chickpea Ascochyta diaries
        ii. Monitor blackleg severity to ensure return on fungicide application
        iii. Spot the difference – identifying fungal diseases on canola

iv. Preliminary Predicta®B results show prevalence of ascochyta inoculum

v. Reduce resistance risk with good fungicide management

3. *Ask an Expert* – visit our website and navigate to the community of practice which you want to ask a question of. Your question will then be directed to the relevant expert.
4. Subscribe to our newsletters – visit our website to subscribe.
5. Join a community of practice – contact Tony Cox via the details below for more information.

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Notes for early risers panel session

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Cereal agronomy and frost concurrent session

Spring frost damage in northern GRDC region in 2017 – a long term risk management perspective

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Key words

frost, risk management, ENSO

GRDC code

CMA00002

Call to action/take home messages

- 2017 will be remembered as a year of severe frost damage across the northern region and we need to learn from this damaging but relatively rare sequence of events.
- While it is useful to focus on the unique aspects of frost risk, it is important to consider the interaction between frost, heat and water.
- Recent modelling studies suggest that the northern region suffers the greatest direct impact of frost, but also the greatest indirect impact from strategies to avoid frost .
- There is useful information from the GRDC National Frost Initiative on genetics, management and environment aspects of reducing frost risk. In this paper we focus on the weather and climate information available for frost risk management.

The GRDC national frost Initiative

Frost is estimated to cost the Australian grains industry over $300 M every year. The GRDC National Frost Initiative conducts RD&E to manage the impact of frost and maximise grower profit. The initiative has three components;

1. Genetics – develop more frost-tolerant wheat and barley germplasm and rank current wheat and barley varieties for frost susceptibility;
2. Management – develop best practise crop canopy, stubble, nutrition and agronomic management strategies to minimise the effects of frost, and search for innovative products that may minimise the impact of frost; and
3. Environment – predict the occurrence, severity and impact of frost events on crop yields and frost events at the farm scale to enable better risk management.

Most of the resources can be found here: https://storify.com/theGRDC/frost

Widespread damage in northern region in 2017 growing season

The 2017 season will be remembered for the widespread and frequent frost events across the northern GRDC region.

For a local perspective of the damage to canola, chickpeas and cereals in the northern region as of September 2017 see:

https://grdc.com.au/news-and-media/news-and-media-releases/north/2017/09/resources-available-to-help-growers-deal-with-frost-affected-crops.

The 2017 damage in the northern grains region followed severe damage in the western region and parts of the southern region in 2016 and 2017 and widespread stem frost in the southern region in 2014. Any regional overview of frost impact will underplay the damage experienced in individual paddocks and for individual grain businesses.

Unfortunately frost was not the only climate concern for grain growers in the northern region in 2017. Although Queensland and northern NSW had a wet October, most of the region experienced rainfall in the lowest decile for the six months April to September. The second half of September was extremely hot. On the 23rd of September, NSW recorded the hottest day since records were kept in 1911 (BoM 2017). Across the grain growing regions of northern NSW and southern Queensland the mean maximum temperature for the week ending 28th of September was 8 to 12^{o} C above average. Experienced agronomists will point to difficulties in separating the impact of frost from drought and heat on final wheat yield.

Cold temperatures do some damage each year

The severe frost damage experienced in 2017 is a low frequency but high consequence event. It is likely that there are more frequent, but less damaging losses in most years. According to GRDC & WA DIPIRD (2017) cold damage can occur when wheat plants are exposed to temperature less 5°C which can cause spikelet damage if this occurs during pollen development (Z39 -45). From 0°C to -2°C moisture is drawn from the leaves resulting in desiccation damage. The greatest damage is freezing damage which might be expected at 0°C; however 0°C is the melting point of ice not the freezing point of water. Freezing usually occurs at temperatures below -2°C and the damage is caused by ice crystals physically rupturing cell walls and membranes.

There is useful guidance on identifying frost damage at: https://storify.com/theGRDC/frost

Ten days after a frost event, bleached leaves, stems, heads and reproductive tissue might be evident (GRDC & WA DIPIRD 2017).

An indirect cost comes from strategies to avoid frost

In addition to the direct damage from frost, there is an indirect effect from conservative sowing time /flowering time strategies to avoid frost. This is captured in the statement in the 1970s by the pioneer of frost research at Tamworth, Dr Bill Single, that the fear of frost does more damage than frost itself. Local advisers and growers will have their own views on whether this is still the case but some recent modelling research indicates that this indirect cost is greatest in the northern region.

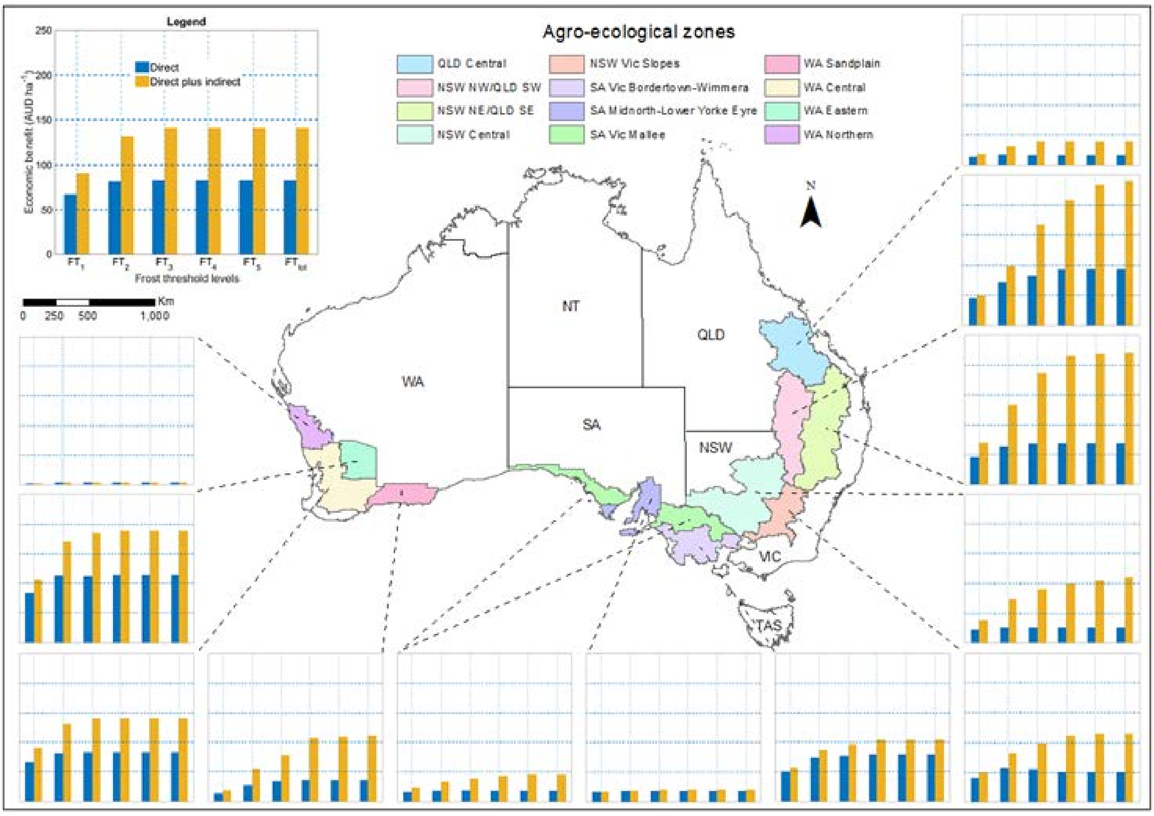


Figure 1. (reproduced from Mushtaq et al. 2017 – see paper for details). Economic benefits (AUD ha–1) of various levels of post head emergence frost (PHEF) tolerance both direct (first bar) and direct plus indirect (second bar)

Under the assumptions of the simulation modelling (described in detail in Mushtaq et al. 2017 and Zheng et al. 2015) the greatest benefit of frost tolerance (because of the greatest current damage) is found in the northern grains region and parts of the western region. The northern region also has the greatest indirect impact (shown as difference between each pair of bars). Not only is thinking about the trifecta of frost, heat and water stress important when diagnosing and attributing damage to frost in a year like 2017, this modelling shows that it is essential when managing frost. The importance of radiation, water, frost and heat in identifying the ideal flowering time is supported by extensive modelling for sites between Dubbo and Eyre Peninsula by Flohr et al. 2017. Similar results have been shown for canola (Lilley et al. 2017).

The need for a risk management approach

The interaction of frost with heat and water stress is a good reason for a risk management approach to frost. A further reason is the acknowledgement that frost is not an issue that can be simply solved or removed from grain farms. Rather it is a something that has to be lived with and managed. Frost risk differs for each grain grower; not only does each paddock have a unique physical exposure to frost, each grain business has its' own financial exposure and the people behind the business have different risk appetites. Under these circumstances, being prescriptive is dangerous.

Frost management decisions at different times

There are some common features of frost management across grain farms. For example, decisions are different depending on the time of the year. A pre-season planning might be held with an adviser in say January or February, this contrasts to decisions in the immediate lead up to sowing or responses to frost within a growing season. Although there are overlaps, separating the timing and types of decisions provides a useful framework and is consistent with the format of the GRDC Frost Tips and Tactics.

Not only do the decisions occur at different times of the year, there are differences in the type of decisions. Running a farm involves many day to day operational decisions but these are influenced by longer term strategic decisions which set the overall direction of the farm and a series of tactical decisions made each season. One way to distinguish between tactical and strategic decisions is that tactical decisions respond to the state of the system such as stored soil water, time of season break, and potentially a seasonal climate forecast. This framework is used in GRDC business management fact sheets (Making effective business decisions, June 2013; Simple and effective business planning, May 2014). Unlike larger corporations, in a grain farming business the same person is usually making the strategic and tactical decisions while carrying out many of the day to day operations.

The time lines or planning horizons of operational, tactical and strategic decisions can be matched to weather forecasts for operational decisions, seasonal climate forecasts for tactical decisions and strategic decisions using longer term climate records, including how these are shifting with climate change. In the following section we have matched weather and climate information to the timing and type of decision. This is based on discussion with farmers and advisers and the purpose is to sort weather and climate information by decisions and complement the information in the GRDC NFI Tips and Tactics fact sheet.

<table>
<tr><td colspan="2">1. Strategic pre-season planning
Planning enterprise mix across the farm such as crops vs livestock vs hay. Crop choice for different paddocks. Decisions about leasing extra land and/or purchasing and selling land.</td></tr>
<tr><td>Information currently available: Many experienced farmers are aware of the frostier parts of their farms, some have data loggers.

The spatial climate information can be supplemented with historical climate data that is analysed the BoM data such as CliMate and YieldProphet and Flowerpower in WA.</td><td>Emerging resources: The NFI is funding research on the fine scale mapping of frost across paddocks using loggers and remote sensing. This will optimise the use of this equipment.

Ongoing challenge: As the cost of loggers and imagery becomes cheaper and more available, the spatial coverage will greatly improve. However there is an ongoing challenge is to link 2 to 3 years of fine scale records with the 50 years of Stevenson screen data from the Bureau of Meteorology.

One of the impacts of climate change is that it makes historical records less reliable for future risk assessments. There are some concerning shifts in frost likelihood that make it difficult to know how to use past data.</td></tr>
<tr><td colspan="2">2. Tactical adjustments at sowing time
Decisions include area of dry sowing, refining choice of crop and variety and changing input levels. Choosing varieties. Input levels. Making plans for extra hay production.</td></tr>
<tr><td>Information currently available: Some farmers tend to use CliMate, FlowerPower or YieldProphet when there is a sowing opportunity outside of the normal sowing window

There has been a history of using SOI based forecasts for frost likelihood. In general when there is a forecast for an</td><td>Emerging resources: We can expect there will be ongoing improvements in the decision aids such as CliMate, Flowerpower and YieldProphet. They will be aided by improved phenology predictions.

Climate forecasts of the likelihood for frost at this time of the year currently only have marginal skill. However there is increasing attention to forecasting of extremes.

Ongoing challenge: Seasonal forecasting remains a relatively low signal to noise and many growers will require very large shifts in forecasts of extremes to change decisions.</td></tr>
</table>

increased chance of El Nino, expect more frost.	We are hampered by relatively rudimentary understanding of the exact relationship between minimum temperature and wheat yield.
3. Responding to frost forecast within the season Management options are greatly restricted once the crop is sown, however a frost warning for the coming week can be useful for herbicide decisions and as a prompt to check for damage. For some enterprises, a warning can be used to plan for hay and grazing options. A forecast for the coming months might influence nitrogen topdressing decisions and possibly forward selling. Some farmers might graze a crop to slow development.	
Information currently available The BoM issues short term frost warning http://www.bom.gov.au/jsp/watl/weather/frost.jsp In terms of seasonal outlook, the state of climate drivers such as ENSO become clearer as the season progresses.	*Emerging resources* The accuracy of 1-7 day forecasts is continuing to improve. The experimental multi-week forecasts from the Bureau of Meteorology will provide some information on the likelihood of lower than expected minimum temperatures. *Ongoing challenges* Although forecasts within season will be more accurate than pre-season, the question remains as to whether they will be good enough to change decisions. It is also challenging knowing how to link uncertain forecasts to uncertain damage functions.
4. Responding to a frost To cut for hay or graze or leave for recovery	
Information currently available The main task after a frost is to rapidly assess the damage. This can be aided by accessing temperature data from the Bureau of Meteorology and other networks of temperature loggers from departments of primary industry and NRM bodies.	*Emerging resources* NFI has guidance on where to place loggers and is researching innovative methods of rapid frost assessment. There is also excellent material on identifying frost damage. Simulation modelling like YieldProphet along with other spreadsheet based decision support system (DSS) can help with the decisions to cut for hay or graze *Ongoing challenges* If a frost occurs relatively early in the season, the decision to cut for hay, graze or leave for recovery is still made difficult by uncertainty in estimating the potential damage and the potential for recovery.
5. Post season evaluation Severe frost is a relatively low frequency but high consequence event. It is important to place the season in context and avoid the natural human response of either over reacting or under reacting to a major event.	
Information currently available Although the BoM network of stations is relatively coarse, the access to archive maps for individual nights is excellent. In some regions this network is enhanced with local data.	*Emerging resources* Improvements in networks of loggers and links to remote sensing will improve the assessment of temperature. *Ongoing Challenges* Placing a single year in context will always be difficult in a variable and changing climate. There is an abundance of psychology evidence that as human's we will always struggle to distinguish

	between decisions that are wise/unwise and those that are lucky/unlucky.

Analysis of frosts in the region in 2017

Table 1. Minimum temperatures at a range of locations in GRDC northern grains region for 19, 20, 28 and 29 August 2017

	Parkes	Dubbo	Gunnedah	Narrabri	Moree	Goondiwindi	Warwick
19-Aug	0.8	1.8	2.5	-1.5	2.7	4.5	5.3
20-Aug	-5.6	-4.9	-3.7	-2.5	-1	-2	-3.9
28-Aug	-5.4	-3.7	-0.9	0.4	1.7	1	-3
29-Aug	-4.7	-1.1	-2.5	-0.3	-0.1	-1.5	-3.7

Table 1 shows the minimum temperatures for widespread and damaging frost events on the 20th and 29th of August. Overnight temperatures at ground level or the top of a wheat canopy can be up to 5°C lower than those measured in a Stevenson screen. The offset used in the DSS Wheatman was that head height was 2.2 degrees colder than the Stevenson screen, but differences of up to 10°C have been recorded.

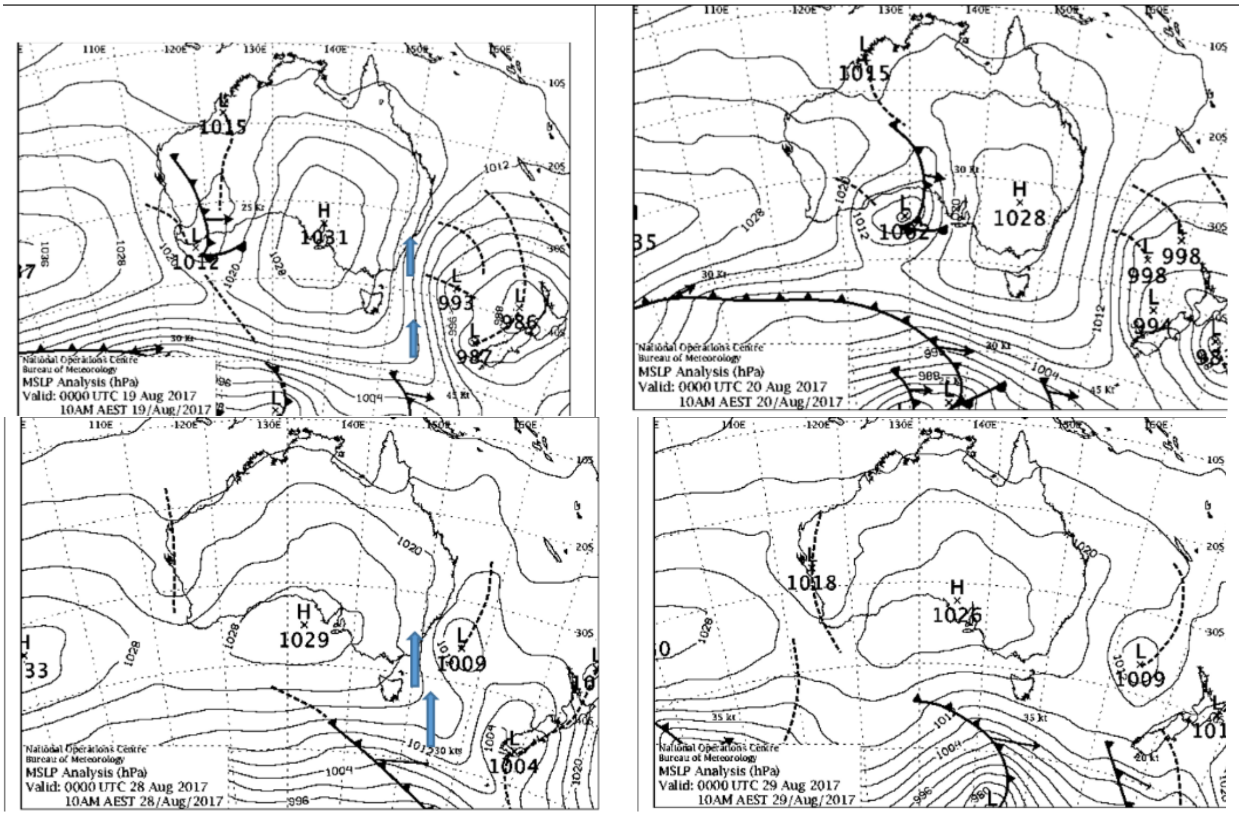


Figure 2. Weather maps showing the mean sea level pressure on 19, 20, 28 and 29 August 2017. Source Bureau of Meteorology. Blue arrows have been added and show southerly flow of air.

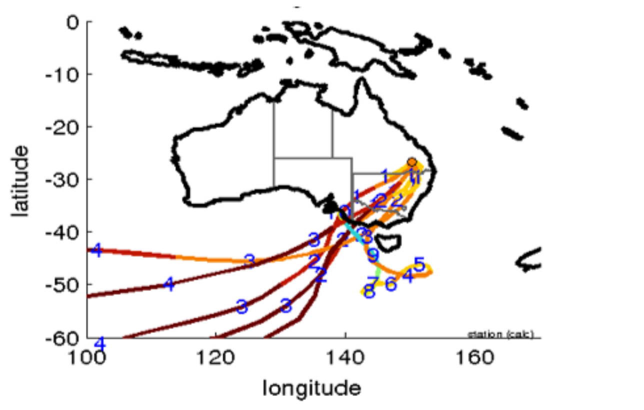
Being located near the centre of a high pressure system provides the stable, descending, dry air required for the clear, calm, night conducive to a rapid temperature fall at dusk and a radiation frost. This raises the question as to why a radiation frost doesn't occur each time there is a high pressure system. Part of the explanation comes from the synoptic pattern of the previous day providing a southerly flow of air (shown as blue arrows). A fuller understanding of the process comes from examining more levels of the atmosphere than the ground level.

Improving the understanding of atmospheric dynamics behind frost events

A team at CSIRO Hobart, led by James Risbey, set out to better understand the synoptic weather events leading up to and during frosts. An understanding of the synoptic drivers provides a basis for confidence and testing of seasonal forecasting, especially if there are broad-scale patterns in the atmospheric dynamics across the southern hemisphere. In discussion with industry, eight high quality climate stations were selected across the Australian grains belt Merredin, Katanning, Kyancutta, Snowtown, Nhill, Wagga Wagga, Gunnedah, and Miles. The historical record from 1955 to 2014 was used to identify mild (T min < 2), moderate (T min < 0), and severe (T min < -2) frost events in the three month period between 15th August and 15th November.

The left hand panel of Figure 3 shows the backtracking of air in the days prior to medium frosts at Miles. This highlights that even northern sites require the inflow of air from a long way south. Not only is the air cold, because it is descending from the middle of the troposphere, it is very dry. Such extreme southerly origin air trajectories are not associated with most high pressure systems in the region and occur mostly in association with the developing blocking high. The blocking highs develop rapidly and persist and are efficient at drawing in and entrapping the cold, dry air. Similar patterns are shown for other locations in the western and southern regions.

A.



B.

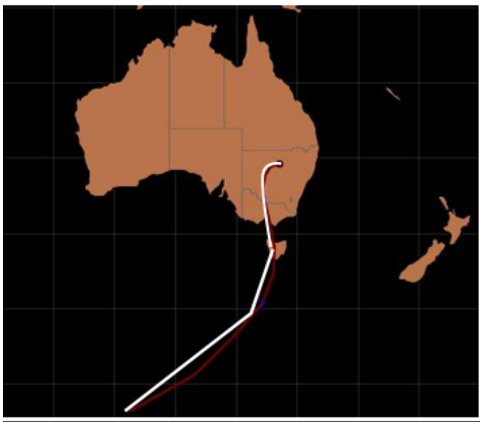


Figure 3. A: Back track of air parcels for spring frost events at Miles Qld (1955 to 2014). The numbers refer to the days prior to the event. B: Backtrack of air parcel for 29th August 2017.

Both the frost events of the 20th and 29th of August involved a front coming through, then a high developing with cold, dry descent trajectories and very cold air mass. These are consistent with the general pattern derived from the 1955 to 2014 data. The late August event was an especially persistent and strong pattern.

The atmosphere flows from west to east sets up what is called a zonal flow which follows the latitudinal lines. The contrast is meridional flow along longitudinal lines. Widespread frosts require meridional flow, that is the interaction of the front and high pressure systems enhance the southern transport of cold dry air. The answer to why each high pressure system is not accompanied by a frost lies in the fact that most high pressure systems are relatively shallow circulation features and do not have the deeper vertical organisation required to entrain very cold, dry air from higher latitudes. The developing blocking high system associated with frost has the appropriate vertical structure to provide cold, dry entrainment. Blocking highs are much rarer at a given location, and thus frost is a relatively rare event.

Research in this project has also shown the importance of synoptic patterns that set up meridional flow to bring hot northern air for spring heat events. The encouraging aspect of the research is that these patterns are not only show consistent synoptic patterns over cropping regions, there is also a strong pattern in the broad-scale southern hemisphere circulation.

Concluding remarks

There is much more climate research on heat and drought than spring frost events. This is not surprising given the enormous interest in heat events due to the direct impact on human health and safety, infrastructure, bushfires and demand for electricity. Likewise drought has always attracted research due to the widespread impact on agriculture but also ecology and increasingly, on urban water supplies. In contrast, spring frosts are only really of concern to grain farmers and horticulturists. This not only applies to the climatology, as there is better understanding on the impact of heat and drought on wheat than post head emergence frost. Although freezing temperatures are an issue for wheat growth in many parts of the world, most of the literature on spring frosts or post head emergence frost damage comes from Australia and South America. The GRDC National Frost Initiative is guided by growers and agronomists and will continue to provide updates on findings as it builds on previous research, much of it from the northern region.

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Climate analysis tools

Australian CliMate: https://climateapp.net.au/

FlowerPower: https://www.agric.wa.gov.au/frost/flower-power

Yield Prophet: https://www.yieldprophet.com.au/yp/Home.aspx

Acknowledgements

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Understanding drivers of phenology to increase grain yield of wheat

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Keywords

phasic development, sowing time, flowering time, photoperiod, vernalisation

GRDC code

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Call to action/take home messages

- Variation in phenology had a significant effect on the grain yield potential of wheat varieties in response to sowing date across growing environments of the northern grains region (NGR).
- The variation in phenology of genotypes is largely due to interactions between genetic responses to vernalisation and photoperiod and growing environment, which determines genotype adaptation.
- High grain yields can be achieved from a range of genotype x sowing date combinations; however there is variation in genotype responses across environments of the NGR.
- Whilst flowering time is important in maximising grain yield potential, pre-flowering phases can have a significant influence on grain yield.

Background

There are a range of commercial cultivars suited for sowing across the northern grains region (NGR), which vary in phenology from slow developing winter types to fast developing spring types, providing growers with flexibility in their sowing window. The adaptation and yield potential of wheat is dependent on matching phenology and sowing time of varieties to ensure flowering and grain formation occurs at an optimal time. In most environments, this is defined by decreasing frost risk, and increasing water and heat stress. The optimal flowering time varies across environments of the NGR, therefore providing growers with an understanding of the drivers of phenology will enable them to tailor suitable combinations of genotype and sowing date to minimise exposure to abiotic stresses and achieve maximum grain yield.

This paper discusses the influence of phenology on yield responses to sowing time for wheat genotypes across five environments of the northern grains region (NGR). These results are part of a project aimed at optimising grain yield potential in the NGR co-invested by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

Phasic development of wheat

The grain yield of wheat is determined by three main components: spike density, grains per spike and individual grain weight. The timing and duration of development phases in wheat is directly related to the formation of specific grain yield components and overall grain yield. During early vegetative development, leaves and tillers are initiated (spike density), prior to the transition to the reproductive stage, when spikelet development commences. Spike growth and differentiation continues in conjunction with stem elongation up until flowering (grains per spike). After flowering, and during the grain filling phase, the embryo develops, producing a viable seed; this coincides with the establishment of grain weight.

Phasic development in wheat is primarily controlled through varied responses to vernalisation (*Vrn*) and photoperiod (*Ppd*) genes. Generally, accumulated temperature accelerates development of all phases, whilst there is an additional effect of vernalisation in some genotypes. Genotypes responsive to vernalisation require a period of cold temperatures to progress from vegetative to reproductive development. Vernalisation accumulates most rapidly in the range 3-10°C, but can accumulate at a slower rate up to 17°C. The direct influence of vernalisation is to alter the length of the vegetative phase, however it can also indirectly affect the duration of subsequent phases. Wheat is a long-day plant; therefore the rate of development is increased with longer day-lengths. However, individual genotypes of current commercial varieties have varying levels of responsiveness to photoperiod, and a large number of Australian cultivars are insensitive to photoperiod. In photoperiod sensitive genotypes, short-day (SD) conditions prolong the vegetative phase and delay the transition to reproductive development, whilst long-day (LD) conditions decrease time to reproductive phases. Flowering time is generally regulated by *Vrn* and *Ppd* genes; there is also an additional effect of a third level of genes, the earliness *per se* (*Eps*) genes. These have been identified as having a fine-tuning effect on flowering time, though these are less associated with regional adaptation of genotypes.

2017 results

In 2017, field experiments were conducted across eight sites in the NGR, in central and southern QLD, northern NSW and southern NSW. This paper presents results from five sites: Wagga Wagga, Trangie, Edgeroi, Wellcamp and Emerald. A range of genotypes with varied development (and with different combinations of *Vrn* and *Ppd* genes) were sown across from late April to late May, with an additional early April sowing at the Wagga Wagga site.

The optimum genotype and sowing date combination for achieving maximum grain yield varied significantly across the five sites (Figure 1). Optimal flowering time was substantially earlier and spanned longer in the northern sites compared to the Wagga Wagga site in southern NSW. In 2017, grain yields were maximised when the sowing date x genotype combinations flowered mid-late July at Emerald, late August-mid September at Wellcamp, mid-late August at Edgeroi and Trangie and early October at Wagga Wagga.

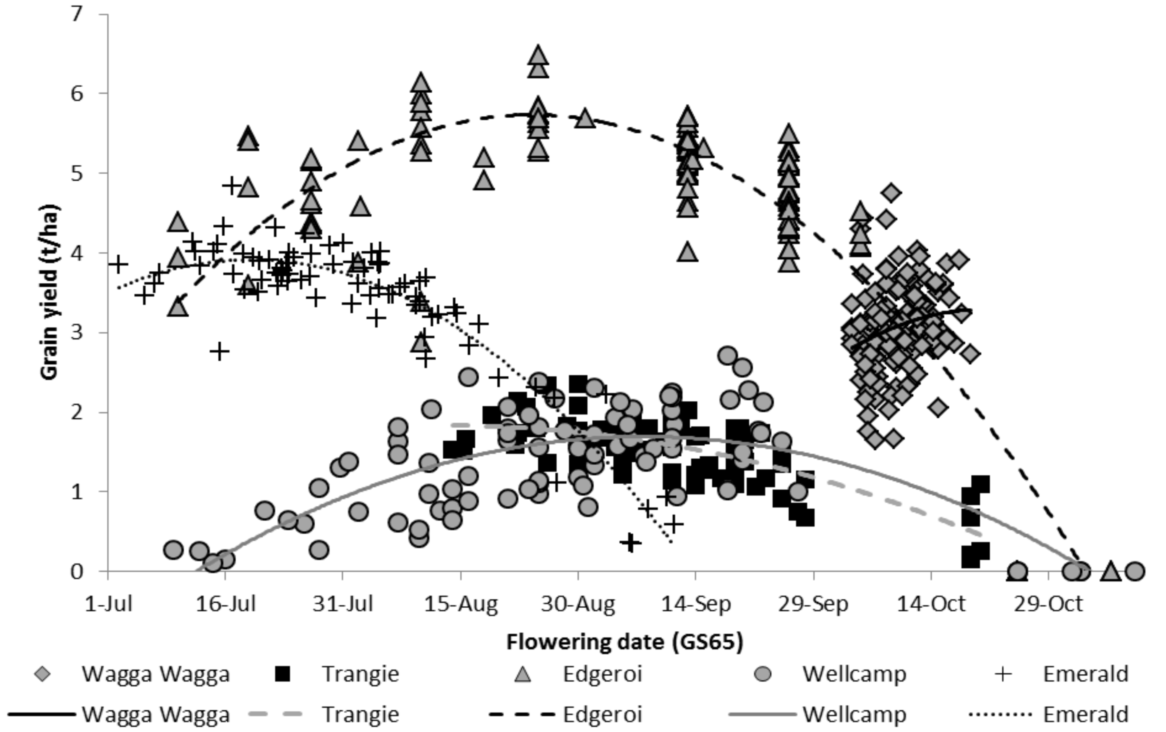

Figure 1. Relationship between flowering date and grain yield of genotypes across sowing dates at five sites in 2017.

Wagga Wagga site

The flowering window at Wagga Wagga was directly influenced by early stem frost damage in 2017. This resulted in significant tiller death and late regrowth of tillers in faster developing genotypes, consequently affecting uniformity of maturity in plots. Flowering dates are expressed as 50% of emerged spikes with visible anthers, as such many of the recorded flowering dates reflect later tillers and do not account for early tiller losses. Faster developing genotypes had lower tiller survival (proportion of tillers which produced a spike) at early sowing dates, whilst the slower developing genotypes, which remained vegetative for longer, were exposed to less frost events and were able to maintain tillers and stabilise flowering time.

Trangie site

The grain yield responses to flowering time at the Trangie site were largely influenced by below average rainfall, recording the driest growing season (April to September) in 2017 (Decile 1). In this warmer environment, winter genotypes flowered much later than the optimal flowering window, as a result yield was severely penalised (EGA_Wedgetail⦶) or not attained (Manning⦶ and RGT Accroc⦶).

Edgeroi site

The optimal flowering window at Edgeroi, as determined by grain yield response in 2017 (Figure 1), was broadly representative of this environment, highlighting the potential for frost risk whilst also underlining the impact of heat and moisture stress. In 2017, this was determined by a combination of abiotic stresses, including frost in August and early September, below average growing season rainfall April to October (195 mm) and temperatures ≥ 30°C in mid-late September. Consequently, the highest yields were achieved by combinations of sowing date x genotype which flowered during this optimal flowering window. The winter types with strong vernalisation responses, for example

Manning⦶, did not flower until late October, even when sown early, which was too late to achieve grain fill in this environment.

Wellcamp site

The optimal flowering window identified for Wellcamp (Figure 1), was generally representative of this environment. In 2017, the site was particularly influenced by cooler temperatures and significant frost events in July-September, and high temperatures throughout the flowering window. Grain yield was also influenced by a hail storm on 24 October, just prior to harvest. Generally, wheat is sown from late May to June for the Inner Downs region, due to increased risk of frost damage, and later onset of heat risk.

Emerald site

The flowering response observed at the Emerald site in 2017(Figure 1) was generally representative of the sowing dates in that environment. The optimal flowering window at Emerald is largely driven by high risk of heat stress August onwards, rather than early frost risk in most seasons. The winter genotypes such as RGT Accroc⦶, Manning⦶, EGA Wedgetail⦶ and Longsword⦶ did not achieve harvestable yield across any of the sowing dates, whilst some slower developing genotypes, such as LongReach Kittyhawk⦶, Sunlamb⦶, Sunmax⦶ and EGA Eaglehawk⦶ did measure grain yield, the Emerald environment favoured mid-fast spring genotypes which flowered within the optimal flowering window and attained the highest grain yields in 2017.

Preliminary results from 2017 indicate some variation in pre-flowering development phases of genotypes with respect to environment and sowing time across the experimental locations in the NGR (Figures 2 and 3). This may have implications to the variation in the flowering grain yield responses in Figure 1, as well as information regarding suitable phenology drivers for different environments. For example, at the Emerald site, winter type EGA Wedgetail⦶ was unable to saturate its vernalisation requirement to progress from the vegetative stage in the first sowing time (TOS1). Start of stem elongation (GS30) was recorded in TOS3 and for 2 of 3 replicates in TOS2 (Figure 2). In contrast, the extended vegetative phase of EGA Wedgetail⦶ at the Wagga Wagga site enabled a level of frost damage avoidance during the stem elongation phase, and recorded consistent flowering dates across sowing dates within the optimum flowering window.

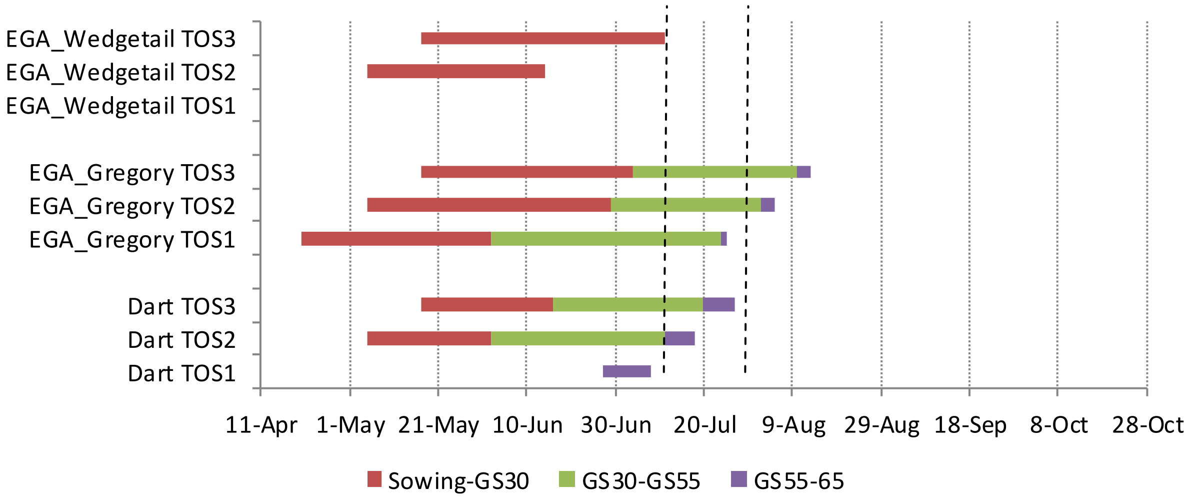

Figure 2. Phasic development in response to sowing time of Dart⦶, EGA Gregory⦶ and EGA Wedgetail⦶ at ***Emerald***. Phase durations measured from sowing to start of stem elongation (GS30), ear emergence (GS55) and anthesis (GS65). Sowing dates: 20 April (TOS1); 5 May (TOS2) and 17 May (TOS3). Dotted lines indicate optimal flowering period in 2017.

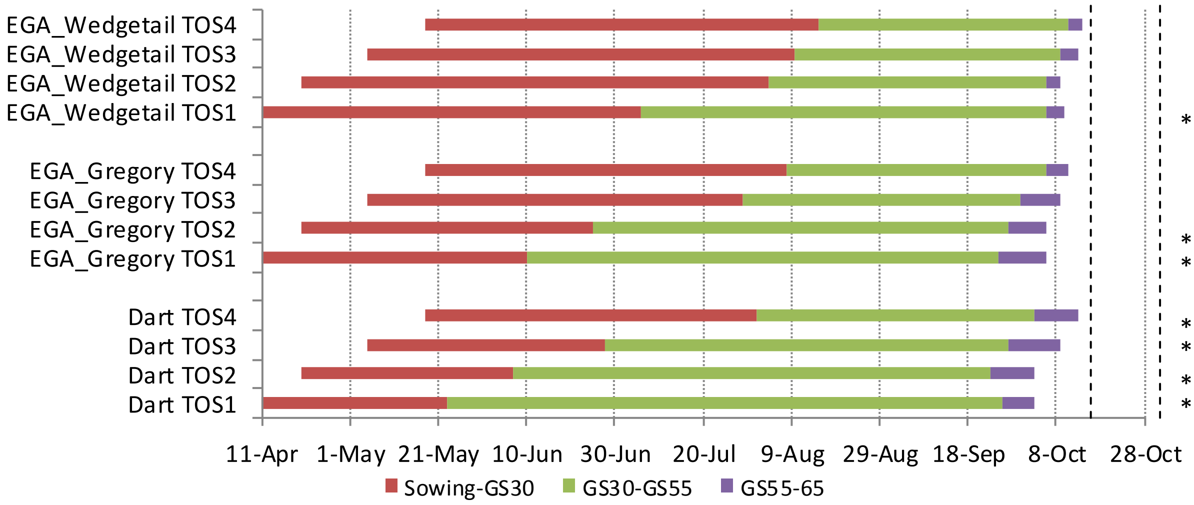

Figure 3. Phasic development in response to sowing time of Dart⦶, EGA Gregory⦶ and EGA Wedgetail⦶ at ***Wagga Wagga***. Phase durations measured from sowing to start of stem elongation (GS30), ear emergence (GS55) and anthesis (GS65). Sowing dates: 10 April (TOS1); 20 April (TOS2); 5 May (TOS3) and 17 May (TOS4). Dotted lines indicate optimal flowering period in 2017, asterisks indicate significant frost damage, resulting in late regrowth influencing development.

Yield responses to sowing time

There was genotypic variation in the grain yield responses to sowing time across the five sites in 2017, as indicated for the selected genotypes in Figure 4. Generally, slow developing genotypes favoured southern sites, characterised with a longer growing season and high risk of frost damage. For example, Manning⦶ (winter type with strong vernalisation response) and EGA Wedgetail⦶ (winter type) had highest yields when sown early (indicated by negative slope) at the Wagga Wagga site. However, the vernalisation requirement of these winter types did not suit the warmer environments of northern NSW and QLD, and as such they either had significant grain yield penalties or did not achieve grain yield. The northern sites favoured mid-fast developing spring genotypes sown late April to early May (indicated by negative slope); in contrast, these were better suited to the late-May sowing at Wagga Wagga (indicated by positive slope). Despite the variability across environments, and conditions in 2017, some spring genotypes such as EGA Gregory⦶ and Suntop⦶ were able to maintain relatively stable grain yields across many sowing dates at some sites (indicated by flatter line). Whilst the general yield responses were similar for some sites, the variability in specific genotype responses across the sites suggests there are differences in suitability of genotypes across growing environments of the NGR.

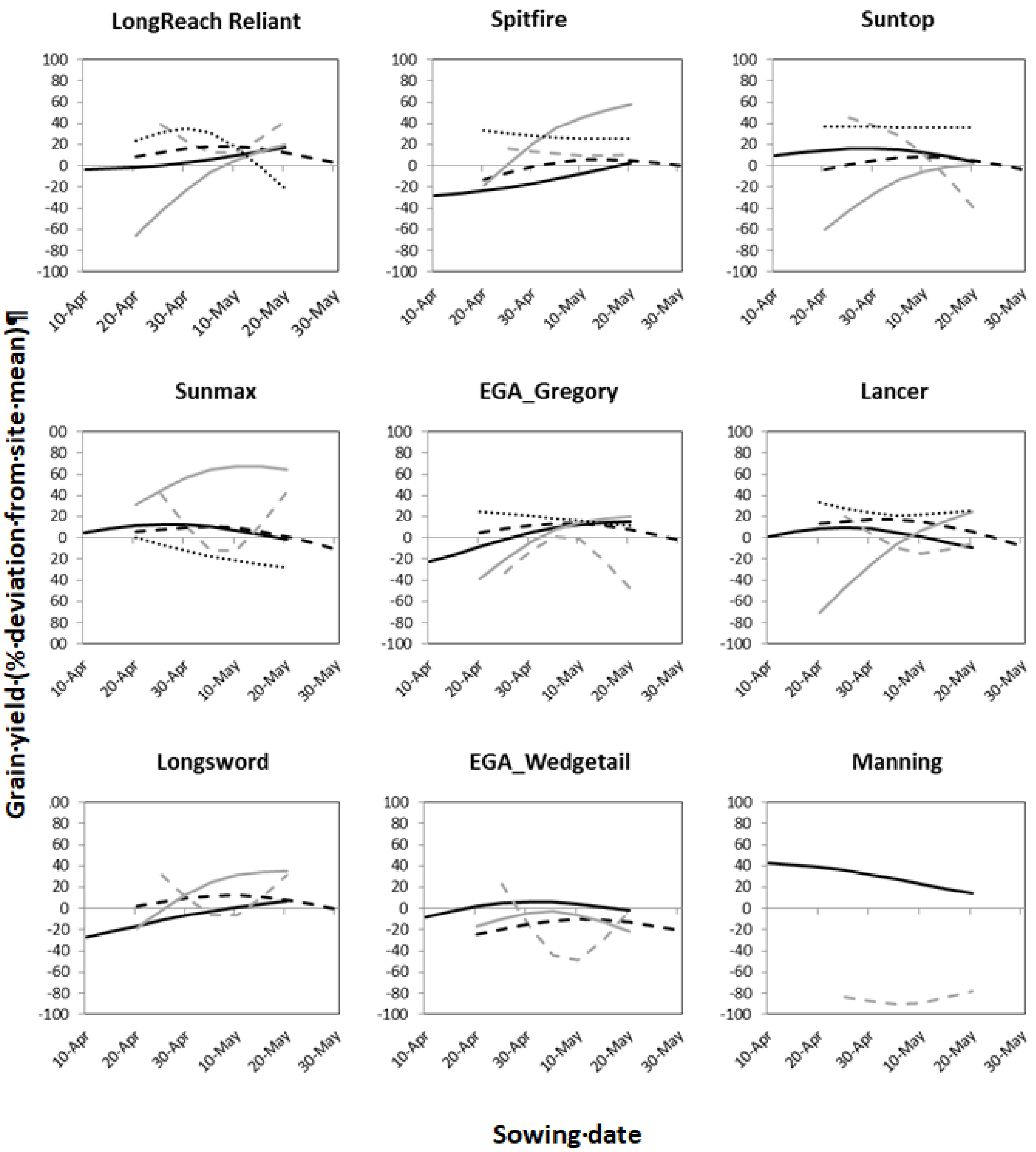

Figure 4. Grain yield response to sowing date in **2017** for selected genotypes across five sites in the Northern Grains Region (black line =Wagga Wagga; grey dash line= Trangie, black dash line= Edgeroi, grey line= Wellcamp, dotted line= Emerald). Grain yield response is presented as deviation from site mean as a percentage for each site. Site means were: Wagga Wagga – 3.07t/ha; Trangie – 1.52t/ha; Edgeroi – 4.98t/ha; Wellcamp – 1.33t/ha; Emerald – 2.93t/ha. (LongReach Relianttᶲ, Spitfireᶲ, Suntopᶲ, Sunmaxᶲ, EGA_Gregoryᶲ, Lancerᶲ, Longswordᶲ, EGA_Wedgetailᶲ and Manningᶲ are protected under the Plant Breeders Rights Act 1994.)

Summary

Our data showed that genotypic variation in phenology had a significant effect on the grain yield potential of wheat varieties in response to sowing date across growing environments of the northern grains region. Genotypes varied in responses to vernalisation and photoperiod genes, which influenced early phasic development in addition to flowering time across the sites. Matching variety and sowing date to achieve an optimal flowering time for each growing environment is the most effective management strategy in minimising effects of abiotic stresses. In southern NSW, winter types can be sown early and regulate flowering to minimise effects of early frost damage and later, heat and moisture stress. However, in northern NSW and QLD, winter types are not able to saturate vernalisation requirements and the shorter growing season favours mid-fast spring types which are generally regulated by responses to photoperiod.

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Matching phenology, environment and variety to optimise wheat yield

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Notes

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Root traits for yield improvement in barley

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Key words

root angle, root number, root system architecture, yield, drought adaptation

GRDC code

GRS10940

Take home messages

- Seminal root angle is a good indicator of the mature root system architecture in barley.
- There is variation for seminal root angle and seminal root number in commercial barley varieties.
- Pre-breeding barley lines have more extreme measures for seminal root angle (both narrow and wide) and root number (both low and high).
- There is a weak to moderate relationship between seminal root traits and yield improvement in barley, where the direction and magnitude of the correlation is highly environment dependent.

Call to action

- Barley improvement programs (breeding and pre-breeding) need to better understand and utilise the extent of genetic diversity in root angle and root number to enhance productivity in water-limited and non-limited environments.
- Since the relationship between seminal root traits and yield improvement in barley is highly dependent on the environment, it is critical for barley improvement programs to characterise the environment, and to optimise specific adaptation (genotype x management) for a range of target environments.
- Root ideotypes need to be designed for water and nutrient uptake, since nutrient and water reserves can be spatially separated in the soil.

Background

Roots play a vital role in resource uptake and plant growth regulation by being the primary interface for water and nutrient capture. In addition, roots provide anchorage and interact with cooperative organisms in the soil. Defined as the spatial distribution of roots throughout the soil space, root system architecture (RSA) is a complex trait with many underlying processes, such as root elongation, curving and branching (Lynch 1995; Rich and Watt 2013). Furthermore, the RSA of a plant has been shown to influence the efficiency and timing of water capture and extraction in cereal crops (Kondo et al. 2000; Pennisi 2008).

The fibrous root system of cereals is broadly divided into seminal roots, emerging from the primordia in the embryo of the seed, and nodal or secondary roots, developing from the lower nodal regions of the culm throughout tillering (Forster et al. 2007). The growth angle between the first pair of emerging seminal roots, described as the seminal root angle, was found to be representative of the mature root system architecture in wheat (Oyanagi et al. 1993; Manschadi et al. 2008; Manschadi et al. 2010). As a result, seminal root angle is considered a proxy trait for mature RSA in wheat (Sanguineti et al. 2007; Hamada et al. 2012; Christopher et al. 2013; Richard et al. 2015).

Water and nitrate, the two resources most highly acquired by crops, are extremely mobile, leaching into the deeper layers of the soil and reducing availability in the surface strata. Generally, higher levels of water and nitrate are located deeper in the soil profile. These levels are further exaggerated throughout the season under terminal drought conditions, where the soil dries progressively from the surface layers as a result of evaporation, drainage and root uptake.

Environment modelling of the northern grain growing region of Australia identified terminal drought stress as the most common pattern of water-stress for this growing area (Chenu et al. 2011). A deep root system is thought to be optimal for maximum resource capture under water-limited conditions for a number of crop species (Herder et al. 2010; Lynch 2011). Root foraging for resource acquisition is a high metabolic cost for crops (Lynch 2015), thus plants with deep roots in close proximity to resources minimise the need for extensive foraging (Lynch 2013). In addition, plants with the deep roots are also believed to adequately access water and nutrients from the top layers of the soil through their shallow lateral roots (Lynch 2013). Thus, theoretically a narrow yet deep root system would be optimal for cereal crops grown across the northern grain growing region of Australia, where in-season rainfall is limited and terminal drought stress is common. In support of this, a narrow root angle, representative of a steep and deep RSA, improves deep-soil foraging and water extraction under terminal drought in wheat, sorghum and rice (Uga et al. 2011; Manschadi et al. 2008; Mace et al. 2012; Uga et al. 2013). In barley, the value of a narrow, yet deep, RSA for water capture and yield improvement has yet to be completely explored.

In this paper, we begin by investigating seminal root angle as a proxy trait for mature RSA in barley. Next, we explore the variation for seminal root angle and root number in a collection of commercial malt and feed barley varieties. Finally, we take a first look at the relationship between seminal root traits and yield in barley grown in the northern region.

Materials and methods

Phenotyping root traits

To investigate seminal root angle as a proxy trait for mature RSA, a panel of five pre-breeding barley lines were phenotyped for seminal root angle using the 'clear pot' method under controlled conditions using a randomised complete block design (Richard et al. 2015). Seminal root angle was defined as the angle measured between the first pair of emerging seminal roots (Figure 1). The 'clear pot' method was also used to phenotype seminal root angle and root number in a collection of commercial barley varieties to explore phenotypic variation. The commercial varieties included Commander⦶, Oxford⦶, Fathom⦶, Westminster⦶, Compass⦶, Shepherd⦶, ScopeCL⦶, Baudin⦶, Rosalind⦶ and La Trobe⦶. To examine the relationship between seminal root traits and yield, a panel of 165 pre-breeding lines were also phenotyped for seminal root angle and root number using the 'clear pot' method. The panel of pre-breeding lines consisted of five families derived from crosses between Commander⦶ and four elite breeding lines from the northern region barley (NRB) breeding program (Warwick, Australia) and one line from the ND24260 × Flagship⦶ doubled haploid population (Hickey et al. 2011). To calculate best linear unbiased predictors (BLUPs) for seminal root traits of varieties in all experiments, a linear mixed model was fitted to the data using ASReml-R (Butler et al. 2008). The experimental variation was accounted for by including all design terms as well as spatial location of the pot in each glasshouse experiment.

The mature root system architecture of the five pre-breeding lines was phenotyped in the field at The University of Queensland (UQ) research station, Gatton, Queensland, Australia using the 'shovelomics' approach (Trachsel et al. 2011). Mature root system architecture was defined as the outer angle capturing the overall direction of root growth.

Figure 1. Illustration of seminal root angle measurement of the first pair of seminal roots, where angle (A) is the measurable seminal root angle.

Yield trials

The panel of 165 pre-breeding lines were evaluated in three yield trials conducted at the Department of Agriculture and Fisheries (DAF) Hermitage research facility (Hermitage, QLD) across 2016 and 2017. Trial environments are detailed in Table 1, where weather data was accessed online from the Bureau of Meteorology (http://www.bom.gov.au/). All field trials were designed as partially replicated (0.5) row-column designs (Cullis et al. 2006). Weeds and diseases were controlled as required. To estimate the association between seminal root traits and yield across the three trials, multi-environment trial (MET) analysis was performed using a linear mixed model and fitting a factor analytic structure for the genetic by environment by trait effects in the model (Smith et al. 2001). Site specific BLUPs for yield and root traits were generated for each pre-breeding line from the model, along with correlations between yield and seminal root traits.

Table 1. Description of three yield trials evaluating panel of 165 pre-breeding lines

Trial	Year	Location	Irrigated	Sown	ARF[a] (mm)	CRF[b] (mm)	Mean yield (t/ha)
H-16-dry	2016	Hermitage, QLD, 28.2° S, 152.1° E	No	22.07.2016	729.4	370.0	5.03
H-16-irri	2016	Hermitage. QLD, 28.2° S, 152.1° E	Yes	22.07.2016	729.4	370.0	4.58
H-17-dry	2017	Hermitage. QLD, 28.2° S, 152.1° E	No	27.06.2017	575.0	171.0	4.96

[a] Annual rainfall
[b] Cropping season rainfall

Results

Seminal root angle as a proxy trait for mature RSA

Wide variation for seminal root angle was observed in the panel of pre-breeding lines, where the narrowest angle of 52.0° was observed for pre-breeding line 1 (PB1) and the widest angle of 77.4° for PB2 (Figure 2A). Similar results were identified for mature root angle, where pre-breeding lines were ranked in a similar order to that for seminal root angle (Figure 2B, C). The exception to this was

PB2, which displayed a wider seminal root angle compared to mature root angle (Figure 2A, B). Overall, like in wheat, seminal root angle appears to be a satisfactory approximation of the mature RSA in barley. It is important to note that only a small number of lines were examined in this experiment and further investigation using a larger collection of lines is required to validate this result.

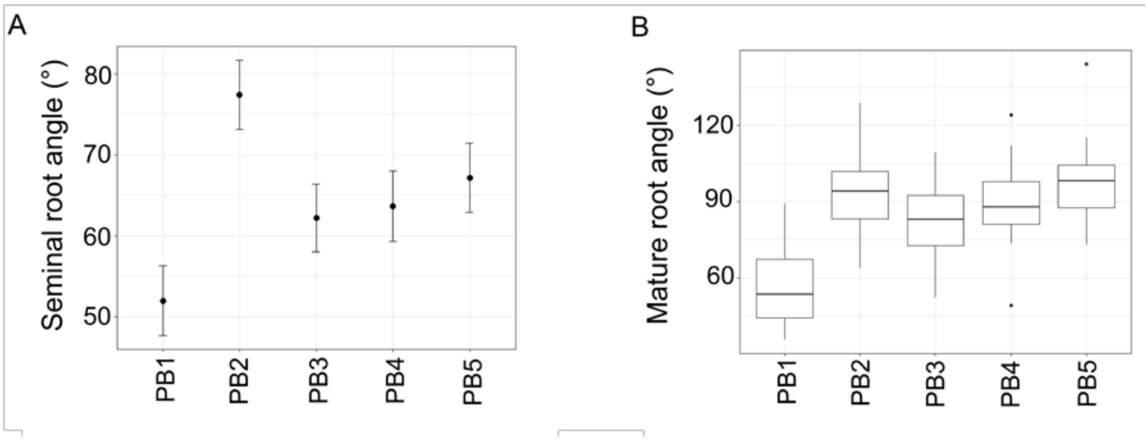

Figure 2. Seminal and mature root angle in the panel of five pre-breeding lines. **(A)** Seminal root angle BLUPs measured using the 'clear pot' method, where error bars represent the standard error of the mean. **(B)** Box-and-whisker plots displaying the full distribution of data for mature root angle measured using the 'shovelomics' methods. Adapted from Voss-Fels and Robinson et al. 2017.

Seminal root trait variation in commercial barley varieties

Seminal root angle and seminal root number varied across the barley varieties (Figure 3A, B). ScopeCL⌽ displayed the narrowest root angle (44.1°) and Westminster⌽ displayed the widest (64.8°). For root number, ScopeCL⌽ displayed the highest number (5.3), whereas the lowest number of roots (4.7) was observed for Commander⌽.

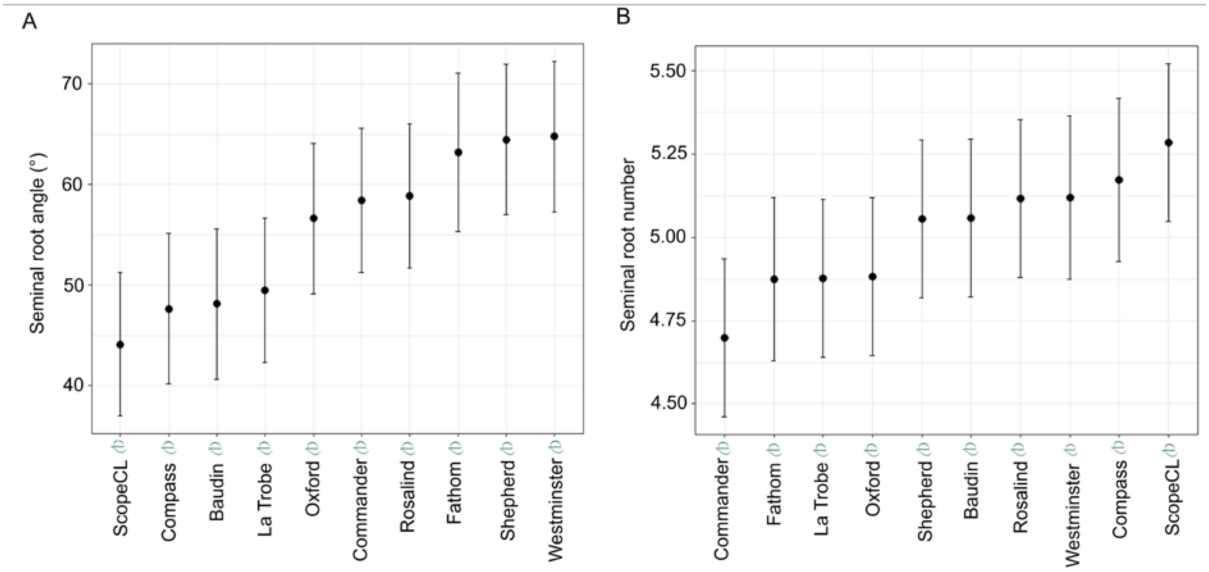

Figure 3. Seminal root trait BLUPs for the collection of 10 commercial barley varieties **(A)** Seminal root angle and **(B)** seminal root number BLUPs. Error bars represent standard error of the mean.

Relationship between seminal root traits and yield

A wide range in root phenotypes were observed in the panel of 165 pre-breeding lines, with angle ranging from 12.50° to 109.70° and root number from 3.00 to 6.19 roots (Figure 4A, B). In comparison to the commercial varieties, the pre-breeding lines have a significantly wider range of phenotypes for both seminal root traits. Depending on the value of root traits for yield improvement, these pre-breeding lines may be a useful source of germplasm for introgression of more extreme root phenotypes into breeding material.

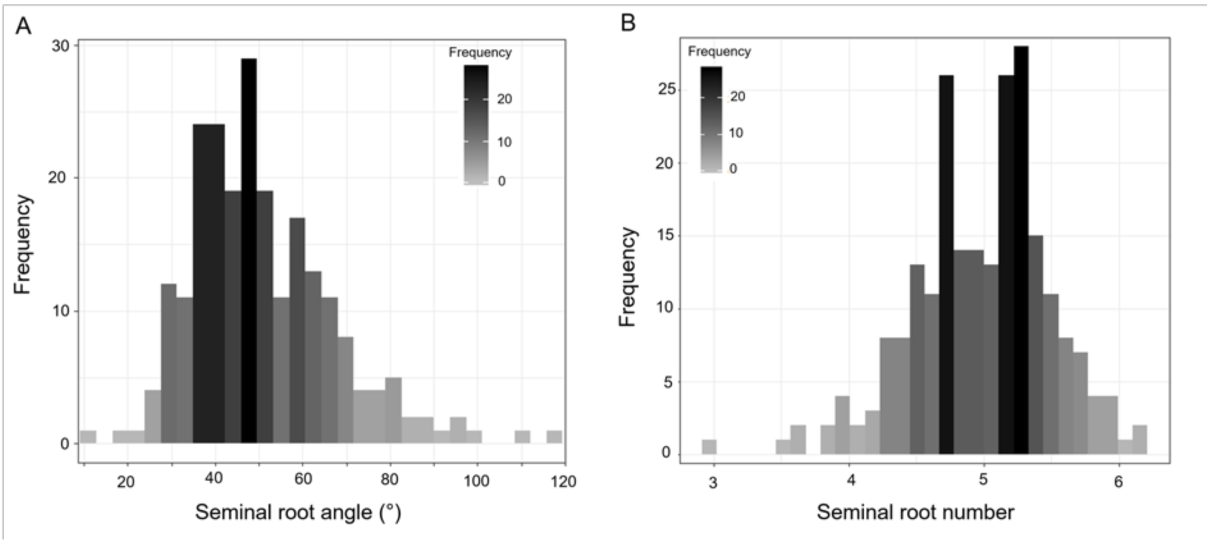

Figure 4. Distributions of root traits for the panel of 165 pre-breeding lines. (A) distribution of seminal root angle (°), and (B) distribution of root number. Increase in darkness represents an increase in frequency of lines with the root phenotype.

Due to uncharacteristically high in-season rainfall throughout the 2016 cropping season (Table 1), the H-16-dry trial was correlated (0.56) with the H-16-irri trial in the MET yield analysis (Figure 5) and was therefore similar in yield to an environment with frequent in-season rainfall. H-17-dry had the lowest in-season rainfall (Table 1) making it the most representative dryland trial of the three trials described in this study. Figure 5 demonstrates there is an association between both seminal root traits and yield, however it appears to be highly environment dependent. In our driest trial, H-17-dry, improved yield was associated with a narrow root angle (-0.28) and a high root number (0.44). In contrast, in the trials characterised by frequent in-season rainfall, a wide root angle with a low root number was associated with increased yield (Figure 5B). Consistent with the current literature, our results suggest a narrow root angle with a high root number may be more beneficial for yield improvement in water-limited environments.

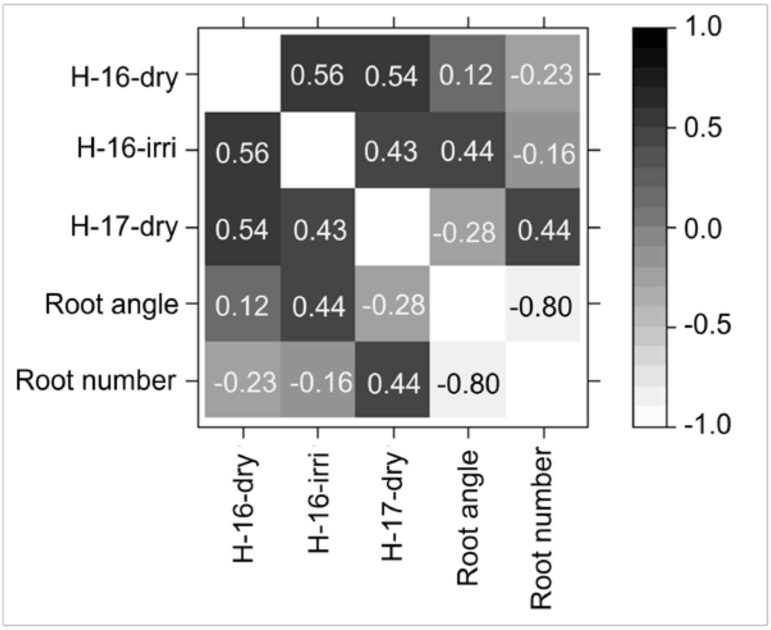

Figure 5. Multi-environment trial analysis for yield and seminal root traits. Heatmap of correlations between yield trials, seminal root angle and seminal root number. Positive correlations between traits increase with increasing colour intensity (darker) and negative correlations with decreasing colour intensity (paler).

Conclusion

Here, we provide preliminary evidence for seminal root angle as a proxy trait for mature RSA in barley. This result provides support for the use of high-throughput methods to measure seminal root angle to better understand the barley root system and its relationship with yield. Further, using the 'clear pot' method to measure seminal root angle and root number, we demonstrated that the collection of commercial barley varieties was wide-ranging for seminal root traits. However, the panel of 165 pre-breeding lines displayed the most extreme measurements for both seminal root traits. This highlights an opportunity to exploit more diverse root traits in commercial breeding material.

Our results reveal that seminal root angle and root number were weakly to moderately associated with yield improvement, where the direction and the magnitude of this relationship was highly environment dependent. For instance, a narrow root angle with a high root number appeared beneficial in drier growing environments where the crop is sown into deep soil with a full moisture profile. This outcome is consistent with the current literature in other cereal crops, where a narrow root system has an increased proportion of roots at depth and thus an improved ability to uptake moisture from deep in the soil profile (Manschadi et al. 2006; Lynch et al. 2014). In contrast, a wide root angle with a lower root number appeared to be more beneficial for environments that experience frequent in-season rainfall in our study. This is likely because a wide root angle tends to promote shallow root growth, thus increasing the proportion of roots in the top soil strata that can take advantage of in-season rainfall. Despite the consistency of these results with previous research, further investigation in a larger number of environments and across more growing seasons is required to extensively validate the relationship between seminal root traits and yield improvement for barley in the northern grain growing region. In addition, the role of roots in nutrient uptake needs to be better understood, particularly in relation to immobile elements like phosphorus (P) and potassium (K). As nutrient and water reserves can be spatially separated in the soil, root systems will be required to respond to this spatial separation.

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Tillage, stubble and zero-till - understanding the data sets underpinning no-till farming systems for productivity and resource sustainability.

David M Freebairn

Key words

tillage, planting, stubble, nutrition, disease, nitrogen, compaction, controlled traffic, water and soil conservation, water quality, erosion, productivity

Call to action/take home messages

- Stubble cover and reduced tillage improve water storage, with very few exceptions;
- Improved water capture in soils leads to improved crop yields, especially in drier years, but negative responses to stubble are observed in southern regions;
- Negative responses in wheat-wheat systems to practices which store more water are due to lower soil nitrate, higher disease and nematodes;
- Sorghum and pulse crop are better able to use extra water stored in stubble and reduced/no till systems;
- Optimizing compaction (controlled traffic), fallow durations, crop sequences and weed management offers additive improvements;
- Conservation tillage has improved water quality and reduced erosion dramatically;
- An occasional tillage to deal with issues associated with no tillage does not have any long term negative impacts and benefits outweigh negatives; and
- The farming community have adopted new practices over wide areas when benefits have been demonstrated;
- Rainfall is used relatively inefficiently with only 25-50% going through plants – therefore there is plenty of room for improvement.

Introduction

Today's tillage and crop systems have evolved dramatically since the first settlers. Not knowing the environment and being short of food, James Ruse was set the task of growing crops near Parramatta after it was found that the soils near Sydney Cove were not suited to cropping. Ruse's first attempts at cropping found that corn was the best bet. As cropping expanded across south eastern Australia, cropping systems were strongly influenced by experience from England and Europe. These systems, based on frequent tillage and clean fallows were found to be wanting, especially in the northern cropping regions. Contour banks were the mainstay of soil erosion control, yet erosion remained an issue.

Hector Tod (1969) was one of the early farmers to explore tillage and planting equipment to handle higher stubble loads while machinery evaluation programs were initiated in Queensland (Ward Norris 1976) in the mid 1970's. These programs involved importing equipment from Canada and the USA and testing them with interested farmers and provided training on appropriate set-ups for this equipment. Roundup® was released in Australia in 1974 being the first broad spectrum herbicide that made weed control feasible in prospective no-till fallows. But it cost $20/L and we used to use 1-2L/ha in 1976!

A long standing agronomy research effort was initiated by Marley and Littler (1989) in 1968 comparing water and nitrogen relations associated with tillage and stubble. This was visionary in that stubble burning and disc tillage were the norm. In the spirit of development the land, the Queensland Government set up a catchment study in 1965 to better understand the influence of land clearing on farm water supply. After a calibration period of 17 years, two catchments were cleared with one cropped and one to pasture. These two sites remain active and demonstrate vision and commitment after 50 years.

In the mid 1970's there was conflicting advice coming from government extension agencies: on one hand farmers were being told to burn or bury stubble to reduce diseases and facilitate tillage and planting, while the soil conservation fraternity were indicating retention of stubble even though tillage and planting machinery was not well suited. This set the scene for a grand era of research, development and extension across the fields of agronomy, soil science and hydrology (Figure 1). There were >12 major agronomy research sites with detailed replicated plots looking at interactions between crop yield, water storage, nutrition and disease. Eight catchment studies was initiated to explore the impact of soil and fallow management on runoff and erosion, while there were numerous on-farm demonstrations and machinery development activities. Herbicide and local machinery manufacturing companies were actively involved in all elements of these studies. This extensive investment in the exploration of conservation tillage forms a foundation for the cropping systems of today. This paper aims to provide an overview of this effort with a sample of results – it is not comprehensive and will demonstrate a Queensland bias, naturally!

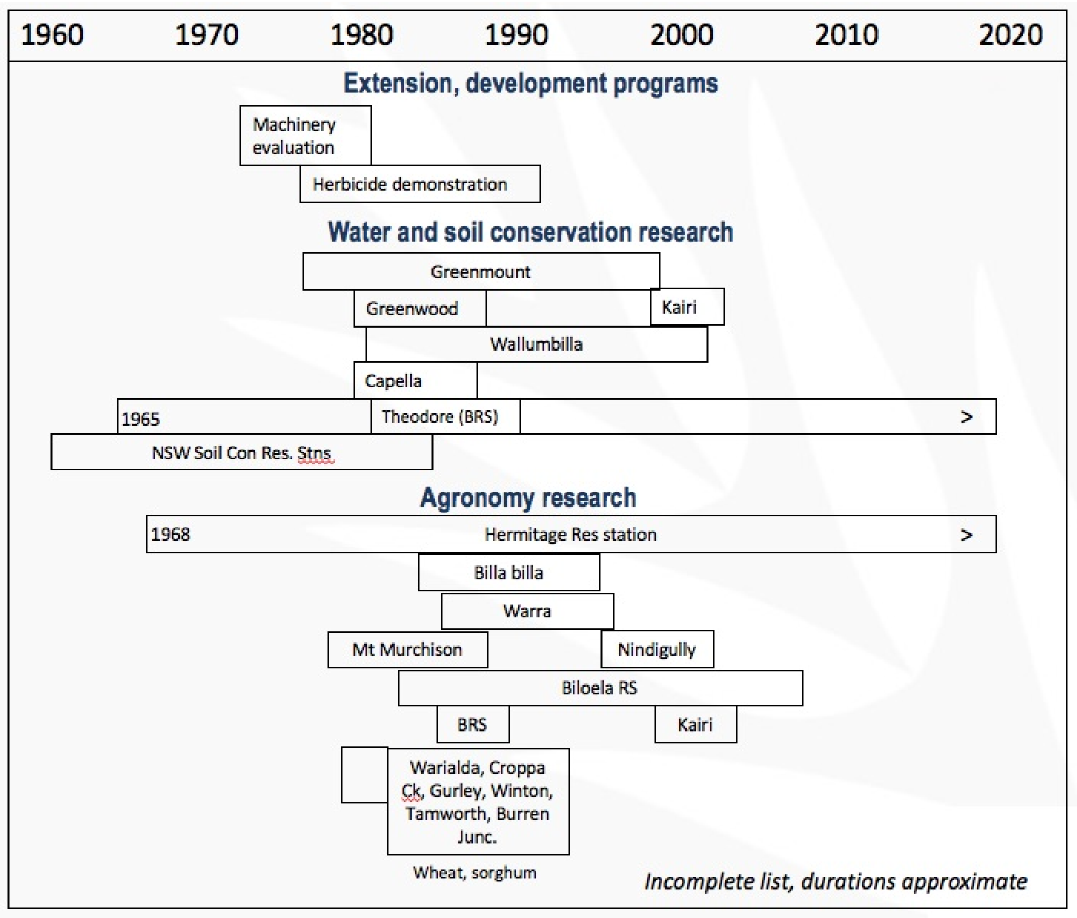

Figure 1. Time line of research and extension activities focusing on conservation tillage in northern NSW and Queensland (adapted from Thomas et al 2007) These studies represent >300 sites years of investigation.

Why is fallow management so important?

Figure 2 shows the dependence of winter crops on starting soil water. For example, 20% of the water supply of a crop at Greenethorpe comes from water in the soil at planting. This value increases to 60% for a winter crop at Dalby. All other things being equal, it's hard to see how better water capture cannot improve productivity and profit.

Catastrophic erosion after our typically sharp summer storms also highlighted the need for a better system to keep soil in place so it can store water for another day!

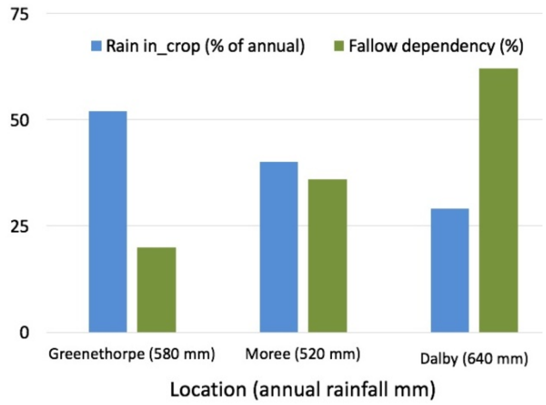

Figure 2. Percentage of in-crop rainfall and "fallow dependency" (the proportion of the crops water supply derived from soil water at planting) for three locations.

The following figures and table provide a snapshot from some key research studies.

Figure 3 shows average fallow efficiency values for four tillage treatments at the long term trial near Warwick, with an extra 9% of rainfall captured when stubble is retained and not cultivated. Similarly, starting soil water over 3 years at three sites in northern NSW was 30mm higher in no till with stubble compared to tilled and stubble burnt (Figure 4). Given the "safe" nature of stored soil water, an extra 30mm could be worth as much as 100mm of extra in-season rainfall.

In both these studies, wheat yields did not reflect these gains in starting soil water. Figure 4 provides some of the evidence for this lack of achievement – lower soil nitrate and lower protein. Additionally, higher root and leaf disease and nematode levels were observed in all stubble and reduce tillage plots. This result is consistent across eastern Australia, and more so in southern Australia where negative yield responses to stubble are common in research studies (Scott et al 2010).

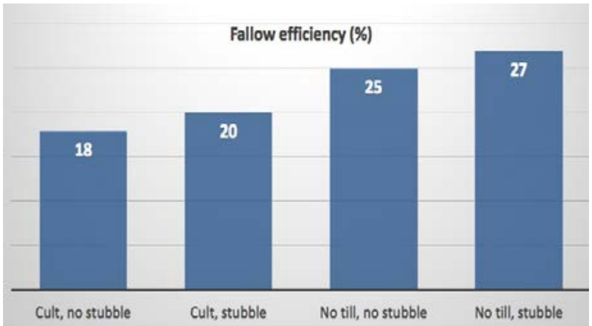

Figure 3. Average fallow efficiency (% of fallow rainfall stored in soil at planting) for four tillage/stubble treatments at the Hermitage Research Station near Warwick 1968-79 (11 years) (Marley and Littler 1989).

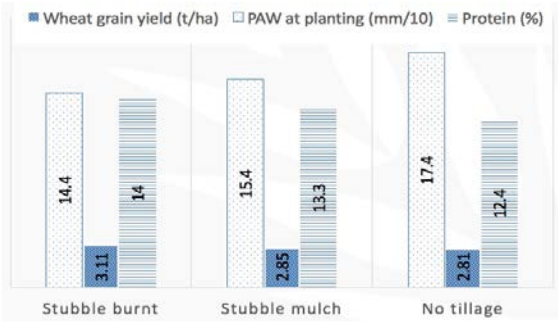

Figure 4. Average yield over 3 years for three fallow management strategies at Warialda, Croppa Creek and Breeza, 1986-88 (Marcellos et al 1995). All treatments received basal fertiliser plus 50kg/ha N.

In contrast Holland and Felton (1989) found that when sorghum was sown into no-till cereal stubble, yields were 0.7-1.8 t/ha greater compared with cultivated, stubble retained fallows (Graeme Schwenke pers. comm.). Apparently sorghum did not have to deal with the disease load of its disease unrelated wheat and could use the extra 31mm of stored water.

One of the more interesting results from these many studies comes from Central Queensland where Radford and Thornton (2011) found that a yield penalty associated with aggressive tillage lasted 3 years after a no-till regime was implemented over the whole trial (Table 1). It is notable that there are no yield differences between the three "stubble retained" treatments and that crop type was varied depending on planting opportunities. They proposed that the lingering yield penalty was due to disease and nutrition.

Table 1. Average grain yield (t/ha) over 20 years for four fallow management options and yield when all plots were managed for the subsequent 3 years (Radford and Thornton, 2011).

Treatment	Mean Yield for 20 Years (t/ha)	Mean Yield Post-treatment years (t/ha)
Disc/scarifier tillage	2.15	1.43
Stubble mulch tillage	2.66	2.73
Reduced till	2.77	2.83
Zero till	2.79	2.71

Controlled traffic is an evolving practice to improve efficiency, timeliness and improved soil conditions leading to better yields. Tullberg et al. found large differences in water capture and grain yields at Gatton (Li et al. 2007) with compaction associated with wheeling having a larger impact on infiltration than soil cover (Figure 5). This encouraging result may well be being replicated across the grain belt as the package appears to offer other advantages.

One point of conflict has arisen associated with controlled traffic – the direction of travel. Should the preference be to cross the slope, similar to cultivating between contour banks, or down the slope? While this debate will continue, my summary at the moment is that if good stubble cover is maintained, then direction is not important, and if there is little soil protection, it is also of little interest as we can expect the worst regardless, when a big rainfall occurs, which it will.

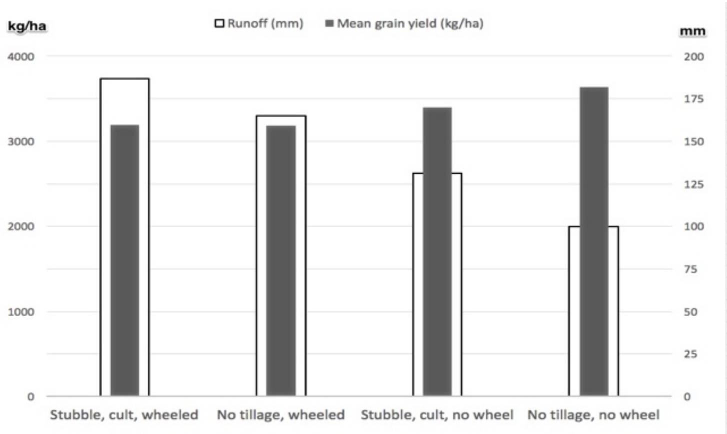

Figure 5. Mean annual runoff and grain yield from four stubble/compaction treatments at Gatton after 6 years of opportunity cropping (Tullberg, 2001 Xi et al.)

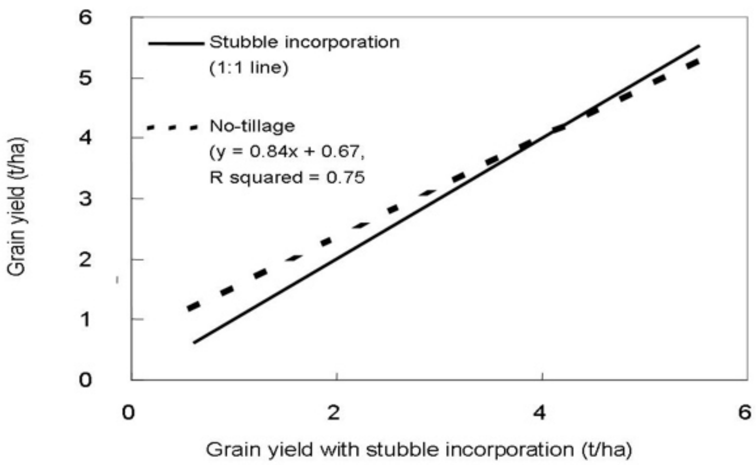

Figure 6. Comparison of grain yields between no–tillage and stubble incorporation across 120 experiment years in southern and central Queensland (Thomas et al. 2009)

Agriculture, like most industries has its fads and its believers in one system or another. There was a belief that no-till systems created cumulative benefits that would be lost from tillage. Dang et al (2017) concluded that the impacts of an occasional "strategic tillage" did not have any lasting negative impacts and on balance was a useful strategy to deal with some aspects of not cultivating for long durations.

Thomas et al (2009) summarised results for the range of published research studies in Queensland, comparing grain yield (Figure 6). Graeme Schwenke (pers. comm.) summarised the N NSW studies from the 1990's as "no-tillage in conjunction with crop rotation and N fertiliser use can be a more productive and economic proposition than a continuous cereal system. Chickpea, faba bean and sorghum perform better sown into cereal stubble (+10-20% yield), legumes fix more nitrogen, and pulses on wide rows (64 cm) retain more stubble, are easier to sow, and increase herbicide options."

Figure 7 lists the positive and negative drivers of reduce tillage and stubble systems. Clearly, farmers have sorted through many of these issues and appear to be implementing conservation tillage systems with better results than most research trials. Well of course, they are professional farmers.

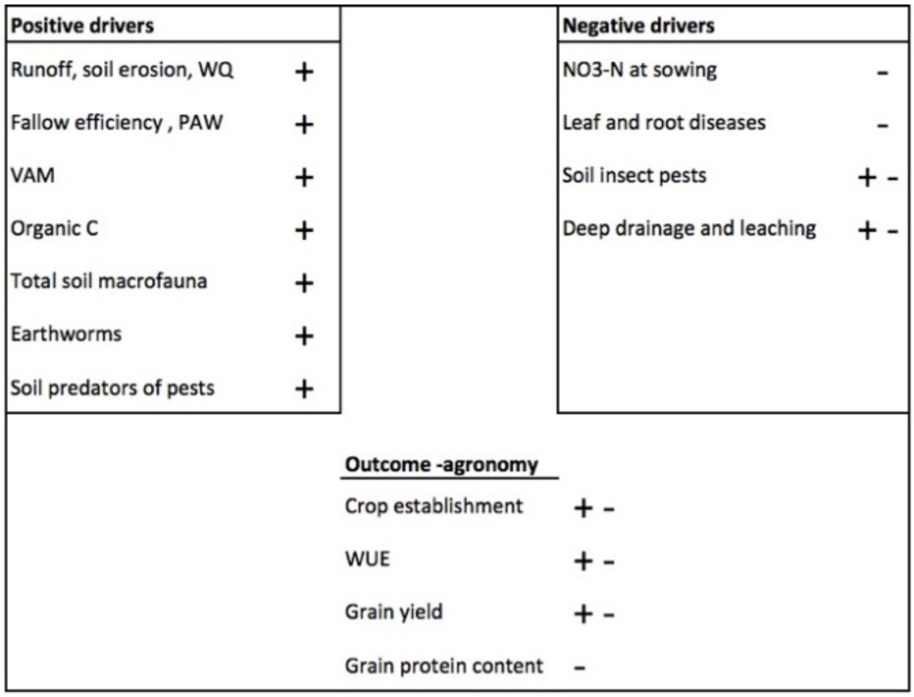

Figure 7. Summary of positive and negative drivers associated with adoption of reduce tillage and stubble retention systems. Note that +- indicates that there are positive and negative impacts

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Acknowledgements

Improved soil and crop systems in the northern regions are the result of 50 years of diligent innovation and exploration by farmers, agronomists, soil scientists, agricultural engineers, chemical & machinery companies.

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Key farming decision points to improve water use efficiency and profit on red soils

John Kirkegaard[1], James Hunt[2], Bonnie Flohr[1], Tony Swan[1]

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[2]La Trobe University

Key words

crop sequence, fallow management, sowing date, nitrogen, timeliness, soil acidity, tillage

GRDC codes

CSP00111, CSP00174, CSP00186, CFF00011

Call to action/take home messages

- Combinations of agronomic decisions, not single factors drive the highest efficiency and profit in grain production.
- The central west of New South Wales has one of the highest grain yield responses to the application of strict summer fallow weed management practices.
- Good crop sequence and fallow management provides the opportunity for early and timely sowing of crops for well-prepared operators to maximise yield and minimise risk, with multiplying effects at the whole-farm scale. Early crops can be grazed on mixed farms providing further benefits.
- In-crop (post-sowing) management should be about protecting the potential, not fixing problems – monitor well, evaluate the return, and be timely and effective.

Business profit drivers and scope for improvement

Several recent studies of commercial farm businesses emphasise the dramatic changes in the economics and risk of grain farming in recent years as cropping intensity has increased. As farm size, cropped area and land values increased, so too have debt levels, machinery costs and total interest, so that despite improvements in productivity, farm income to cost ratios have decreased significantly. However, the fact that the top 25% of grain businesses make double the return on capital (8.8%) as compared to the other 75% (4.5%) (ABARES 2015), emphasises the point that *"it is not what you do, but how well you do it"* that defines the success of most farm businesses. Numerous recent studies of the key drivers of successful businesses emphasise three important areas – (1) agronomic and technical; (2) business and financial and (3) people and relationships (e.g. Hillicoat *et al*., 2018) and they make important reading. As a farming systems agronomist, my talk will focus on the agronomic and technical, where a consistent message in studies of successful intensively cropped farms (in addition to sound financial management) is the importance of more frequent monitoring and measurement to assist in management decisions, and timeliness in implementing them.

Recent national studies of "yield gaps" between the water-limited potential of crops and those achieved by farmers suggest there is significant scope for improvement – including in the central west, where wheat and canola crops achieved around 50-60% of water-limited yield potential for the years 1990 to 2015 (www.yieldgapaustralia). Field studies investigating the economic performance of a range of different 3-4 year crop sequences and management suggest differences in the average annual gross margin of up to $400/ha between the best and worst sequence and management options, and $150/ha between the best and common district practice. Thus there appears to be significant scope to improve management for increased profit – but what are the key decisions that can provide the biggest “bang for the buck”, while managing business risk? Here we provide a framework to consider them, and evidence for their impact using examples from the central west, or nearby environments on red soils where possible.

Management levers for high efficiency and profit – at paddock and farm scale

No one technology – be it a new variety, tillage system, new machine, or fertiliser – will alone close existing yield gaps to maximise yield and profit. Highly efficient systems must combine several pre-crop and in-crop management strategies that only together can capture, store and use water most efficiently (Figure 1). It is convenient to discuss them alone to consider the scale of the response possible – but the key message is that maximum efficiency is only achieved when they act together.

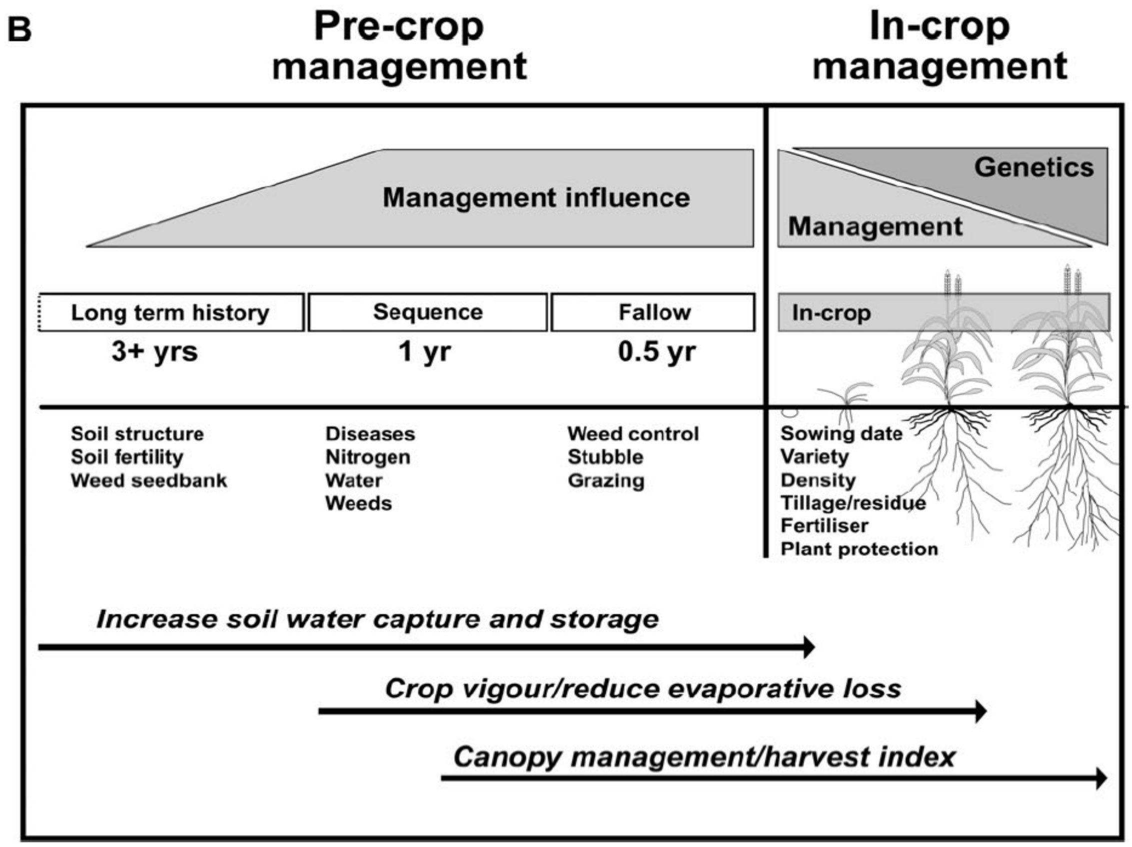

Figure 1. Using water efficiently requires a combination of pre-crop and in-crop management to capture, store and use water to produce grain. No single management factor alone drives efficiency and much of the effort occurs well before seeding (from Kirkegaard and Hunt 2010).

1. Long-term soil management

Long-term management decisions can affect the capacity of the soil to capture, store and supply water to the crop. Some examples include:

Soil structure: Pasture phases, maintaining cover (stubble, cover crops), no-till, controlled traffic (CT) and gypsum on sodic soils all act to maintain stable soil structure for maximum water capture and storage. Many red soils in CNSW are prone to hard-setting and crusting if excessively tilled or left bare.

Weed seed banks: Pasture phases, diverse rotations, hay, herbicide rotations, and inclusion of non-herbicide weed management tactics such as harvest weed seed management, all act to keep weed seed banks at low levels.

Nitrogen (N) fertility: Inclusion of legumes (pasture or pulses), increased N fertiliser and more efficient N use will preserve long-term soil fertility.

Sub-soil constraints: On red soils, soil acidification is inevitable without regular addition of lime, and sub-surface acidity (5-15 cm) due to insufficient incorporation is an emerging issue.

Flexibility may be required to deal with short-term issues (e.g. strategic tillage, stubble reduction, consecutive cereals) but these are of little consequence provided a longer-term strategy of sound soil management is maintained.

2. A suitably diverse crop sequence

System choice: Economic modelling to compare continuous cropping and mixed farms at low rainfall sites in southern Australia including West Wyalong show that while continuously cropped farms and mixed farms may have similar profitability in average seasons, the continuously cropped farm was able to better capitalise in good seasons, but were at greater risk in poor seasons (Analysis by Ed Hunt, Michael Moodie and Mallee Sustainable Farming). Less diverse, continuously cropped farms (i.e. 100% cereal) had the lowest economic performance in all but the very best of seasons, supporting much of the experimental data related to the benefits of diversity.

Crop sequences: Crop sequences in central NSW remain cereal-dominated (~80% cereal), and this increased to 93% during the millennium drought (2002-2010) when limited early sowing opportunities and dry springs increased the risk of legume and oilseed break crops. GRDC-funded research in several projects confirmed that in all areas including CWNSW and other low rainfall sites, crop sequences that were more diverse were as profitable, or more profitable, than continuous cereal rotations – and that diversity in both crops and practices (graze, hay, brown manure) were required to cost-effectively manage paddocks with herbicide resistant weed or disease problems (http://www.farmlink.com.au/project/crop-sequencing). In a range of experiments over the last 5 years, the most profitable crop sequences often made $450/ha more annual average gross margin than the worst, and around $150/ha more than common district sequences (Peoples *et al.*, 2015). Predicting the longer-term economic benefits is difficult as the weed and disease control benefits of diverse sequences are not captured by farming systems models such as APSIM, which focus on water and N.

Fallow: Long-fallowing is still used to manage production risks associated with cropping in central and south west NSW's variable climate. Fallows comprised 25-30% of farm area between 2000 and 2010, but with more favourable seasons this has now declined to 5-10%. Fallowing can provide benefits at the whole-farm level by compressing the sowing window allowing more crops to be sown on time, and reduce risk in specific crops by provided stored water and N. In theory, long fallowing and early sowing are complementary practices, as the fallow reduces weeds and diseases which can be difficult to control in early sown crops, and early sowing with slow developing cultivars allows the crop to better use soil water and N that is stored during the fallow. Stored soil water also helps to establish early sown crops when there is minimal autumn rainfall.

3. Summer fallow management – weeds, stubble and stock

Weeds: In a national study on the potential value of summer rainfall (Hunt and Kirkegaard, 2011), the red soils of central west NSW had some of the greatest predicted opportunity to capitalise on summer rainfall to produce grain because:

a) equi-seasonal rainfall means there is significant rain to store in summer;

b) the red loam soils have good water-holding capacity; and

c) dry and variable springs mean the stored water is extremely valuable to fill grain.

Preserving summer fallow rain through strict weed management and retained stubble was predicted to contribute 58% of wheat grain yield (0.5 to 2.0 t/ha) and be profitable in 91% of years. In a subsequent series of experiments in the central west (2010 to 2012, Haskins and McMaster 2010; Kirkegaard et al., 2014), strict summer weed control increased the amount of stored water by 48mm at sowing, and mineral N by 59 kg/ha, increased yield by 1.1 t/ha with a return on investment of $6.45 for every $ spent. Delayed or missed sprays could halve the percentage return on investment (ROI) by reducing the water and N available to crops, but were always preferable to not spraying at all.

Stubble: Maintaining stubble cover to protect soil structure, increase infiltration and water storage over summer is accepted practice. The main decision in regard to the need to manage, reduce or remove stubble prior to sowing, is to ensure effective and timely seeding. At least 3 t/ha of cereal residue (70% cover) is required over summer to capture most of the benefits of stubble in the majority of seasons. Heavier stubble loads can increase the duration of soil water storage in the surface by slowing evaporation, but the benefits for early sowing depend on the timing of rainfall at sowing. A good policy is to retain stubble whenever you can, but manage it to ensure a timely seeding operation and good weed control.

Livestock: Recent studies on red soils at Condobolin and Temora have shown that light grazing of stubble in summer has little impact on water storage or the yield of subsequent crops, provided sufficient cover (70%, >3 t/ha) is retained on the soil surface. On the contrary, the yield of some crops increased due to increased soil mineral N after grazing stubble in some seasons. Consequently whole-farm income is generally unaffected or improved by careful stubble grazing. Overgrazing is the bad decision – *"sheep do damage with their mouths, not their hooves!"*

4. Fit crops to the growing season – variety and sowing time management

Good fallow management will increase the opportunities for well-prepared growers to capitalise on early and timely sowing opportunities, as the crops can be sown and established into water stored from the summer fallow rainfall. The need to sow on time to ensure flowering occurs at the optimum time to maximise yield potential is widely recognised, with at least 5% reduction in yield potential for every week delay past the optimum sowing date. As autumn rainfall declines and sowing programs increase, the sowing window for common fast-maturing spring varieties is being stretched. Establishing crops earlier on stored moisture can increase yield at the paddock scale if suitable varieties with appropriate phenology are used (Table 1). Some recent examples are shown in Tables 1 and 2.

In 2014, Wedgetail⟑ sown 17 April after long fallow out-yielded Suntop⟑ (at that time the highest yielding milling cultivar in SW NSW NVT) sown 22 May by 1.4 t/ha. In 2015 Wedgetail⟑ sown 15 April after fallow, out-yielded Condo⟑ (at that time the highest yielding milling cultivar in SW NSW NVT) by 1.5 t/ha (Hunt et al., 2015) (Table 1). As new, slower-maturing varieties (e.g. Kittyhawk⟑, Longsword⟑) are developed, more opportunities to capitalise on early sowing will emerge.

Table 1. Yield of early-sown, slow maturing varieties compared with later-sown fast maturing varieties sown after long fallow at Rankin Springs in 2014 and 2015.

Variety	2014 Grain yield (t/ha)			2015 Grain yield (t/ha)	
	Sowing date			Sowing date	
	17 April	22 May		15 April	14 May
Wedgetailⓓ	5.8	4.6		6.2	4.9
Eaglehawkⓓ	4.4	4.4		5.1	4.5
Gregoryⓓ	4.0	4.9		5.3	4.0
Suntopⓓ/Condoⓓ	4.0	4.4		3.0	4.7
LSD (P<0.05)	*0.4*			*0.5*	

For canola in the tough 2017 season at Condobolin, the slower developing variety Wahooⓓ sown early (6 April) after good fallow rainfall (313mm), had double the yield of the faster maturing variety Stingrayⓓ under both dry conditions (122 mm growing season rainfall) and when rainfall was supplemented with 150 mm irrigation (272 mm growing season rainfall) (Table 2) (Brill *et al*., 2018).

Table 2. Yield of earlier-sown slower maturing canola variety was superior to later-sown fast variety even in the tough 2017 season at Condobolin at 0.5 to 1.6 t/ha yield levels (see Rohan Brill related paper).

Variety	2017 (Dry) Grain yield (t/ha)			2017 (Wet) Grain yield (t/ha)	
	Sowing date			Sowing date	
	6 April	20 April		6 April	20 April
Stingrayⓓ (fast)	0.4	0.4		0.7	1.0
Wahooⓓ (mid-slow)	0.9	0.8		1.6	1.6

Success with early sowing requires good paddock selection and preparation, and ensuring the right variety is chosen that will flower at the optimum time for the selected sowing time. A recent e-booklet providing *Ten Tips to Early-sown Canola* can be accessed at: https://grdc.com.au/10TipsEarlySownCanola.

On mixed farms early-sown crops also provide opportunities for grazing to further increase profit. Best-bet management guidelines are available for grazing crops, but the key decision is the lock-up time https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/managing-dual-purpose-crops-to-optimise-profit-from-grazing-and-grain-yield-north.

Careful timing of livestock removal prior to the elongation of stems (cereals) or buds (canola) and with sufficient biomass to achieve the target grain yield are key to profitable outcomes. High stock prices compared to grain may favour prolonged grazing.
"Luck is when opportunity meets preparedness."

5. Managing nitrogen well

Without adequate N, the yield and profit potential established with good sequence, fallow and sowing operation management will not be realised. Attention to the long-term N fertility has been covered in Item 1 in this paper. Persistent low protein in cereal crops (<10%) and pre-sowing soil N of < 50 kg/ha in the top 60cm may be signals of N-rundown, and a trigger for legume inclusion or increased N rates. Nitrogen is a significant input cost and a driver of yield (and quality) in non-legume crops and the general "4R principles" promoted by IPNI (right product, right rate, right time, right place) should be adopted (http://www.ipni.net/4R). In most cases the following basic decisions will assist:

- Soil test March-April.
- If < 40 kg N/ha (0-60cm) apply some upfront N, especially if soil water store is good, crops are sown early for grazing, and especially for canola. Separate seed and fertiliser.
- Most N can be top-dressed at stem elongation according to seasonal conditions and yield targets, at rates to ensure the total mineral N supplied to the crop (soil + fertiliser) is 40 kg/ha per tonne of expected wheat yield; 35 kg/ha/t for barley and 80 kg/ha/t for canola. Relying on soil mineralisation for N makes sense in the short-term, but will run down soil fertility in the longer-term if legume pastures and crops are not included.

In central west (CW) NSW, seasonal uncertainty means N management is more about farm finances than agronomy. What are the consequences of not getting a return in the current season? Target crops where the return on investment is most likely – weed-free, sown on time, following a good break. If you err on the side of too much N, remember canola is less likely to hay-off than wheat and much of the N will remain in the system.

6. Crop protection – in-crop "fine tuning" with weeds and disease

Good long-term soil, crop sequence, fallow management, variety choices and harvest weed-seed management will mean that in-crop management of weeds and diseases often becomes a matter of cost-effectively protecting the yield when necessary with good monitoring and sound economic decisions. One exception is the longer term focus on running down the weed seedbank, which requires monitoring and weed management action to minimise weed survivors every year in every paddock. The management of most diseases (e.g. rust in cereals, blackleg in canola, Ascochyta in chickpea) involve a series of integrated approaches over time (residue management, variety choice, fungicide programs). Some decisions (seed dressings) are cheap insurance, while some such as later canopy fungicide sprays require careful assessment of the likely costs and return. Unlike nitrogen, there is no chance to recoup costs from unnecessary crop protection inputs, as there are no residual benefits beyond the active period. So prepare well, monitor well, be realistic about your yield potential and response to treatment, and be timely and effective with the application.

Capturing the synergies from the system

Whole-farm multipliers: Do the yield increases at paddock-scale (Tables 1 and 2) in one year translate to the whole farm, and across seasons? The capacity to start the farm sowing program earlier with slower-maturing crops provides a multiplying effect across the farm in any particular year, as all paddocks move into a better sowing window, and the sowing program is completed earlier. The benefits in specific years for a typical 20-day sowing program can be significant and are generally higher on deeper soils in higher rainfall areas, but diminish on shallow soils, and as you move from southern to northern NSW. The central west is a transition area, but increases in estimated whole-farm wheat yields for a site such as Condobolin by sowing slower maturing wheat varieties when the opportunity arises on a red soil with 200mm PAWC to 1.6m, is estimated to be 5 to 17% (Flohr *et al*., 2018).

Legacy effects: But will the higher yielding crops simply "steal" water from following years – how often will the profile re-fill?. In the last 5 to 10 years, novel early sowing systems involving slower-maturing varieties suited to earlier sowing have been developed. In CW NSW, wheat varieties such as Wedgetail have provided such options for some time, but newer wheat and canola varieties with appropriate agronomy packages are currently in development. The most recent experimental and simulation evidence (Hunt *et al.,* 2018; Flohr *et al.*, 2018) suggest that capturing opportunities to sow early when they arise, especially with longer coleoptile, fast maturing winter wheats could provide a further boost to farm productivity by using more of the season and more of the soil. Sequences with forage legumes or fallow provide stored water and N that can boost subsequent wheat yields (Table 3). Such varieties, now in development can be sown deep into stored water in March and established on stored summer rain (rather than waiting for an autumn break) and have a stable optimum flowering window due to vernalisation requirement that stabilises flowering irrespective of sowing time. Table 3 shows the predicted average yield benefit for a 20 day sowing program for these novel wheat types at Condobolin, as compared to existing spring wheat sown late April to mid-May. The early sowing can especially capitalise on the water and N saved by previous legumes or fallows.

Table 3. The predicted average wheat yield for novel, long-coleoptile wheats sown from 15 March in different rotations, as compared with the current baseline of spring wheat sown from 29 April for a typical 20 day sowing program at Condobolin (from Flohr *et al.,* 2018).

Cropping system, wheat variety and management	**Mean wheat yield (t/ha)**
Continuous spring wheat, short coleoptile, sow from 29 April (Baseline)	2.3
Continuous fast winter wheat, long-coleoptile, sow from 15 March	3.1
As above, rotation with forage legume	3.5
As above, rotation with long-fallow	4.0

The increased efficiency predicted by these novel systems involving earlier sowing systems are now being tested at paddock and whole-system scale in GRDC funded projects CFF00011 and ULA9174837.

Conclusion

Evidence suggests that with combinations of current, best practice management technologies, focussed on the cost-effective capture, storage and use of rainfall, significant increases in whole-farm productivity, efficiency and profit are possible. New wheat and canola varieties with flexible sowing windows that maintain optimum flowering times will provide an excellent additional tool to shift whole-farm sowing programs into an earlier and more efficient window in the face of drying autumns and more variable springs. Success requires a combination of decisions that combine to provide a step-change in farm productivity potential with systems that manage the risk in variable climates.

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Analysis of risks and returns for different crop sequences. Climate and financial risks associated with rotations of differing types and intensities

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Key words

crop rotation, crop sequence, gross margin, double crops, economics

GRDC code

CSA00050

Call to action/take home messages

- Intensifying a crop rotation beyond the environmental capability of the site can increase downside risk for minimal economic benefit.
- If your risk of a failed crop moved from 1 crop in 10 to 1 crop in 5, would an annual average increase of $100/ha be worth it? Everyone's risk profile is different so the decision to intensify is personal.
- All environments will provide opportunities to intensify, identifying when and how often these occur is the dilemma.
- Structuring a crop sequence to ensure the highest value crops receive the best opportunity for success can significantly improve sequence productivity.

Introduction

This paper reports on some of the work conducted as part of GRDC's Northern Farming Systems project. One of the goals of this project is to use both experimental research and simulation modelling to understand the benefits and trade-offs associated with different crop rotations across the northern grains region. For this paper we will use the term rotation to mean a sequence of crops and fallows that regularly follow each other in a cyclic pattern. We are aware that not all grain growers follow a structured fixed rotation and we are not advocating this approach. However, by examining rotations in this structured way, key features (benefits and costs) of the sequence can be observed. This paper reports the first step in our process, future work will look at more opportunistic and pure rule based crop selection sequences.

The components of a grain rotation include the crops and the fallows (periods without crops) and aims to maximise returns by achieving yield potentials while minimising the development of crop yield reducing constraints such as weeds and diseases. In addition, most crop rotations are intertwined with herbicide and pesticide rotations used to minimise the development of resistance.

This analysis builds on earlier work that looked at the probability of achieving a crop yield by measuring the soil water at sowing. This work concentrates on matching a rotation (sequence of individual crops) to an environment and the trade-offs between the components of the rotation as crop intensities increase. The ability of the rotation to manage weeds and diseases is not presented as part of this discussion.

Methods

Simulations

This study is a simulation analysis that uses the APSIM systems framework (Holzworth *et al.*, 2015) to simulate crop rotations from historic climate records (1900-2012). APSIM has a long history of simulating northern farming systems (Carberry *et al.*, 2009; Whish *et al*., 2007) and uses environmental signals to trigger appropriate management decisions. However, these simulations only considered the dynamics of water and nutrients. Losses due to waterlogging, heat or frost shock events, disease, pests, weeds or crop nutrition other than nitrogen were not considered by these simulations.

The simulations of all crop sequences were phased, so that each year of the rotation was exposed to each year of the climate record.

Rotations

The rotations presented are a subset of those analysed, and are considered the dominant rotations used across the northern grain region, based on interviews of leading growers and advisers. The rotations used in this discussion cover a range of intensities, but have been restricted to only include the northern region's most commonly grown crops (Table 1).

Table 1. Summary of key management rules applied to crops across the set of simulations

Crop	Sowing window	Minimum planting soil water (mm)	Variety	Row spacing (cm)	Plant density (#/m^2)	Starter fertiliser (N kg/ha)
Wheat	15 May-1 Jul	100	Gregory	25	100	25
Chickpea	1 May-1 Jul	100	Amethyst	50	30	0
Sorghum	15 Oct – 15 Jan	100	Buster	100	7	25
Mungbean (spring)	15 Oct-15 Nov	60	Green Diamond	50	30	0
Mungbean (double crop)	15 Nov – 15 Jan	60				

Table 2. Rotations presented and their cropping intensity measured as number of crops per rotation cycle

Rotation	Rotation code	Crops and rotation length (years)	Intensity (crops/year)
Wheat, long fallow, Chickpea, long fallow	Wx|xx|Chx|xx	2 crops in 4 years	0.5
Sorghum, long fallow, Chickpea, fallow, Wheat, long fallow	Sx|xCh|xW|xx	3 crops in 4 years	0.75
Sorghum, long fallow, Chickpea, fallow Wheat, fallow, Chickpea, fallow, Wheat, long fallow	Sx|xCh|xW|xCh|xW|xx	5 crops in 6 years	0.83
Sorghum, fallow, Sorghum, fallow Sorghum, long fallow, Chickpea, fallow, Wheat, long fallow	Sx|Sx|Sx|xCh|xW|xx	5 crops in 6 years	0.83
Wheat, fallow, Wheat, fallow, Chickpea, fallow	xW|xW|xCh	3 crops in 3 years	1
Sorghum, fallow, Sorghum, fallow, Mungbean, double crop Wheat, long fallow	Sx|Sx|MgW|xx	4 crops in 4 years	1
Sorghum, fallow, Sorghum, double crop Chickpea, fallow, Wheat, long fallow	Sx|SCh|xW|xx	4 crops in 4 years	1
Sorghum, fallow, Mungbean, double crop Wheat, fallow, Chickpea, double crop	Sx|MgW|xCh	4 crops in 3 years	1.3
Sorghum, double crop Chickpea, fallow, Wheat, double crop Sorghum	SCh|xW|Mgx	4 crops in 3 years	1.3

All rotations were run at each of the 6 sites (Table 3) to highlight the importance of matching crop choice and intensity to the environmental conditions. The sites were selected to represent a transect from the summer rainfall dominant north to the more equal summer winter split in the south with representative sites from the more marginal cropping areas to highly productive sites. Each site used a locally representative soil (Table 3).

Table 3. Soil details used in simulations at the 6 locations across the northern grains region

Location	Soil description	APSoil No.	Soil plant available water capacity (PAWC) (mm)				Annual rain
			Wheat	Sorghum	Chickpea	Mungbean	(mm)
Pampas	Black Vertosol	006	290	234	290	211	698
Goondiwindi	Grey Vertosol	220	188	188	167	140	619
Gunnedah	Loam over clay	615	176	203	176	104	620
Mungundi	Grey Vertosol	157	186	201	186	141	505
Coonamble	Sandy clay duplex	247	181	194	181	134	546
Trangie	Medium clay	684	192	207	192	129	498

Economic analysis parameters

Average annual gross margin (GM) analysis was conducted for each phased crop sequences using the equation below. Long-term average grain prices (2008-2017) and current variable input prices were used and these were held constant across all locations. Insurance and levy costs together were 2% of the grain income value and were deducted from grain prices. The price for nitrogen (N) fertiliser applied was set at \$1.30/kg N and each fallow spray was set at \$17/ha excluding GST. The simulations did not account for application losses of N fertilisers; therefore, an additional 30% of applied N was used to ensure fertiliser N reached the soil mineral N pool. The baseline “variable cost” for each crop included planting, non-N nutrients and in-crop pesticide applications. Harvesting costs, N fertiliser and fallow spray frequency were included separately, as these varied between the crop sequences or if crops failed. Crops were considered as failed if the yield was less than the thresholds (Table 4) and harvesting costs were not included. Machinery costs were based on an owner-operated production system; therefore, fuel, oil, repairs and maintenance (FORM) costs where included in the variable costs.

$$GM_{seq}(\$/\mathrm{ha/yr}) = \frac{\sum\{(\mathrm{Grain\ yield} \times \mathrm{price}) - (\mathrm{kg\ N} \times 1.3) - (sprays \times 17) - \mathrm{variable\ costs} - \mathrm{harvest\ costs}\}}{no.of\ years}$$

Table 4. Crop prices and variable costs used in gross margin calculations for crop sequences

Crop	Average price (\$/t)#	Harvest cost (\$/ha)	Variable costs (\$/ha)	Failed crop threshold (kg/ha)
Wheat	264	40	175	500
Sorghum	225	55	218	800
Chickpea	569	45	284	340
Mungbean	710	55	276	300

#*farm gate price with grading & additional harvesting costs already deducted*

Do higher intensity sequences increase gross margins?

One strategy of improving profitability is to increase the number of crops grown and reduce the number of fallows. This increasing intensity aims to use water that would otherwise be lost through drainage or evaporation to improve system water use efficiency and increase profitability. However, this idea depends on exploiting slack in the current system. One fear with intensification is that inefficiencies within the system, which can work as a buffer from seasonal variability, are lost resulting in similar or lower profits for more work (ie more crops, more work, greater risk but similar returns).

Our initial analysis looks at the annual gross margin for each sequence at each site (Figure 1). The most conservative crop sequence long-fallow, wheat, long-fallow, chickpea, (Wx|xx|Chx|xx) lies on the left hand side (lowest GM) of the gross margin exceedance plot for the highly productive environments (high rainfall and/or high soil PAWC) of Pampas and Gunnedah. Yet as we move to areas with lower average rainfall and soil PAWC, this conservative approach is only on the left side (lowest GM) (bottom half of the figure 25% Mungindi, 38% Coonamble, 25% Trangie) more productive wetter years. Moving from the top of the figure to the bottom reflects a ranking of the cropping seasons from worst to best. It is important to note that the conservative approach does not produce a negative annual gross margin at any site in any season.

The aggressive strategy of the high intensity cropping 1.3 crops per year (SCh|xW|Mgx, Sx|MgW|xCh) produce the greatest gross margin in environment with good water supply (large PAWC or rainfall, (Pampas, Gunnedah) and for more than 50% of seasons at the other sites – but what was the cost?

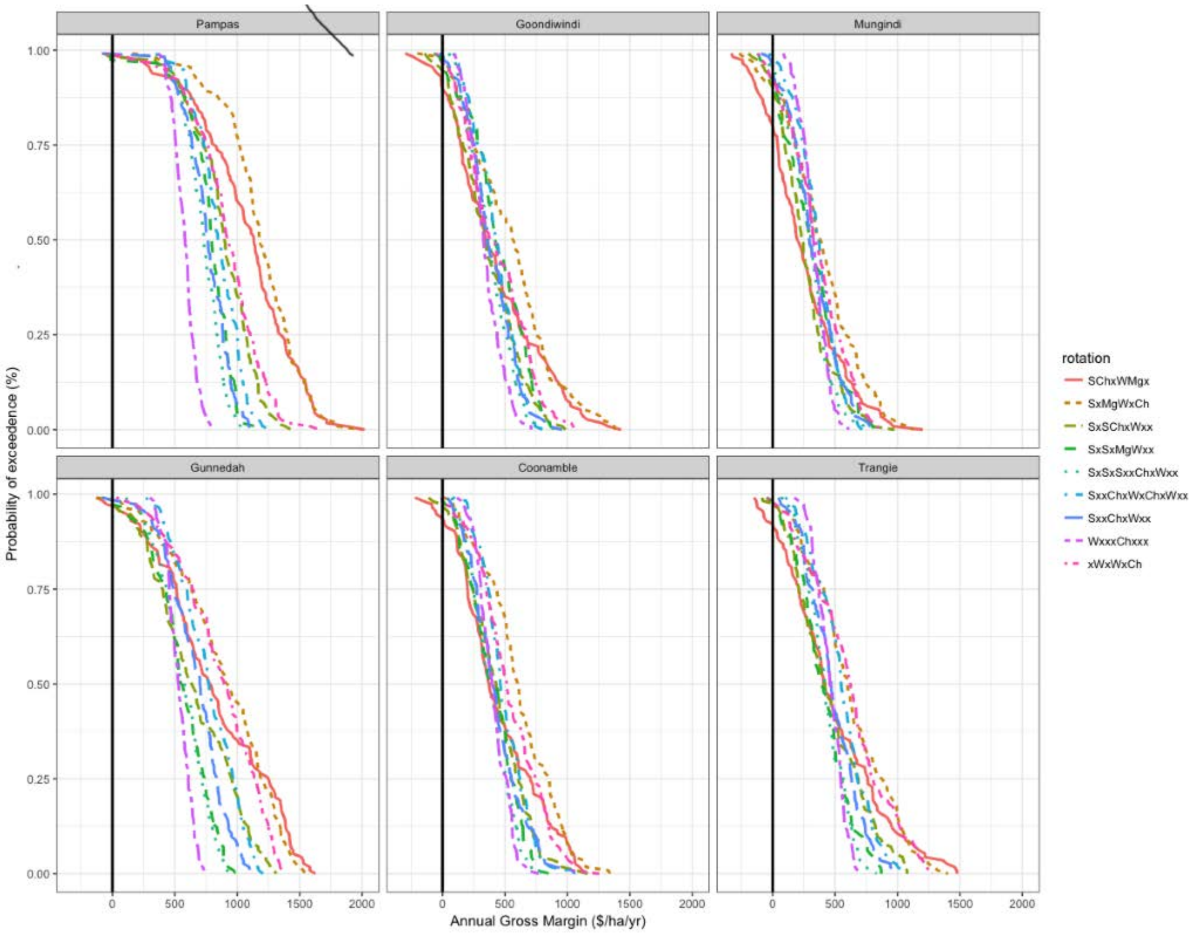

Figure 1. Comparison of the nine crop rotations examining their probability of exceeding an annual gross margin. The solid black line marks the zero gross margin point with negative gross margins occurring to the left of this line.

Should I increase my cropping intensity?

Gross margin is only part of the story; the use of a diverse rotation has many practical and logistic considerations beyond the scope of this presentation. However, increasing the intensity of cropping has risks. One way to consider this risk is to look at the variability of the gross margin (Figure 2). If the variability (or standard error) around the average gross margin is large, then the potential for a boom bust pattern increases. If the variability is low, then gross margins are more stable over time.

Fitting a boundary curve to data highlights those rotations that have the highest gross margin for the least risk. As you move along the boundary towards the top of the curve, the mean gross margin tends to increase as does the risk. Once you pass the top of the curve or move to the right of the line, risk increases but returns do not. This figure also shows how the different environments favour rotations with different patterns. The northern summer dominant patterns favour sequences with summer crops while winter dominated rotations are favoured as you head south (Trangie).

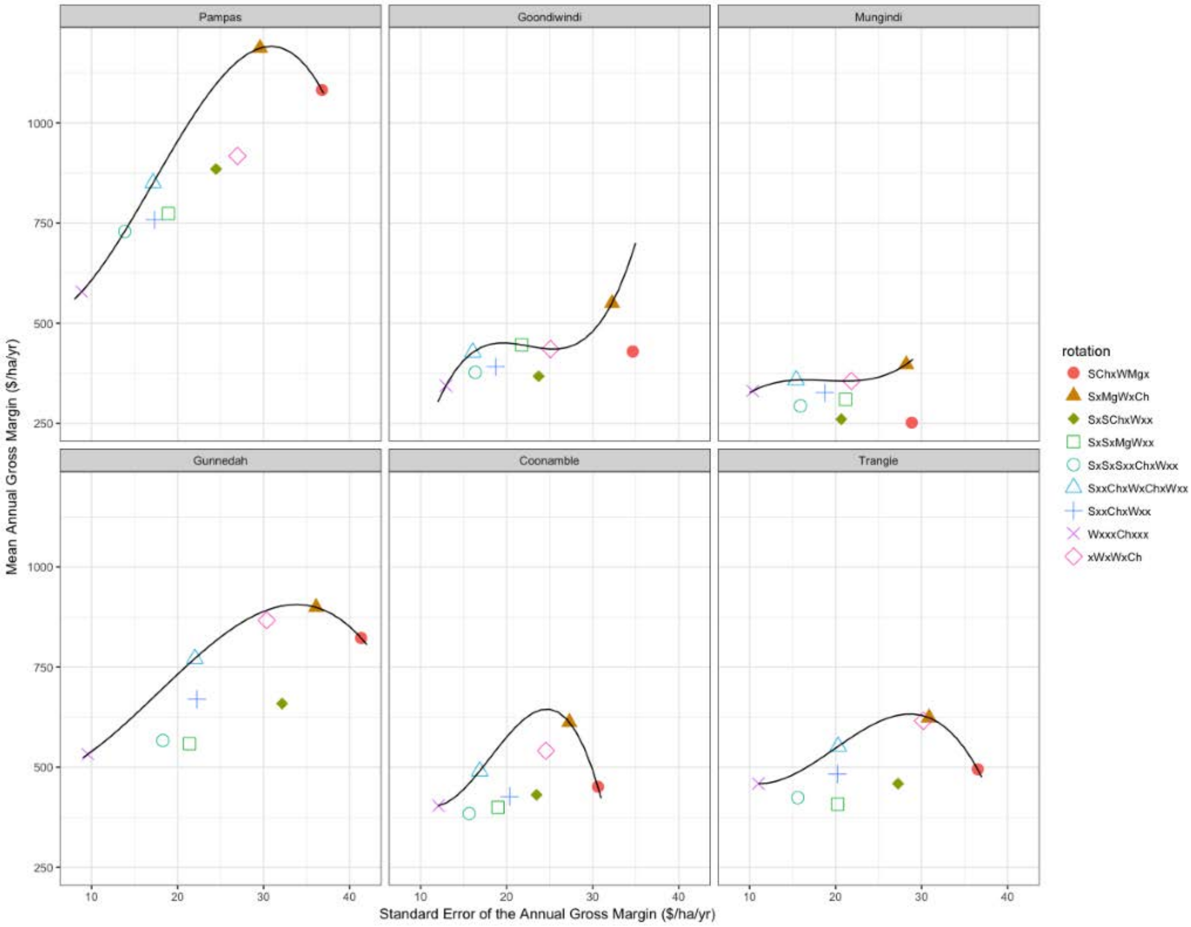

Figure 2. Mean annual gross margin compared to the standard error of the mean annual gross margin. The solid line represents the boundary between increasing returns and increasing variability (risk) around the gross margin mean.

One difficulty with thinking about risk in this statistical way is the standard error does not discriminate between upside and downside risk. An alternative approach is to look at the number of failed crops that may occur (Figure 3). For this analysis a crop was considered to have failed if it generated a negative or zero gross margin. The shape of the boundary fitted to the point where gross margin is maximised and crop failures are minimised, highlights the potential resource supply of the different environments. For example, in Gunnedah swapping from a (SCh|xW|Mgx) to (xW|xW|xCh) will result in similar annual gross margin. The greater supply of water (rainfall and/or PAWC) at Pampas and Gunnedah increase potential yields with few crop failures, less than one crop in 10 failing for most rotations, including the intensive 1.3 crops/year (SxMgWxCh) rotation at Pampas.

The boundary line for the southern and western sites flattens and lengthens suggesting smaller economic benefit for an increase in potential crop failure (risk). This is particularly apparent at Mungindi where the high intensity rotation would have 1 in 3 crops failing. The benefit of sorghum in northern rotations can also be seen with rotations that have little sorghum being less profitable. In contrast, moving south the rotations with little sorghum have fewer failures.

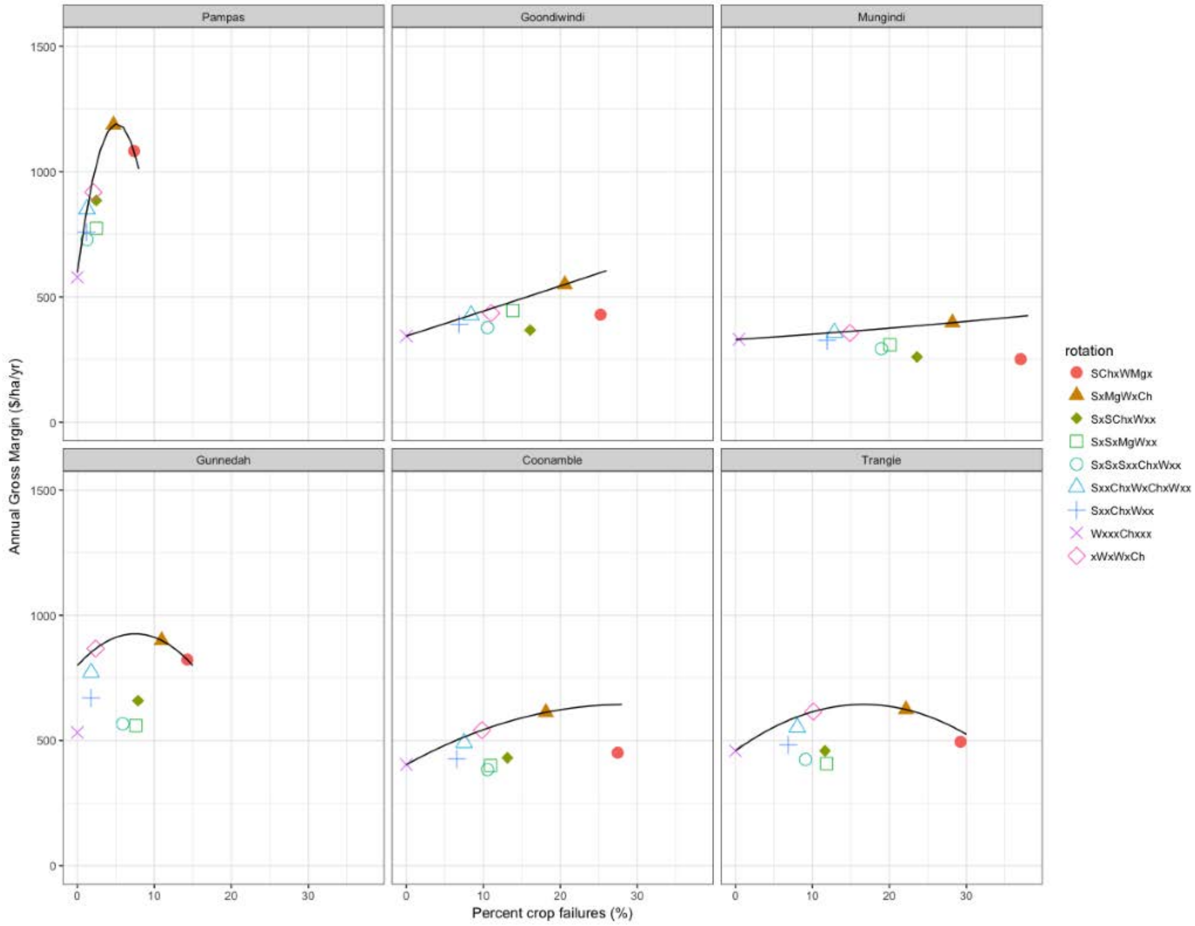

Figure 3. Mean annual gross margin compared to the percentage of failed crops. The solid line represents the boundary between increasing returns and increasing chance of a crop failure

If I increase my cropping intensity will this reduce the amount of water I store during fallows?

The key to understanding the risk of an individual crop in northern farming environments is to know how much water is stored within the soil prior to planting. This same rule applies when examining a sequence of crops within a rotation. The order of different crops within a sequence can have a significant influence on how well water infiltrates into the soil. The increased water infiltration, resulting in increased water storage, following a spring millet cover crop during a long fallow, is testament to this (Whish *et al*., 2009. The level of risk (amount of soil water at sowing) an individual is prepared to take is a personal decision. However, the simulations completed during this analysis aimed to plant following a 20mm sowing rain with 100mm (2ft wet soil in a clay soil) of stored water. If this had not been achieved by the end of the sowing window the crops were planted anyway. This allowed us to see those rotations that regularly planted on good soil moisture and those that planted, and how often they planted, on less than ideal soil moistures (Figure 4). A clear difference can be seen between those sites that had a soil with high PAWC and an environment that provided sufficient rainfall to refill the soil. The high intensity systems reduced the initial soil water for all crops. Progressing to the dryer environments of Condobolin and Goondiwindi the more conservative rotations regularly, > 70% of the time, had more than 100mm of stored water at sowing, but as cropping intensity was increased this declined to less than 50 %.

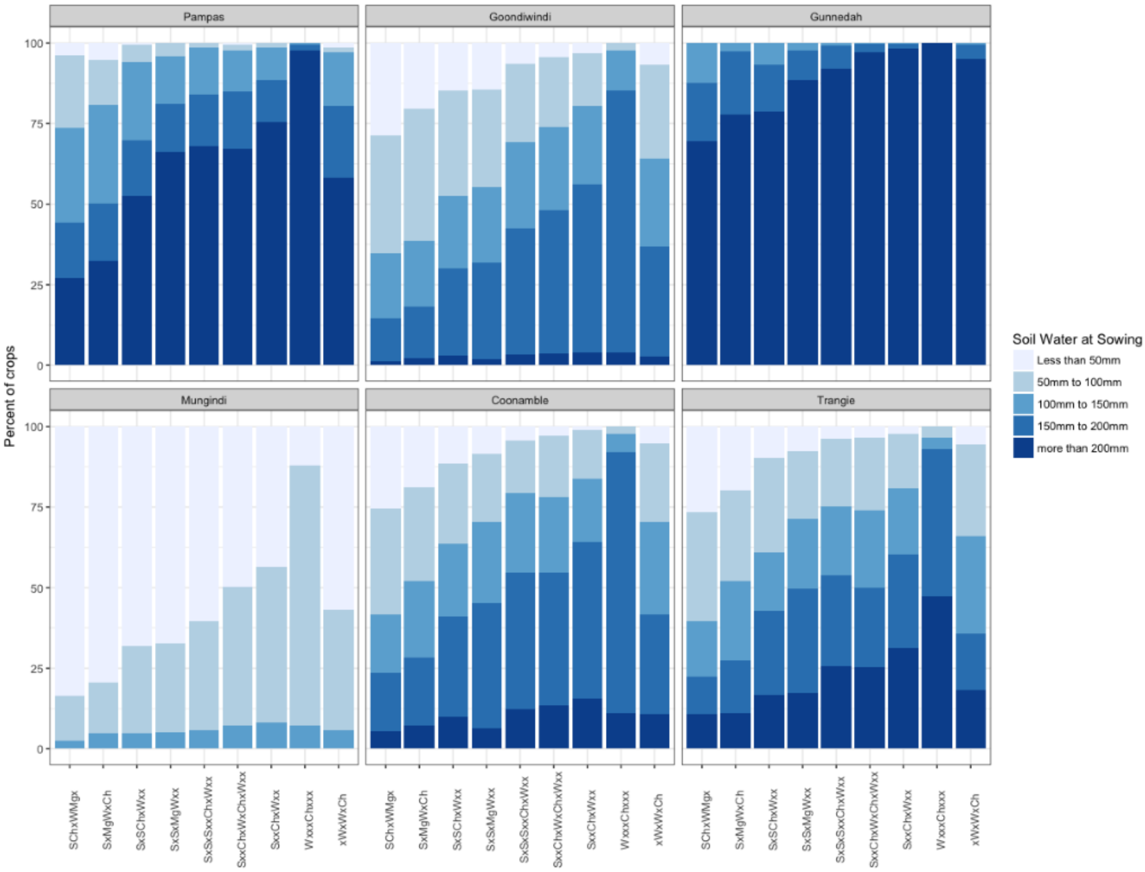

Figure 4. Percent of crops within a rotation sown on a set soil water range (less than 50mm, 50 to 100mm, 100-150mm, 150-200 mm and more than 200mm)

Conclusion

Will increasing the cropping intensity improve returns? The short answer is yes, but risk may also increase. Therefore, before making changes a detailed knowledge of the farm environment and its location is required. Alternatively, increasing the cropping intensity does not have to mean a significant change to an existing rotation. We are currently conducting simulation studies looking at opportunistically including additional crops within the rotation when conditions are favourable. This approach could more accurately be described as tactically including fallows when conditions are unfavourable. Nonetheless, recognising that each crop will have consequences for those crops that follow it is an important decision when aiming to reduce negative and increase positive consequences across the sequence.

Intensification can increase returns, but this increase needs to be placed in context with the known trade-offs, potential for failed crops, increased work load, additional grain storage needs, and logistic and management concerns. Looking at the annual gross margins (Figure 1) the highly productive environments (high rainfall, high soil PAWC) had the widest spread between the different rotation options for the greatest number of years. The rotations at the other sites were similar (little spread) for 50% of the time and then began to separate in the more productive (wetter) seasons, suggesting that intensification is valuable during this time only. Identifying productive seasons at sowing is not possible, but using simple soil water rules may help predict them. A future analysis will compare the benefits of a fixed rotation to those of a structured opportunistic rotation that uses soil water to try and predict the more productive seasons.

One interesting observation from this study is the comparison of the two high intensity rotations. One used the pulses (mungbean and chickpea) as double crops to swap between seasons, the other ensured the pulses were always planted following a fallow and the cereals (wheat and sorghum) became the double crops. The difference in gross margin between the two, highlight how restructuring an existing rotation can improve returns without changing intensity. Shifting the focus within a rotation to ensure the most valuable crop receives the greatest opportunity for success is one way to increase profitability without forsaking the good agronomic practices of the rotation.

The reliability of the ultra-conservative long-fallow wheat long-fallow chickpea in the more marginal cropping regions offers the notion of a base rotation which can be intensified when the opportunity arises; this allows the cropping intensity to match the variability of the environment. However, this approach requires strict rules to ensure the lure of high prices for specific crops does not negate good agronomic principles.

This study has focused on the biotic factors of water, temperature, and nitrogen supply, to look at the productivity of different crop rotations. As acknowledged earlier, there is far more to the design of a rotation than looking at which sequence uses resources efficiently. However, it is hoped that by providing insight into how a rotation interacts with its environment, better decisions can be made to improve the resilience and productivity of crop sequences.

Acknowledgements

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The effects of stubble on nitrogen tie-up and supply

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GRDC code

CSP00186, CSP00174

Call to action/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 ~6% of the N requirement of crops is derived from stubble.
- N 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 0.3 to 0.4 t/ha.
- Management is reasonably straightforward – supply more N (5 kg 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 in stubble-retained systems.

Background

Most dryland farmers 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*., 2017). One such situation is where large amounts of retained stubble, especially high carbon (C):nitrogen (N) ratio cereal stubble, "ties-up" soil nitrogen 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 we firstly review in simple terms the process of N tie-up or immobilisation as it is known, to understand the factors driving it. We then provide the results from a series of recent experiments in southern NSW (both long-term and short-term) that serve to illustrate the process, and the ways in which the negative consequences can be avoided while maintaining the benefits of stubble.

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

Farmers are always growing two crops – the above-ground crop (wheat, canola, lupins etc) is obvious, but the below-ground crop (the microbes) are always growing as well; and like the above-ground crop they too need water, warm temperatures and nutrients to grow. There's as much total nutrient in the microbes/ha as in the mature crop, and 2/3 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 their source of energy (carbon). Secondly they don't live as long as crops – they can grow, die and decompose again ("turnover") much more quickly than the plants – maybe 2-3 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 carbon in residues and root exudates – but they need mineral nutrients as well. Over the longer-term the dead microbe bodies (containing C, N, P, 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 5th April with 8 t/ha of undecomposed standing wheat stubble from the previous crop after a dry summer. A 30 mm 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 the 'bud visible growth stage' due to the dry subsoil.

In this case, the cereal stubble (high carbon and low nitrogen – usually ~90:1) is well mixed through a warm, moist soil giving the microbes maximum access to a big load of carbon (energy) – but not enough nitrogen (microbe bodies need a C:N 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 (so carbon is lost from the soil). 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 nitrogen 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:

1. The stubble load could be reduced by baling, grazing or burning (less C to tie up the N).
2. If the stubble was from a legume or canola rather than cereal (crop sequence planning) it would have lower C:N ratio and tie up less N.
3. The stubble could be incorporated earlier (more time to move from immobilisation to mineralisation before the crop is sown).
4. N could be added during incorporation (to satisfy the microbes and speed up the "turnover").
5. 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).
6. A different seeder could be used that can handle the higher residue without incorporation (less N-poor residue in the soil).

7. 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 (CSP00187, CSP00174), we have been investigating the dynamics of N in stubble-retained systems. Here we provide examples from recent GRDC-funded experiments in southern NSW, and discuss the evidence for the impact of immobilisation and provide some practical tips to avoid the risks of N tie-up.

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 0.3 t/ha in stubble retained *vs* 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, we were not convinced N tie-up was an issue (though we had insufficient measurements to confirm it).

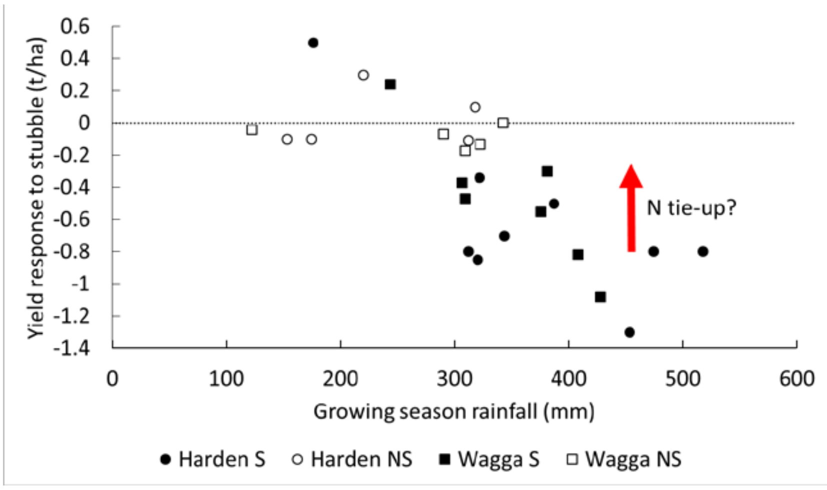

Figure 1. Effect of retained stubble on wheat yield is worse in wetter seasons at the Harden (circles) and Wagga (squares) long-term tillage sites. Open symbols where difference between retain and burnt were not significant (NS), solid where significant (S).

In 2017, we implemented two different experiments in sub-plots at Harden to investigate the potential role of nitrogen tie-up in the growth and yield penalties associated with stubble. A crop of wheat (cv. Scepter⁽ᵇ⁾) 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 we compared 50 or 100 kg N/ha broadcast as urea at sowing in one experiment, and compared the 100 kg N/ha surface applied with 100 kg/N deep-banded below the seed. The pre-sowing N to 1.6 m was 166 kg N/ha in retained and 191 kg N/ha in burnt, but was not significantly different. Plant population, growth and N content at GS 30 did not differ between treatments (data not shown) but by anthesis, the biomass and tiller density were significantly increased by the additional 50 kg/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 (0.6 t/ha) than stubble burnt presumably due to improved 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.

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*

Deep-banding the N fertiliser had no impact on crop biomass or N% at GS 30, 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 (38 kg N/ha *cf* 15 kg 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. It's 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.

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*

Temora site

At Temora, a 9-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, nitrogen and crop growth. In the stubble retain 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 7-10 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 5 kg/ha N was applied at sowing and N was top-dressed at Z30 to attain 70% of maximum yield potential according to Yield Prophet® (see Swan *et al*., 2017 for full details).

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 9 years, but consistently reduced the yield of the second wheat crop by an average on 0.5 t/ha (Table 3). This yield penalty was associated with an overall significant reduction in pre-sowing soil mineral-N of 13 kg/ha, while there was no significant difference in pre-sowing N for the first wheat crop (Table 4).

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. * shows where significantly different (P<0.05)

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*

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*	

Grazing

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

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. * shows where significantly different (P<0.05)

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***	*2.3*

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 we believe 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.

Table 6. Effect of deep banding vs surface applied N (122 kg N/ha as urea) at seeding, at Temora NSW in 2016 (starting soil N, 58 kg/ha). The crop captured more N early in the season which increased biomass and yield in a very wet season. (Data mean of 3 stubble treatments). *indicates significant differences (P<0.01). (Data source: Kirkegaard et. al., CSIRO Stubble Initiative 2016 CSP00186)

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*

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 50 kg N/ha applied at sowing completely removed the early 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 N for crops

Studies at 3 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 55 kg/ha of N contained in 7.5 t/ha of retained wheat residue retained in 2014, only 6.6 kg/ha N (12 %) was taken up by the first crop (representing 12 % of crop requirement); and 5.6 kg/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 (19.1 kg N/ha or 35%) and some remained as undecomposed stubble (10% or 5.5 kg 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 50 cm, denitrified). In similar work carried out in the UK which persisted for 4 years, crop uptake was 6.6%, 3.5%, 2.2% and 2.2% over the 4 years (total of 14.5%), 55% remained in the soil to 70 cm, 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.

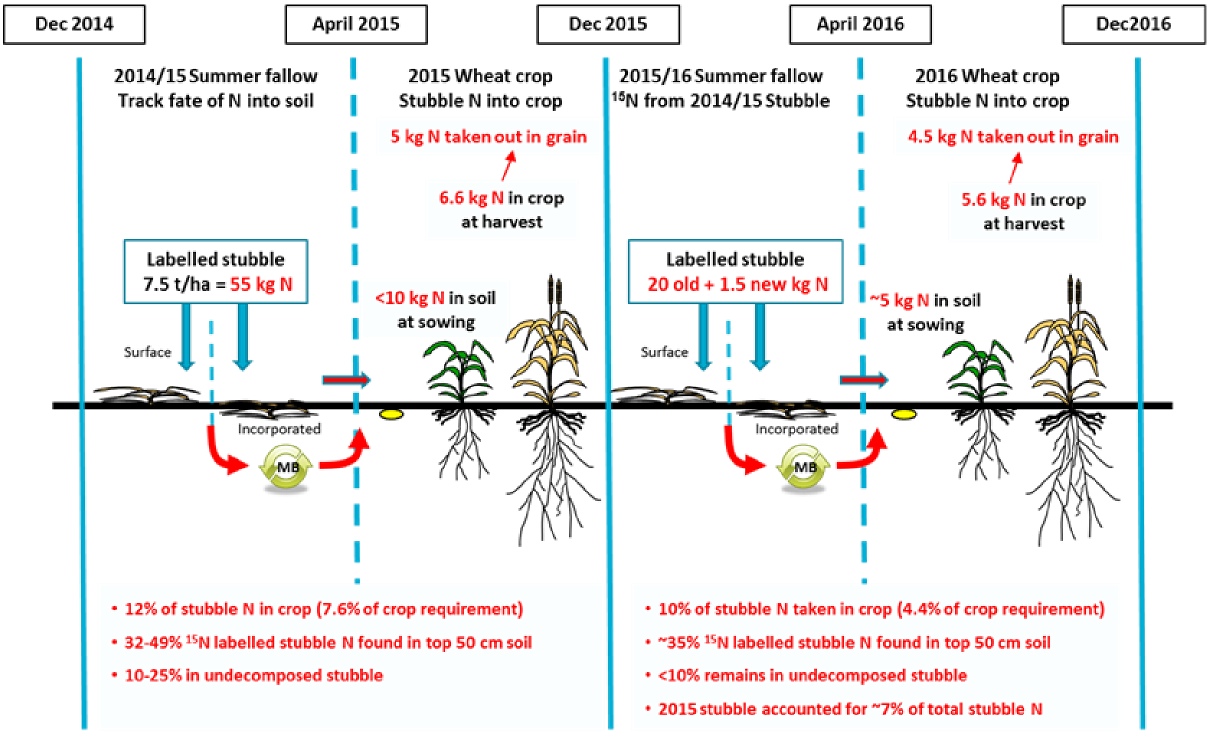

Figure 2. The fate of the N contained in retained wheat stubble over two years in successive wheat crops following the addition of 7.5 t/has of wheat stubble containing 55 kg/ha N. The successive crops took up 12% (6.6 kg N/ha) and 10% (5.6 kg N/ha) of the N derived from the original stubble representing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

Conclusion

Our studies have confirmed a risk of N-tie up by surface-retained and standing cereal residues which may occur in-season, rather than during the summer fallow, and so may not be picked up in pre-sowing soil mineral N measurements. Yield penalties for retained residues were significant, but confined to successive cereal crops, and could be reduced by reducing the stubble load or by applying more N (~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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A flexible approach to managing stubble profitably in the Riverina and Southwest Slopes of NSW

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Key words

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CSP00174

Call to action/take home messages

- Don't let stubble compromise the big things (weeds, disease and pest management and timeliness op crop operations).
- Be flexible in your approach to managing stubble.
- Pro-actively manage the stubble for your seeding system and deep band nitrogen (N) at sowing.
- Diversify your crop sequence: Add legumes to rotation with double break to reduce N fertiliser inputs, reduce annual ryegrass (ARG) weed seedbank and be more profitable.
- Options to reduce stubble load include mulching, incorporation + nutrients, baling and grazing.
- If stubbles are too thick to sow through, consider strategic late burn, especially before 2nd wheat crop or if sowing canola into large stubbles. Increase of > 0.5t/ha wheat grain yield in 2nd wheat crop following burning.

Background

Previous studies have highlighted potential negative yield impacts of retained stubble in SNSW (Kirkegaard 1995; Scott *et al.* 2013), but strict no-till advocates recommend retaining all of the stubble to enhance water capture and storage, 'soil health' and crop yields. Over past decades, farmers and scientists have continued to examine a range of methods to flexibly manage stubble to improve profitability. These have included the adoption of minimum till (tine) or zero till (disc) seeding equipment, diversifying management strategies such as changing crop sequences/ nitrogen applications/ herbicide options, adopting various new harvesting options for weed seed control such as the Harrington weed seed destructor/chaff carts or windrow burning, and using techniques such as stubble incorporation, grazing or baling stubble to reduce the stubble load. A late strategic burn can also be incorporated into the mix.

A canola (*Brassica napus*) crop followed by two wheat (*Triticum aestivum*) crops (C-W-W) has been a very common crop sequence during the last decade in the no-till farming systems that predominate in southern NSW. As the area comprises 50% of farms with mixed crop livestock enterprises (Kirkegaard et al. 2011), post-harvest residue management by grazing or late burning has been part of the flexible approach to managing stubble. Increasing concern has been raised about the potential negative impacts of these practices on soil health which prompted an experiment to be designed to investigate impacts of stubble burning and grazing on soil conditions and crop growth.

The addition of a break crop such as canola or a pulse legume into the sequence have been shown to be profitable in its own right and an effective management tool for controlling weeds and diseases in stubble retained systems (Swan *et al*. 2015, Peoples *et al*. 2016). However, while farmers have found that there are many benefits for retaining stubble, increases in stubble loads in wetter seasons combined with a greater adoption of zero till seeding equipment, can negatively impact on herbicide flexibility, weed control and crop yield.

In this paper, we initially examine what questions farmers and advisors need to ask when managing stubble using a flexible approach and answer some of them by reporting results from the recent stubble management project (GRDC CSP00174). We examine the cost and effectiveness of various harvesting options that have been tested using farm equipment in the Southwest Slopes and Riverina. We report some of the main findings from two field experiments established in the Temora region over the past 4 to 8 years comparing different farming systems. The first experiment compared three management strategies (aggressive, sustainable and conservative) in a full factorial 4 year experiment located at the Temora Agriculture Innovation Centre (TAIC) using a single disc and a tine seeder on yield, gross margin and weed control. The second experiment, a long-term (8 year) field trial examining a canola–wheat-wheat (C-W-W) sequence determined the impact of post-harvest stubble management (heavy grazing, burning, or retaining stubble) on soil mineral N and wheat yield under no-till, controlled traffic cropping with strict summer fallow weed control.

Questions to ask when managing stubble using a flexible approach

It has been well documented that to successfully establish a crop into a full stubble retained system requires an integrated management approach incorporating three main stages of stubble management - pre-harvest, post-harvest/pre-sowing, and finally at sowing (Ref 1,2,3,4,5). During these periods, a series of questions (some outlined below) need to be addressed by farmers to successfully establish a crop.

- What is my preference for tillage system?
- What is my seeding system?
- What is my row spacing and accuracy of sowing?
- What crop will be planted into the paddock next year?
- What is the type of crop residue?
- What is the potential grain yield and estimated amount of crop residue?
- Is the crop lodged or standing at harvest?
- What is the desired harvest speed and harvest height?
- How uniform is the spread of straw from my harvester?
- Should I spread residue or place in a narrow windrow?
- Do I have a weed problem which requires intensive HWSC, chaff carts or chutes for chaff-lining?
- Will the stubble be grazed by livestock?
- Am I prepared to process stubble further post-harvest: mulch, incorporate, bale?
- If incorporating stubble, should I add nutrients to speed up the decomposition process?
- What is the risk of stubble-borne disease in next year's crop?
- Am I likely to encounter a pest problem next year: mice, slugs, earwigs, weevils, snails?
- What is the erosion risk based upon soil type and topography?
- Do I need to burn or what else can I do?

Prior to harvest, all crops should be assessed to estimate grain yield, potential stubble load and weed issues. As a rule of thumb, the stubble load following harvest will be approximately 1.5 to 2 times the grain yield for wheat and between 2 to 3 times the grain yield for canola (Riverine Plains Stubble management guide No 1 and Stubble management – an integrated approach (2010)). There is no perfect stubble management strategy for every year. Crop rotations, weeds, disease, pests, stubble loads, sowing machinery and potential sowing problems will largely dictate how stubble should be managed.

Methods and materials

Part 1: Harvest stubble management – harvest height

Eight commercial harvesters were tested between 2014 and 2016 on farm scale strips across the west slopes and Riverina to examine the effect of cutting height (15 to 60cm) on harvest efficiency and grain yield. The harvesters included a Case IH 7240, Case IH 8240, John Deere 5680, Case IH 1920, John Deere 9770, Case IH 8230 and New Holland 8090. A prototype Integrated Harrington Seed Destructor (iHSD®) was also tested in Temora, NSW in December 2015, Inverleigh in December 2015 and Furner, SA in January 2016.

Part 2: Strategy management experiment – impact on weeds, yield & profitability

The experiment was located on a red chromosol soil with surface pH_{CaCl2} of 5.0 (0-10 cm) and 4.6 (10-20 cm) and little slope at the Temora Agricultural Innovation Centre (TAIC) 4 km N of the township of Temora in SE NSW (S 34.49°, E 147.51°, 299 m ASL). A fully phased systems experiment was established in 2014 at a site with high levels of group B resistant annual ryegrass ARG (average seedbank of 1864 plants/m^2) to compare the yield, profitability and sustainability of three management strategies in a stubble retained no-till (Flexi-Coil tine seeder with Stiletto deep banding & splitting boots) and zero-till (Excel single-disc seeder with Arricks' wheel) farming system (Table 1). Nitrogen was applied at sowing by deep banding below the seed (tines) or surface applied pre-sowing (disc) at either 20 or 40 kgN/ha (Table 2). Pre-emergent and post emergent grass herbicides were applied to the three management strategies as outlined in Table 3. One of the main differences between the herbicides applied in the disc and tine systems related to trifluralin being used in the tine systems, but not in the disc systems, due to crop safety restrictions. Insecticides and fungicides were applied to treatments at sowing and during the crop development to minimise the effects of disease or insect damage.

The annual ryegrass ARG (*Lolium rigidum* Gaudin) seedbank was initially measured in March 2014 prior to sowing by taking 40 soil cores, each 58 mm in diameter x 50 mm deep. All plots were then measured in February or March of 2015, 2016 and 2017 by taking 8 cores in each plot to determine the change in ARG seedbank relating to management strategies. The soil was cooled to 4 degrees C for 7 days, then emptied into seedling trays in a glasshouse that were kept wet for the following 3 months. All ARG seedlings emerging were counted fortnightly and removed from each tray before being re-wetted.

Three soil cores (42 mm diameter) were taken in April of each year in each plot to a depth of 1.6 m and segmented for analysis (0.1 segments to 0.2 m depth and 0.2 m segments to 1.6 m depth) with an additional 4 foot cores taken at 0-0.1 m and 0.1-0.2 m depths, with cores bulked according to depths. Soil from each depth increment was analysed for mineral N (NH_4 and NO_3). Nitrogen was applied to all crops except the legume hay crop at GS31 (cereals) or stem elongation (canola) at different amounts determined by the starting soil mineral nitrogen concentration to attain a predicted yield of 70% of maximum potential as determined by Yield Profit® for each year. Grain yields were measured by plot header harvesting only th4e middle 4 rows and by hand harvesting large areas (> 1.0 m^2) of crop and threshing to measure the total dry matter production, harvest index and to estimate the amount of crop residue returned to the plot.

ARG, soil mineral N and grain yield were analysed by ANOVA with "treatment" as (management/sequence) x opener, and "block" as block/plot pair/plot using GenStat 18 software package (VSN International Ltd.). The ARG data often required transformations using either $\log_e$ or square root to normalise the residuals. Results in the tables are reported following back transformation and significant difference indicated by letters. Significance is assumed at the 95% confidence level and tests of mean separation were made using Fisher's least significant difference for the 95% confidence level.

Table 1. The crop rotation for each sequence in the three management strategies in a fully phased experiment at TAIC between 2014 and 2017.

Management Strategy	Sequence	Crop 2014	Crop 2015	Crop 2016	Crop 2017
Aggressive	4	Wheat 1 (H)	Wheat 2 (H)	Canola RR	Wheat 1 (H)
Aggressive	6	Wheat 2 (H)	Canola RR	Wheat 1 (H)	Wheat 2 (H)
Aggressive	10	Canola RR	Wheat 1 (H)	Wheat 2 (H)	Canola RR
Sustainable	1	Barley	Legume Hay	Canola TT	Wheat (L)
Sustainable	3	Wheat (L)	Barley	Legume Hay	Canola TT
Sustainable	7	Legume Hay	Canola TT	Wheat (L)	Barley
Sustainable	9	Canola TT	Wheat (L)	Barley	Legume Hay
Conservative	2	Wheat 1 (L)	Wheat 2 (L)	Canola TT	Wheat 1 (L)
Conservative	5	Wheat 2 (L)	Canola TT	Wheat 1 (L)	Wheat 2 (L)
Conservative	8	Canola TT	Wheat 1 (L)	Wheat 2 (L)	Canola TT

Table 2. The planned crop density and seed bed nitrogen quantity/application method at sowing for each crop in the three management strategies for both opener types.

Management Strategy	Crop	Plant density (plants/m^2)	Seed bed nitrogen quantity (kgN/ha)		N type and application
			Tine^	Disc#	
Aggressive	Wheat 1 (H)	150	40	40	Urea IBS
Aggressive	Wheat 2 (H)	150	40	40	Urea IBS
Aggressive	Canola RR	40	20	20	SOA IBS
Sustainable	Barley	120	20	20	Urea IBS
Sustainable	Wheat (L)	80	20	20	Urea IBS
Sustainable	Legume Hay	40	Nil	Nil	Nil
Sustainable	Canola TT	40	20	20	SOA IBS
Conservative	Wheat 1 (L)	80	20	20	Urea IBS
Conservative	Wheat 2 (L)	80	20	20	Urea IBS
Conservative	Canola TT	40	20	20	SOA IBS

Nitrogen spread on soil surface prior to sowing (Disc)
^ Nitrogen deep banded below the seed using stiletto boots (Tine)

Table 3. The herbicides applied at sowing and in-crop to control herbicide resistant annual grasses at TAIC for each management strategy x opener type.

Management strategy	Crop	IBS herbicides x opener Tine	Disc	In-crop grass herbicides tine and disc
Aggressive	Wheat 1 (H)	Sakura® + Avadex Xtra®	Sakura + Avadex Xtra	Atlantis®
Aggressive	Wheat 2 (H)	Boxer Gold ®	Boxer Gold	Atlantis
Aggressive	Canola RR	Rustler® + TriflurX®	Rustler	Roundup Ready®
Sustainable	Barley	Boxer Gold	Boxer Gold	Nil
Sustainable	Wheat (L)	Sakura + Avadex Xtra	Sakura + Avadex Xtra	Atlantis
Sustainable	Legume Hay	Nil	Nil	
Sustainable	Canola TT	Rustler + Gesaprim® + TriflurX	Rustler Gesaprim	Status® + Gesaprim
Conservative	Wheat 1 (L)	Diuron** + TriflurX	Diuron**	Atlantis
Conservative	Wheat 2 (L)	Diuron** + TriflurX	Diuron**	Atlantis
Conservative	Canola TT	Gesaprim + TriflurX	Gesaprim	Status + Gesaprim

** Diuron is not registered for control of annual ryegrass in winter cereals in NSW

Note: When using any of the registered products above check labels and follow label directions.

Part 3: Grazing x stubble management experiment – impact of grazing, burning or retaining stubble on soil nitrogen, crop yield and profitability

The experiment was located on a red chromosol soil with surface pH_{CaCl2} of 5.0 (0-10 cm) and 4.85 (10-20 cm) and little slope 5 km SSE of the township of Temora in SE NSW (S 34.49°, E 147.51°, 299 m ASL). Treatments were applied in two different phases in adjoining areas of a paddock which had been in lucerne pasture (*Medicago sativa*) since 2005. In phase 1, lucerne was terminated with herbicide in late spring 2008; in phase 2 it was terminated in late winter 2009. Following lucerne removal, large plots (7.25 x 16 m) were established which allowed all operations to be conducted using controlled traffic. All plots were fenced so they could be individually grazed by sheep. Lime was evenly applied at a rate of 2.5 t/ha across all plots in April 2009.

In both phases, the two grazing treatments (nil graze – NG, stubble graze – SG) were applied in a factorial randomised complete block design with two stubble management treatments (stubble burn – SB, stubble retain – SR) and four replicates. Following harvest in each year (late November-early December), weaner ewes grazed stubbles in the SG treatment (average 2263 sheep.days/ha). The stubble burn treatments were applied in mid to late March of each year.

Crops were sown in mid-late April in all years of the experiment, and both crop phases were kept in a rotation of canola-wheat-wheat (Table 4). All crops in both phases between 2009 and 2016 were inter-row sown using a plot seeder equipped with contemporary no-till seeding equipment consisting of six Flexi-Coil 250 kg break out tines set on 305 mm row spacing and fitted with Agmaster® boots, 12 mm knife points and press wheels. Summer weeds that emerged at the site were controlled with herbicide within 5-10 days of emergence, and all in-crop weeds, disease and pests were controlled with registered pesticides such that they did not affect yield. The same rate of synthetic fertilisers were applied to all treatments determined annually following soil analysis to ensure the treatment with the lowest mineral nitrogen concentration was able to yield to 70% of maximum potential as determined by decision support tool, Yield Prophet® for that year.

Table 4. Crop sequence of Canola (C) – Wheat (W) – Wheat (W) in phase 1 and phase 2 of the experiment following lucerne pasture (P) since 2005. Second wheat crop is shown in bold.

	2008	2009	2010	2011	2012	2013	2014	2015	2016
Phase 1	P	W	C	W	**W**	C	W	**W**	C
Phase 2	P	P	W	C	W	**W**	C	W	**W**

Prior to seeding each year two soil cores (42 mm diameter) were taken per plot to a depth of 1.6 m and segmented for analysis (0.1 segments to 0.2 m depth and 0.2 m segments to 1.6 m depth). Six additional cores were taken for 0-0.1 m and 0.1-0.2 m depths, and cores were bulked according to depths. Soil from each depth increment was analysed for mineral N (NH_4 and NO_3). Grain yield was measured using a plot header harvesting only the middle four rows of each seeding run to remove edge effects from rows adjacent to tram tracks. Grain yields were also measured by hand harvesting large areas (> 1.0 m^2) of crop and threshing to measure the total dry matter production, harvest index and to estimate the amount of crop residue returned to the plot.

Table 5. Monthly and annual rainfall data (mm) from Temora airport 2008-2017

Year	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Annual (mm)**	**GSR (mm)**
2008	43	69	41	26	7	17	48	22	27	24	39	59	423	171
2009	22	14	16	53	7	58	32	8	24	23	24	44	327	205
2010	6	109	79	39	41	22	59	63	63	87	105	76	749	374
2011	62	196	72	17	17	18	25	46	30	48	108	64	702	201
2012	62	59	24	5	16	18	44	38	15	17	35	30	363	153
2013	10	40	20	2	52	87	18	25	29	15	47	9	354	228
2014	21	25	56	70	31	74	5	24	29	17	18	66	436	250
2015	61	21	3	49	20	51	79	54	10	13	90	29	481	276
2016	57	9	8	9	90	113	61	71	205	42	5	34	704	591

Soil mineral N and grain yield were analysed using mixed linear models with grazing, stubble, rotational position (1st or 2nd wheat crop after canola) and year as fixed effects, and block and phase as random effects in the GenStat 18 software package (VSN International Ltd.). Significance is assumed at the 95% confidence level and tests of mean separation were made using Fisher's least significant difference for the 95% confidence level, estimated by doubling the average standard error of means.

Monthly, annual and growing season rainfall (April-Oct) at Temora is outlined in Table 5. In 2010, 2011 and 2016, harvest for the canola was delayed until late November early December and wheat until early December, so the November rainfall could be added to GSR in those years.

Results

Part 1: Harvest stubble management – Harvest height

Using a stripper front or harvesting high is the quickest and most efficient method to produce the least amount of residue that needs to be threshed, chopped and spread by the harvester. Harvesting high (40-60 cm) compared to 15 cm increased grain yield and combine efficiency by reducing bulk material going through the harvester and reduced harvests costs by 37 to 40% (Table 6). As a general rule, there is a 10% reduction in harvest speed for each 10 cm reduction in harvest height (Table 6). Slower harvest speed across a farm also exposes more unharvested crop to the risk of weather losses (sprouting, head/pod loss, lodging) during the harvest period, and the cost of this is not accounted for in Table 6.

Table 6. Harvesting wheat low or high using a JD9770 harvester in 2014 (Ref 7). Ground speed was altered to achieve similar level of rotor losses at both harvest heights. Values are means of three replicates STS yield monitor and all differences are significant (P<0.05). Operating costs determined at $600/hr.

Harvest height	Efficiency (ha/h)	Speed (km/hr)	Fuel (l/ha)	Yield (t/ha)	Cost $/ha	Cost $/ton
60cm	9.5	10.6	5.4	2.19	$63.2	$28.7
15cm	5.7	6.2	9.6	2.05	$105.3	$50.1
% Change to 15cm	**-41%**	**-42%**	**+78%**	**-6%**	**+40%**	**+57%**

There is substantial evidence indicating wide spread resistance or partial resistance of ARG to a wide range of herbicide groups across south eastern Australia (Broster *et al*. 2011). Harvest weed seed control (HWSC) which includes narrow windrow burning, chaff carts, chaff lining, direct baling, and mechanical weed seed destruction is an essential component of integrated management to keep weed populations at low levels and thus slow the evolution and spread of herbicide resistance ARG. HWSC requires crops to be harvested low in order for weed seeds to be captured in the chaff fraction from the harvester, and if practiced provides an additional reason to harvest low. The prototype Integrated Harrington Seed Destructor (iHSD) was tested in Temora, NSW in December 2015, Inverleigh in December 2015 and Furner, SA in January 2016 at a constant speed of 4 km/hr to compare the efficiency and cost with non-weed seed destruction methods (Table 7). We found no significant difference in grain yield when harvesting at 15 cm *cf* 30 cm at 4 km/hr, but there a 9% increase in engine load and 11% reduction in fuel efficiency (Table 7). However, when the weed seed destructor was activated, there was a 33% increase in engine load which resulted in a 40% reduction in the fuel efficiency of the header (Table 7).

Table 7. A Case 9120 harvesting wheat conventionally at 30 cm, harvesting at 15 cm for baling or narrow windrow burning and harvesting at 15 cm with a prototype iHSD at Furner, SA in 2016. (Data supplied by GRDC project SFS00032)

	Harvest height	Grain Yield (t/ha)	Speed (km/hr)	Engine Load (%)	Fuel (L/ha)	Fuel Efficiency (L/hr)
Conventional Harvest - Burn	**30cm**	4.7	3.8	59.8	14.3	52.7
Windrow Bale/burn	**15cm**	4.6	4.0	65.5	16.4	59.5
iHSD	**15cm**	4.6	4.0	88.7	22.7	87.8
lsd (P<0.05)		**ns**	**ns**	**2.26**	**1.36**	**2.18**
% Change to 15 cm				**+9%**	**+11%**	**+11%**
% change to iHSD				**+33%**	**+37%**	**+40%**

Part 2: Results from the strategy management experiment 2014-2017

Stubble load: The cereal stubble load following harvest in 2014 and 2015 ranged between 6.3 and 7.7 t/ha. By April 2016, the cereal stubble /ryegrass DM load that crops were sown into ranged between 7-10 t/ha (Table 8). Following the 2016 decile 9 season with high grain yields, the cereal stubble / ryegrass DM quantity increased in many treatments with a further 8-10 t/ha added to the previous 3 years undecomposed stubble. To ensure all treatments could be established in April 2017, the cereal stubble load was reduced in all treatments to between 4-6 t/ha (total amount of straw at sowing) by baling excess stubble.

Table 8. Stubble type and quantity (t/ha) in April 2016 that crops were sown into at Temora.

Management Strategy	Stubble type & year	Crop 2016	Disc (t/ha)	Tine (t/ha)
Aggressive	Wheat 1 (H)	Wheat 2 (H)	7	8
Aggressive	Wheat 2 (H)	RR Canola	9	8
Conservative	Wheat 1 (L)	Wheat 1 (L)	7	7
Conservative	Wheat 2 (L)	TT Canola	8	9
Sustainable	Barley	Vetch	10	9

The most profitable crop across all management strategies between 2014 and 2016 were canola with an average nett margin of between $694 and $769/ha/year and a profit/cost ratio of between $1.40 (aggressive strategy) to $1.80 (sustainable strategy) for every $1 spent (Table 9a). The highest grain yield was produced by the hybrid RR canola in 2014 and 2015 (2.2 t/ha and 3.1 t/ha respectively), however, this required an increase of 20% in average total costs (Table 9a). The decile 9 season of 2016 (Table 5) resulted in all canola yielding between 2.8 and 3.0 t/ha (Table 11). The introduction of diversity with the sustainable strategy resulted in an average net margin over the three years of $512/ha/year which is higher than in the aggressive strategy ($498/ha/year) and 25% higher than the conservative strategy, with 10% lower cost than the aggressive ($465 *cf* $517/ha/year) and thus higher profit:cost ratio ($1.12 *cf* $0.96) (Table 9b). A major difference in the average total costs between the sustainable and either the aggressive or the conservative strategies was the 30-35% saving in nitrogen costs (Table 9b). The vetch hay treatment was profitable in its own right with an average net margin over the three years of $416/ha/yr and a profit:cost ratio of $0.90:$1.00. It also reduced the fertiliser N input for the following and subsequent crops by up to $39/ha/year.

Table 9a. Average net margins (EBIT) and profit:cost ratio averaged across openers at Temora, NSW, 2014-2016

Cropping strategy	Crop type	Average total cost 2014-16 ($/ha/yr)	Average net margin 2014-16 ($/ha/yr)	Average 3yr profit:cost ratio
Aggressive	Canola RR	$524	$722	1.4
Aggressive	Wheat (yr 1)	$525	$378	0.7
Aggressive	Wheat (yr 2)	$504	$394	0.8
Conservative	Canola TT	$452	$694	1.5
Conservative	Wheat (yr 1)	$415	$289	0.7
Conservative	Wheat (yr 2)	$419	$261	0.6
Sustainable	Vetch (Hay)	$463	$416	0.9
Sustainable	Canola TT	$426	$769	1.8
Sustainable	Wheat	$492	$422	0.9
Sustainable	Barley	$478	$441	1.0

Table 9b. Average nitrogen & total costs, net margins and profit:cost ratio for each management strategy combined for opener type

	Average N costs ($/ha/yr)	Average total cost 2014-16 ($/ha/yr)	Average net margin 2014-16 ($/ha/yr)	Average 3yr profit: cost ratio
Aggressive	$109	$517	$498	$0.96
Conservative	$103	$429	$415	$0.95
Sustainable	$70	$465	$512	$1.12

The barley phase in the sustainable strategy produced the highest yielding cereal crop in all years and were 12% more profitable than the second wheat crop in either the aggressive or conservative strategies (Table 9a), despite record low barley prices in the 2016/17 season. The second wheat grain yield in both the aggressive and conservative strategies were lower (reduction of between 0.3 and 0.7 t/ha) than wheat grain yield following canola (Table 11). Similar results were found in grazing x stubble management experiment (Table 17). There were no significant differences in the net margin of strategies when sown with either the disc or tine openers, except in the conservative strategy when sown with a disc opener. The profit:cost ratio was reduced from $1.14 for every $1 spent to $0.75 (Table 10).

Table 10. Average net margins across all crop types for each crop system by opener type between 2014 and 2016 at Temora, NSW.

Management strategy	Net margins 2014 ($/ha)		Net margins 2015 ($/ha)		Net margins 2016 ($/ha)		Average net margins 2014-16 ($/ha/yr)		profit:cost ratio 2014-2016	
	Tine	Disc	Tine	Disc	Tine	Disc	Tine	Disc	Tine	Disc
Aggressive	$424	$422	$569	$591	$533	$449	$508	$487	$0.98	$0.94
Conservative	$441	$171	$540	$463	$537	$336	$506	$323	$1.14	$0.75
Sustainable	$488	$493	$520	$525	$552	$495	$520	$504	$1.14	$1.10

Table 11. Effect of management strategy on crop grain yields sown with disc and tine openers at Temora, NSW, 2014-2016

Manageme nt strategy	Se q	Crop 2014	Crop 2015	Crop 2016	Grain/DM yield 2014 (t/ha)		Grain/DM yield 2015 (t/ha)		Grain/DM yield 2016 (t/ha)	
					Disc	Tine	Disc	Tine	Disc	Tine
Aggressive	4	Wh 1 (H)	Wh 2 (H)	Can RR	3.1	3.0	3.9	3.5	2.9	3.0
Aggressive	6	Wh 2 (H)	Can RR	Wh 1	3.2	2.9	3.1	3.1	5.5	6.0
Aggressive	10	Can RR	Wh 1 (H)	Wh 2	2.2	2.2	3.5	3.4	4.9	5.3
Sustainable	1	Barley	Leg Hay	Can TT	4.2	4.5	2.9	3.4	2.9	3.0
Sustainable	3	Wh (L)	Barley	Leg Hay	3.3	3.1	5.0	5.0	3.9	4.0
Sustainable	7	Leg Hay	Can TT	Wh (L)	4.2	4.2	2.6	2.4	5.2	5.8
Sustainable	9	Can TT	Wh (L)	Barley	1.8	1.7	3.5	3.3	6.0	6.1
Conservativ	2	Wh 1 (L)	Wh 2 (L)	Can TT	1.9	2.5	2.8	3.0	2.8	3.0
Conservativ	5	Wh 2 (L)	Can TT	Wh 1 (L)	1.5	2.9	2.1	2.4	2.4	4.7
Conservativ	8	Can TT	Wh 1 (L)	Wh 2 (L)	1.6	2.1	3.6	3.5	3.3	4.4

Effect of management strategy on weeds

The average annual ryegrass seedbank across the trial area in February 2014 were 1864 plants/m^2. Both the aggressive and sustainable management strategies significantly reduced the ARG seedbank to 351 plants/m^2 by February 2016, significantly lower than in the conservative strategy (Table 12).

Table 12. Main effect of management strategy on ARG seedbank averaged across disc and tine openers at Temora, NSW, 2014-2017.

	Seedbank Feb 2015	Seedbank Feb 2016	Seedbank Feb 2017
Management strategy	seeds/m^2	seeds/m^2	seeds/m^2
Sustainable	865*b*	449*b*	145*b*
Aggressive	556*b*	253*b*	573*b*
Conservative	2276*a*	2830*a*	4188*a*
P value	0.003	<0.001	<0.001
Transformation required	#	*	#

* No lsd - data analysed by square root and back transformed. Letters indicate significant difference.
# No lsd - data analysed by log e and back transformed. Letter indicate significant difference.

However, following the wet 2016 season with a soft late finish, the sustainable strategy had reduced the ARG seed bank measured in February 2017 by 70% compared to the aggressive strategy, with the conservative strategy increasing ARG seedbank by 600% to above 4000 seeds/m^2 (Table 12). There were significant main effects of opener type (disc vs tine) on ARG seedbank populations in 2016 and 2017 with lower ARG seedbank populations in 2016 (650 seeds/m^2 in tine *cf* 1080 seeds/m^2 in disc) and 2017 (384 seeds/m^2 in tine *cf* 944 seeds/m^2 in disc) (data not shown). When comparing strategy by opener types, there were no significant difference between the aggressive and sustainable strategy x opener type in 2016 but by February 2017, the sustainable strategy sown with a tine seeder had reduced the average ARG seedbank population by 95% to 82 seeds/m^2. The aggressive strategy (disc and tine) and sustainable (disc) reduced the ARG seedbank by 75% to an average of 472 seeds/m^2 (Table 13). The average ARG seedbank in the conservative strategy increased to 2322 and 7631 seeds/m^2 when sown with a tine and disc opener, respectively (Table 13). There was a general increase in ARG seedbank in all wheat crops sown in 2016 in the conservative strategy by a factor of 2 to 10 with a 230% increase in sequence 5 sown with a disc opener compared to a tine opener (17671 *cf* 5261 seeds/m^2, Table 14).

Table 13. Main effect of management strategy x opener type (disc & tine) on ARG seedbank for annual ryegrass at Temora, NSW, 2014-2017.

Management Strategy	OPENER	Seedbank Feb 2015 seeds/m^2	Seedbank Feb 2016 seeds/m^2	Seedbank Feb 2017 seeds/m^2
Sustainable	Tine	734*cd*	346*c*	82
Aggressive	Tine	866*c*	300*c*	498
Conservative	Tine	1291*b*	1840*b*	2322
Sustainable	Disc	1020*c*	562*c*	260
Aggressive	Disc	356*d*	207*c*	659
Conservative	Disc	4008*a*	4045*a*	7631
P value		<0.001	0.023	0.345
Transformation		#	*	#

* No lsd - data analysed by square root and back transformed. Letters indicate significant difference
# No lsd - data analysed by log e and back transformed. Letters indicate significant difference

By February 2017, the competitive 2016 barley crop reduced the ARG to 43 seeds/m^2 (Table 15) or to 28 and 64 seeds/m^2, respectively sown with a tine or disc opener (Table 14). The double break of the legume hay 2015/canola TT 2016 in the sustainable strategy sown with a tine opener was also very effective at reducing ARG seedbank (Table 14). The canola single break tended to be more effective at reducing ARG seedbank populations when sown with a tine seeder however, the double break in the sustainable strategy was more effective.

The expensive herbicides such as Sakura, Boxer Gold and Rustler provided good early weed control in both the aggressive and conservative strategies as indicated by the low ARG plant numbers in June of each year whereas, there were significantly higher early ARG plant numbers in the conservative strategy (Table 15). There were significant effects of strategy x sequence x opener type with higher ARG plant numbers in the conservative strategy sown with a disc opener compared to a tine opener (Canola TT: 2014 = 99 vs 16, 2015 = 117 vs 10 and 2016 = 452 vs 140 in disc vs tine; data not shown). There were similarly higher plant numbers in the wheat sown with a disc than with a tine seeder. The higher early ARG populations resulted in a greater increase in ARG panicles, especially in the 2nd wheat crop in 2016 (466 panicles/m^2 in tine vs 1066 panicles/m^2 in disc – data not shown). In contrast, in the sustainable strategy, all sequences by November 2016 had low numbers of ARG panicles and although not significantly lower than the aggressive strategy, had significantly less ARG seedlings in the seedbank in 2017 (Table 15).

Table 14. The effect of management strategy x sequence on ARG seed bank of each year between 2015-17 for disc and tine openers at Temora, NSW, 2014-2017.

Sequence No	Management Strategy	Crop 2014	Crop 2015	Crop 2016	Crop 2017	Seedbank Feb 2015 seeds/m^2	Seedbank Feb 2016 seeds/m^2	**Seedbank Feb 2017 seeds/m^2**
		Strategy Sown with a Tine Seeder						
9	Sustainable	Canola TT	Wheat (L)	Barley	Legume Hay	551	190ef	**28**
7	Sustainable	Legume Hay	CanTT	Wheat (L)	Barley	368	146ef	**198**
3	Sustainable	Wheat (L)	Barley	Legume Hay	CanTT	757	502def	**125**
1	Sustainable	Barley	Legume Hay	CanTT	Wheat (L)	1887	676def	**65**
10	Aggressive	Canola RR	Wheat 1 (H)	Wheat 2 (H)	Canola RR	734	114f	**590**
6	Aggressive	Wheat 2 (H)	Canola RR	Wheat 1 (H)	Wheat 2 (H)	1026	250ef	**441**
4	Aggressive	Wheat 1 (H)	Wheat 2 (H)	Canola RR	Wheat 1 (H)	864	645def	**478**
8	Conservative	Canola TT	Wheat 1 (L)	Wheat 2 (L)	Canola TT	410	269ef	**2122**
5	Conservative	Wheat 2 (L)	CanTT	Wheat 1 (L)	Wheat 2 (L)	2071	1096cde	**5271**
2	Conservative	Wheat 1 (L)	Wheat 2 (L)	CanTT	Wheat 1 (L)	2533	6288a	**1108**
		Strategy Sown with a Disc Seeder						
9	Sustainable	Canola TT	Wheat (L)	Barley	Legume Hay	800	164ef	**64**
7	Sustainable	Legume Hay	CanTT	Wheat (L)	Barley	368	692def	**119**
3	Sustainable	Wheat (L)	Barley	Legume Hay	CanTT	552	156ef	**488**
1	Sustainable	Barley	Legume Hay	CanTT	Wheat (L)	6694	1892bcd	**1212**
10	Aggressive	Canola RR	Wheat 1 (H)	Wheat 2 (H)	Canola RR	248	108f	**742**
6	Aggressive	Wheat 2 (H)	Canola RR	Wheat 1 (H)	Wheat 2 (H)	329	77f	**513**
4	Aggressive	Wheat 1 (H)	Wheat 2 (H)	Canola RR	Wheat 1 (H)	553	571def	**750**
8	Conservative	Canola TT	Wheat 1 (L)	Wheat 2 (L)	Canola TT	2453	2746bc	**8022**
5	Conservative	Wheat 2 (L)	CanTT	Wheat 1 (L)	Wheat 2 (L)	6905	5868a	**17677**
2	Conservative	Wheat 1 (L)	Wheat 2 (L)	CanTT	Wheat 1 (L)	3801	3807ab	**3103**
P value						0.375	0.007	**0.35**
Transformation required to normalise residuals						#	#	**#**

Table 15. The effect of management strategy x sequence on ARG plant numbers in June, ARG panicle numbers in November and the ARG seedbank between 2014-17 averaged across disc and tine openers at Temora, NSW, 2014-2017.

						ARG plants (plants/m^2)			**ARG Panicles (panicles/m^2)**			**ARG Seedbank (seeds/m^2)**		
Seq No	**Strategy**	**Crop 2014**	**Crop 2015**	**Crop 2016**	**Crop 2017**	2014	2015	2016	2014	2015	2016	2015	2016	2017
9	Sustain	Canola TT	Wheat (L)	Barley	Leg Hay	30cd	1d	5de	5bcd	14cdef	7c	663c	176d	43f
7	Sustain	Leg Hay	Canola TT	Wheat (L)	Barley	148a	3cd	2e	13b	9f	8c	368c	151d	153e
3	Sustain	Wheat (L)	Barley	Leg Hay	Canola TT	4d	6bc	115ab	3cd	31cde	7c	647c	595cd	247de
1	Sustain	Barley	Leg Hay	Canola TT	Wheat (L)	51bc	20ab	24c	156a	0f	7c	3555ab	1204bc	279de
10	Aggress	Canola RR	Wheat 1 (H)	Wheat 2 (H)	Canola RR	27cd	2cd	4e	2d	11ef	26bc	427c	112d	665cd
6	Aggress	Wheat 2 (H)	Canola RR	Wheat 1 (H)	Wheat 2 (H)	8d	4c	2e	13bc	2f	23bc	692c	151d	473d
4	Aggress	Wheat 1 (H)	Wheat 2 (H)	Canola RR	Wheat 1 (H)	6d	3cd	11cd	6bcd	50bcd	20bc	581c	610cd	602cd
8	Conser	Canola TT	Wheat 1 (L)	Wheat 2 (L)	Canola TT	49bc	6bc	60b	12bc	90b	376a	1003abc	1183bc	4105ab
5	Conser	Wheat 2 (L)	Canola TT	Wheat 1 (L)	Wheat 2 (L)	92b	35a	207a	224a	84bc	705a	3782a	3014b	9604a
2	Conser	Wheat 1 (L)	Wheat 2 (L)	Canola TT	Wheat 1 (L)	51bc	37a	202a	151a	376a	49b	3103ab	4970a	1863bc
P value						<0.001	0.004	<0.001	<0.001	<0.001	0.028	0.035	0.002	0.018
Transformation required to normalise residuals						*	#	#	#	*	#	#	*	#

* No lsd - data analysed by square root and back transformed. Letters indicate significant difference.

No lsd - data analysed by log e and back transformed. Letters indicate significant difference.

Part 3: Results from grazing x stubble management experiment 2009-2016

Grazing is an effective, inexpensive method of reducing stubble while burning removes stubble, assists in reducing disease carryover, reduces certain seedling pests and weed populations. Over the eight years of the experiments, neither burning nor grazing affected yield in the 1st wheat crop after canola (Table 16). However, both heavy grazing and burning increased yield in the second wheat crop after canola and the effects were partly additive (Table 16). Across all years, grazing and burning alone increased yield of the 2nd wheat crop on average by 0.7 t/ha and 0.8 t/ha respectively, but when applied together increased yield by 1.0 t/ha. In three of the four phase years in which the 2nd wheat crop was grown, burning increased yield by between 0.5 and 0.6 t/ha, but in one year (2013) by 1.4 t/ha.

Table 16. Mean grain yield (t/ha) for either 1st or 2nd wheat crop following canola under different grazing and stubble treatments between 2009 and 2016. P-value and LSD are from the three-way interaction between grazing treatment, stubble treatment and rotational position and means followed by the same letters are not significantly different from each other.

		Rotational position	
Graze treatment	Stubble treatment	1st wheat	2nd wheat
Nil graze	Retain	4.58^{b}	3.93^{c}
Stubble graze	Retain	4.63^{b}	4.58^{b}
Nil graze	Burn	4.63^{b}	4.68^{b}
Stubble graze	Burn	4.73^{ab}	4.89^{a}
	P-value	0.007	
	LSD (P=0.05)	0.18	

Grazing stubble increased soil mineral N by 13 kg/ha in the first wheat crop (Table 17) and by 33 kg/ha in the 2nd wheat crop, and there was no interaction between grazing and stubble treatments. Burning stubble had no significant effect on soil mineral N in the 1st wheat crop, but increased soil mineral N by an average of 13 kg/ha in the 2nd wheat crop (Table 17).

Table 17. Mean soil mineral N (kg/ha N) to 1.6 m depth prior to sowing following either 1st or 2nd wheat crops following canola for different grazing and stubble treatments between 2009-2016. P-values and LSDs are for two way interactions between either grazing treatment of stubble treatment and rotational position.

	Grazing treatment		Stubble treatment	
Rotational position	Nil graze	Stubble graze	Burn	Retain
1st wheat	107	120	110	117
2nd wheat	92	125	115	102
P-value	0.031		0.035	
LSD (P=0.05)	13		13	

Averaged across both phases for the seven years of this experiment, grazing and then retaining the stubble generated the highest gross income (Table 18). If the grazing was valued assuming one dry sheep equivalent (DSE) consumed 7.6 MJ of energy per day at an agistment rate of $0.4/DSE/week, the grazing value of the stubble was $117/ha/year with an additional increase of $55/ha/year due to higher yields and higher N availability (Total increase = $172/ha yr).

Table 18. Gross income per year averaged across both phases for all years (2010-2016) of the experiment at Temora.

Graze treatment	Stubble treatment	Assuming grazed stubble has no value	Assuming grazed stubble has a value
Nil graze	Retain	$1,231	$1,231
	Burn	$1,269	$1,269
Stubble graze	Retain	$1,286	$1,403
	Burn	$1,277	$1,397

Discussion

There is no perfect stubble management strategy for every year with crop rotations, weeds, disease, pests, stubble loads, grazing and machinery largely dictating how to manage the stubble successfully. How a farmer answers the questions outlined on page 2 for each paddock and each farm and is able to adapt his/her farming system will influence their ability to handle stubble profitability.

A flexible approach to managing stubble means crops can be harvested high or low depending on the season and situation, stubbles can then be grazed with considerable economic advantage, straw baled and sold, mulched, incorporated or burnt. The flexible strategy provides a range of options for all farming systems and seeder types to improve profitability while trying to maximize the stubble retained.

We found that using a stripper front or harvesting high is the quickest and most efficient method to harvest grain that produces the least amount of residue at the lowest costs. However, if farmers plan to harvest high but intend to sow with a tine seeder, they may need to determine how they can reduce their stubble load to ensure there are no major problems with the timeliness of sowing the following crop. Large stubble loads potentially create issues for <u>all sowing systems</u> with regards to the type and effectiveness of herbicides that can be applied, the ability of the pesticides to reach the soil surface/ weed or insect, and the effect that the thick stubble load could have on the emerging seedling. Narrow windrow burning has proved very effective in reducing ARG seedlings, but in cereal paddocks with high stubble loads, it may be necessary to incorporate mechanical methods of control such as harvesting low with a HWSD to assist in reducing herbicide resistant ARG seed set, although this will be more expensive and be slower.

One of the negatives we found when sowing wheat into tall wheat stubble (45 cm *cf* 15 cm) was that seedlings received less radiation and were exposed to cooler temperatures, which often resulted in a reduced early growth and a reduction in tiller number. In our experiments, this didn't persist to a reduction in grain yield, however, the Riverine Plains Inc grower group found a significant reduction in 2014 in grain yield (4.98 t/ha cf 5.66 t/ha with lsd @ $P<0.05$ = 0.45 t/ha) in tall compared to short stubble.

In the strategy management experiment, we compared two canola-wheat-wheat sequences against a diversified sequence (canola-wheat-barley-vetch for hay). One was aggressively managed for weed control and to maximize yield which included more crop competition, more expensive herbicides, the inclusion of a hybrid RR canola and higher rates of N at sowing (deep banded in tine opener only) against a conservatively managed sequence with cheaper herbicides, lower crop densities, lower rates of N at sowing and cheaper crop types. The third comparison, a diverse or sustainable cropping strategy allowed each crop to be sown into a less antagonistic stubble i.e. wheat into canola, barley into wheat, vetch into barley and cut for hay followed by, canola sown into low stubble load.

The income from the vetch hay combined with highly effective weed control and the additional N plus water conservation, especially preceding the higher value and risky crops such as canola, were able to make the sustainable strategy a reliable profitable management option for farmers wanting to retain stubble. The double break from the legume hay/canola treatment combined with the crop competition from the barley crop was extremely effective at reducing ARG seedbank to below that of the aggressive canola-wheat-wheat sequence under extremely wet and dry seasonal conditions when sown with a disc or tine opener. The benefit of the double break was most noticeable following the wet season of 2016. With no knockdown applied before the early sowing in 2016, the expensive pre-emergent herbicides sprayed in the aggressive and sustainable strategies such as Sakura®, Boxer Gold® and Rustler® proved extremely effective at controlling the early ARG populations even with high stubble loads (Table 15). However, all pre-emergent herbicides had become ineffective by August 2016 as late ARG plants emerged in the first 3 weeks of August. As crop topping was not possible in this experiment, late control of ARG was left to increased crop competition from barley and/or in combination with the benefits of the legume hay or canola crop in the sustainable tine strategy that resulted in significantly lower (P=0.082) ARG panicles compared to the 1st or 2nd wheat crop in the aggressive strategy (data not shown)**.** In comparison, the conservative management strategy although reasonably profitable especially when sown with a tine opener, was largely ineffective at reducing the ARG seedbank, which significantly increased following the wet 2016 season. The ability to apply trifluralin as a pre-emergent herbicide with a tine opener reduced the ARG seedbank compared to the conservative strategy sown with a disc opener, however, the conservative strategy would not be recommended with either opener type where there is any ARG weed problem.

Deep banding of N was incorporated into the management strategy (tine only) of this experiment. The amount of applied N at sowing captured by wheat crops has been found to increase when deep banded below the seed in the presence or absence of stubble (Kirkegaard *et al.* 2017). Although the rates of N deep banded were 122 kgN/ha, similar results from 2017 have been observed with rates at 100 kgN/ha. Similar benefits are expected to have occurred in the cereal and canola crops sown with the tine opener in the management experiment as N was deep banded at sowing. The application of early N applied to the soil surface pre sowing with a disc opener may have resulted in slower early growth. There is the potential for mid-row banding technology to be used with disc openers to apply N deep below the seed at sowing.

With careful planning and diverse management, burning can be kept for those occassions where the system needs to be reset which can result in farmers retaining stubble for another series of years. A late burn, conducted wisely just prior to sowing to minimise the time the soil is exposed is one option farmers may need to consider when dealing with large stubble loads. Grazing and burning canola stubbles had no effect on the yield of the 1st wheat crop following canola, but grazing or burning the stubble of the first wheat crop increased yield substantially in the 2nd wheat crop. Whilst this difference could logically be attributed to various biotic mechanisms such as disease, no treatment differences were recorded within the very low level of stubble-borne diseases (yellow leaf spot, crown rot, *Zymoseptoria tritici*) that were present at the site in some years. It thus appears more likely that N dynamics are principally responsible for the observed differences in yield.

Grazing and burning stubbles increased soil mineral N accumulation during the summer fallow to a much greater extent in the 2nd wheat crop compared to the 1st wheat crop presumably due to both higher amounts and higher C:N ratio of wheat stubble compared to canola stubble which would lead to more N immobilisation (Hunt *et al.* 2016). The average increase in mineral N due to grazing in the 2nd wheat treatment was 33 kg/ha N. Hunt *et al*. (2016) suggested that grazing either removed C from the system or neutralised C with potential immobilising power of 52 kg/ha N. Under the no till surface-retained residue management practiced at this site, immobilisation would presumably occur over several years as residues slowly decompose. The greater effect of grazing stubble on mineral N compared to burning stubble in this experiment is likely due to differences in the timing of the two treatments with respect to soil measurement. The grazing treatment was applied immediately after harvest, giving 4 to 5 to months between removal of stubble by grazing and measurement of soil N. In contrast, the burn treatment was applied only ~1 month before measurement of soil mineral N, giving less time for differences in N immobilisation to act before the pre-sowing soil N tests. Both treatments influenced grain yield as they both would have presumably altered in-season net N mineralisation. The results suggest that where disease is absent or controlled and good crop establishment achieved, N immobilisation by wheat residue can significantly reduce crop yield in subsequent wheat crops.

Beyond the effects of N dynamics on grain yield, burning stubble also reduced frost-induced sterility of the 2nd wheat crop from 59 to 30% following severe frosts of -2.6^{o}C, -1.8^{o}C and -3.6^{o}C (screen temperatures) that occurred on the 15, 16 and 18 October in 2013. In that year, grazing increased the yield of the 2nd wheat crop by 1.0 t/ha, burning by 1.4 t/ha and combined by 1.6 t/ha. However, no differences in frost-induced sterility were measured in any other year of the experiment.

It must be recognised that some of the negatives to burning include loss of nutrients (amount depends on temperature), increased regulation and potential losses of soil from erosion. Increasing restrictive regulations are being implemented that also make burning more difficult in the future. In some shires, a single burn requires 6 people, 2 fire control units (1 with 5000L and the other with 500L) and you are not able to leave the paddock until NO smoke is detected.

Conclusion

It is extremely important for farmers NOT to compromise managing weeds, disease, pests or being able to sow their crop in a timely manner due to excessive stubble loads. Farmers need to be pro-active in managing their stubble which should have commenced before harvest and continued until sowing to ensure their stubble management will suit their seeding system. It has been shown that by diversifying a crop rotation (increasing the number of pulse crops and barley), deep banding nitrogen, managing pests and diseases, managing stubble by baling or grazing that it is easier to manage stubble without the need to burn. A diversified sustainable management strategy incorporating a double break crop offers a profitable farming system with reduced nitrogen costs that is effective at controlling weeds. Farmers can also retain their stubble in most years even when establishing crops with a tine opener. However, if the stubble load remains too large or the potential weed/disease/pest burden remains too high, then a one off strategic late burn can be used to “re-set” the system.

We suggested that growers wishing to retain all stubble should avoid growing wheat after wheat, that residue loads are reduced by grazing and/or burning where wheat is to be grown following wheat, or supplementary N fertiliser is applied to offset that immobilised by the residue. Grazing wheat stubbles can increase the yield of subsequent wheat crops due to less immobilisation and greater availability of mineral N to subsequent wheat crops. Burning wheat stubble residues also increased yield of subsequent wheat crops, but did not increase pre-sowing soil mineral N to the same extent as grazing, possibly due to later timing. However, both treatments presumably influenced in-crop N availability and thereby crop yield. Burning wheat stubble can also reduce frost damage in subsequent wheat crops and increase yield accordingly in frosty seasons.

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Weeds concurrent session

How widespread are different types of resistance in central NSW – new survey data. How different farming systems select for different types of resistance in key weeds.

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Keywords

herbicide resistance, ryegrass, wild oats, sow thistle

GRDC codes

USC00020, UCS00024, US00084

Call to action/take home messages

- In central NSW a significant proportion of paddocks surveyed contain ryegrass resistant to one or more herbicide groups.
- Group A fop resistant wild oats are more prevalent in central NSW than in NSW overall.
- Despite resistance, most weed populations are still present below one plant per metre square at harvest time.
- Management practices do influence resistance development, but the high levels of resistance mean the relationships are harder to determine.

Herbicide resistance surveys

Since 2007 as part of several GRDC funded projects, Charles Sturt University has been conducting annual surveys to determine the level of herbicide resistance across the cropping regions of NSW. Each year a specific region of NSW is surveyed with the aim of re-surveying each region on a five year cycle. During the surveys, whenever present, samples are collected of ryegrass, wild oats, barley grass, brome grass, wild radish, Indian hedge mustard and wild radish. This enables the reporting of:

a) differences between regions as to the extent of herbicide resistance and

b) the rate of increase between surveys.

At the same time as the sample collection the densities of the collected species and any other species in the paddock are estimated. Densities are classified as very low (occasional plant), low (<1 plant/m^2), medium (1-10 plants/m^2), high (>10 plant/m^2) and very high (>10 plant/m^2 and dominating crop). To allow for differences in biomass and competitiveness, species smaller than ryegrass have higher thresholds, while those larger have lower thresholds.

Results and discussion

Weed species present

Over this period, 1528 paddocks (Figure 1) have been visited across NSW, resulting in 939 ryegrass, 777 wild oat, 148 barley grass, 133 brome grass, 356 sow thistle, 76 wild radish and 76 Indian hedge mustard samples being collected for resistance screening. Despite the presence of herbicide resistance in all species, and for some species in the majority of populations, many of the weeds are present only in low densities (Figure 2).

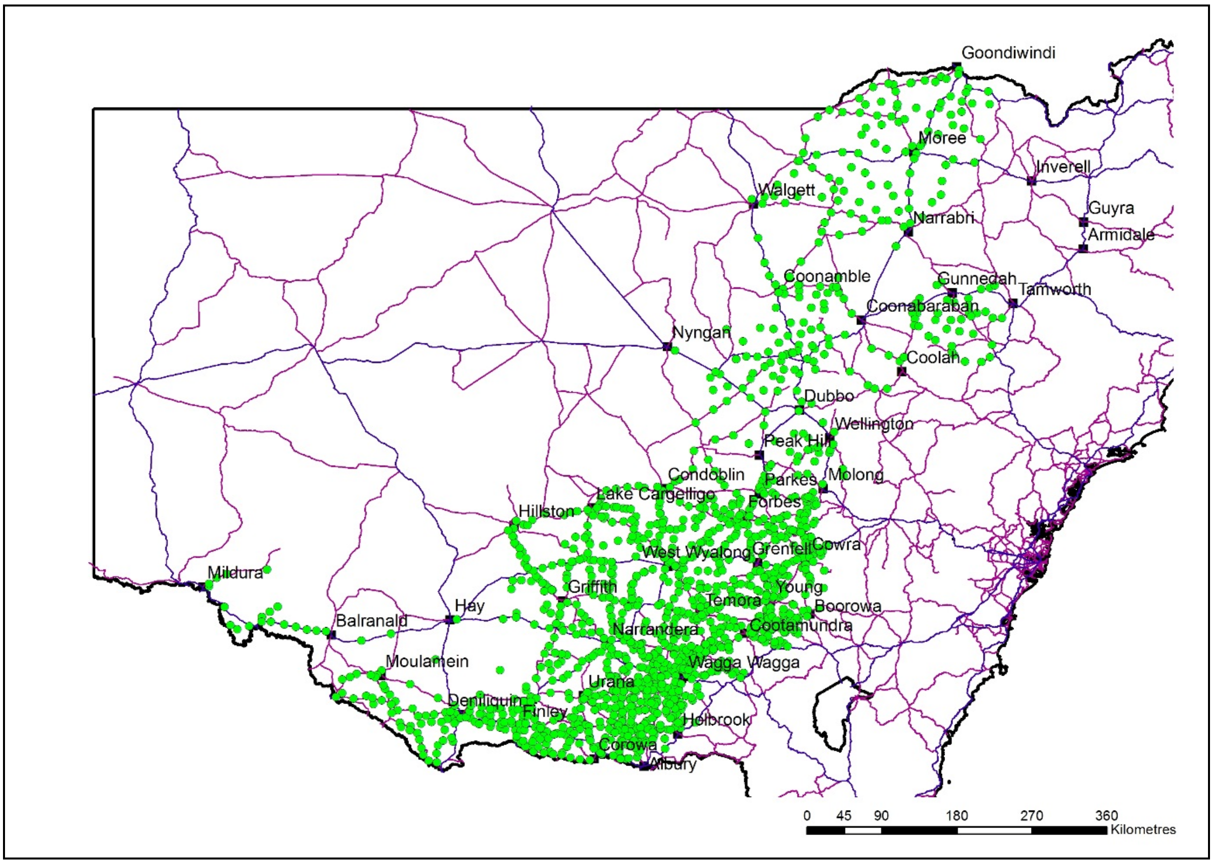

Figure 1. Locations visited for collection of samples during surveys (2007-2017)

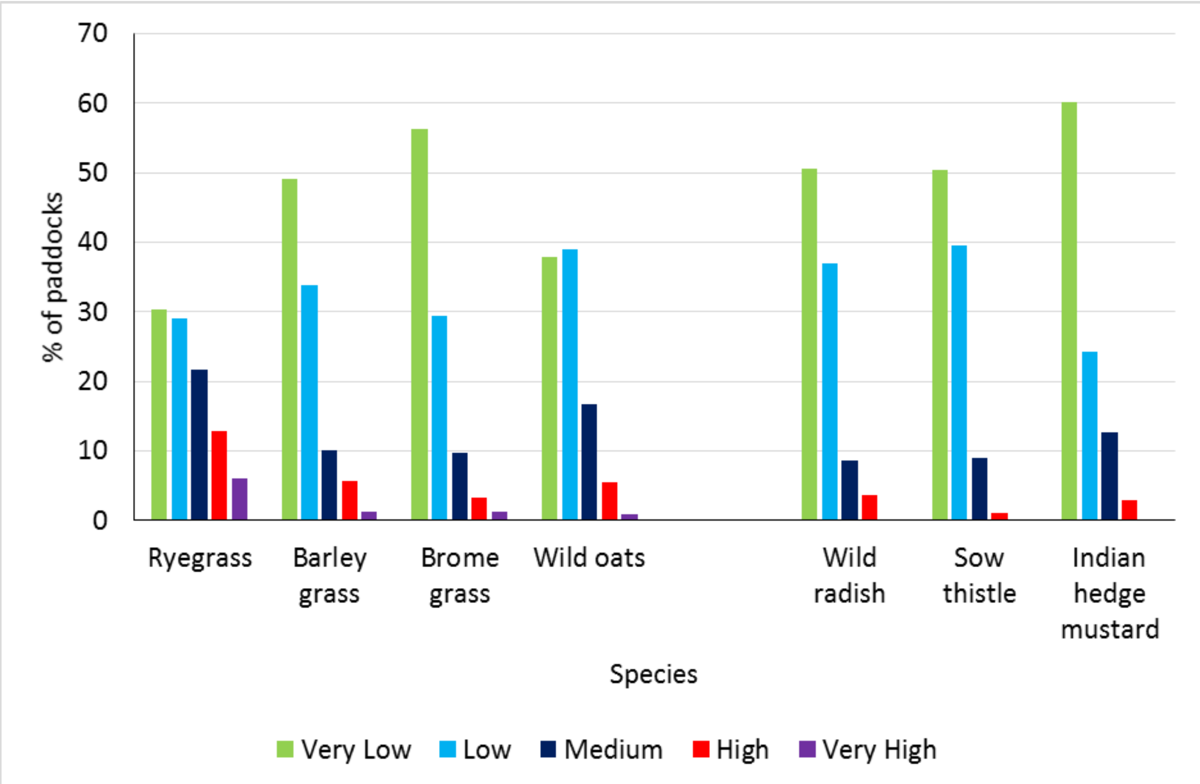

Figure 2. Density of different weed species across all surveys between 2010 and 2017

Ryegrass

Results from the latest surveys across the Australian cropping region show that approximately two thirds of ryegrass populations are resistant Group A fop herbicides, with a similar level of resistant to Group B herbicides (Table 1). The extent of resistance to both the Group A dim herbicide clethodim and Group D herbicides is lower but still at a significant level of 17% of populations. Five percent of populations across New South Wales (NSW), Western Australia (WA) and Tasmania were classed as resistant to glyphosate (not tested in South Australia (SA) or Victoria). The extent of resistance across NSW was similar to that of the overall level for the Australian cropping region, with WA having the highest resistance levels for all herbicides (Table 1).

The extent of resistance varies markedly across the different survey regions in NSW. For the Group A (fop and dim) and B (SU and Imi) herbicides, a greater percentage of populations were resistant in the slopes (approximately between Newell and Olympic Highways north of the Sturt Highway), higher rainfall (approximately east of the Olympic Highway) and southern (south of Sturt Highway and east of Newell Highway) regions (Table 2). The extent of Group D resistance was highest in the slopes and southern regions, with the other regions having few populations resistant to trifluralin.

Table 1. Extent of herbicide resistance in ryegrass populations from the most recent surveys across Australia and differences between States. Resistance levels are as defined by the various researchers.

	Australia 2005-15	NSW 2010-16	WA 2010	SA 2007-09	Victoria 2005-09	Tasmania 2014
A fop	64	64	96	48	50	46
A dim	17	10	42	16	8	8
B SU	63	56	98	73	26	16
B Imi	-	48	-	-	-	20
D	17	11	27	25	2	8
J/K	-	0	-	-	-	0
K	-	0	-	-	-	0
M	5	3	7	-	-	0
Samples	2039	597	466	606	318	52

Data: NSW – Broster unpublished data (Broster et al. 2011; Broster et al. 2013), WA - (Owen et al. 2014), SA and Victoria - (Boutsalis et al. 2012), Tasmania - (Broster et al. 2012)

Among the other regions the extent of Group A fop and B resistance was only slightly lower in the Plains (approximately east of Newell Highway, and north of Irrigation Way and Kidman Way) region but Group A dim and D resistance was markedly lower. The regions with the lowest levels of resistance to the selective herbicides, the Western (approximately west of Newell Highway, Irrigation Way and Kidman Way) and Northern (north of Peak Hill, Dubbo and Wellington) had the greatest percentage of populations resistant to glyphosate (Table 2).

As several of these regions join in the Central West the results for samples collected south of Coonabarabran and north of the Lachlan River were consolidated for the region. For most herbicides the findings were similar to NSW with 66% of samples resistant to Group A fop, 8% to A dim, 7% to trifluralin and 2% to glyphosate. Only the Group B herbicides had lower resistance levels with 43% resistant to Group B SU and 41% to Group B Imi.

Table 2. Extent of herbicide resistance in ryegrass populations from the most recent surveys for various regions within NSW. Data is total of both resistant (>20% survival) and developing resistant (10-20% survival) populations.

	Southern 2010 & 2013	Slopes 2013	High rainfall 2014	Western 2015	Northern 2016	Plains 2016
A fop	79	90	84	23	44	71
A dim	20	18	17	5	2	5
B SU	78	70	77	36	29	47
B Imi	56	50	87	30	33	44
D	21	25	2	7	1	3
J/K	0	0	0	0	0	0
K	0	0	0	0	0	0
M	0	3	0	6	10	1
Samples	96	115	64	117	94	111

Of the 597 ryegrass populations collected across NSW in the most recent surveys for each region, 497 of these had enough seed to be tested to five selective herbicide groups; A fop, A dim, B SU, B Imi and D. Nearly a quarter of these populations (121) were susceptible to all these herbicides, however 105 of these were, as would be expected, from the regions with the lowest resistance levels (plains, western and northern) (Figure 3). Overall, nearly half of these samples were resistant to three or more herbicide groups, limiting farmer options for ryegrass control with eight of the populations resistant to all five herbicides.

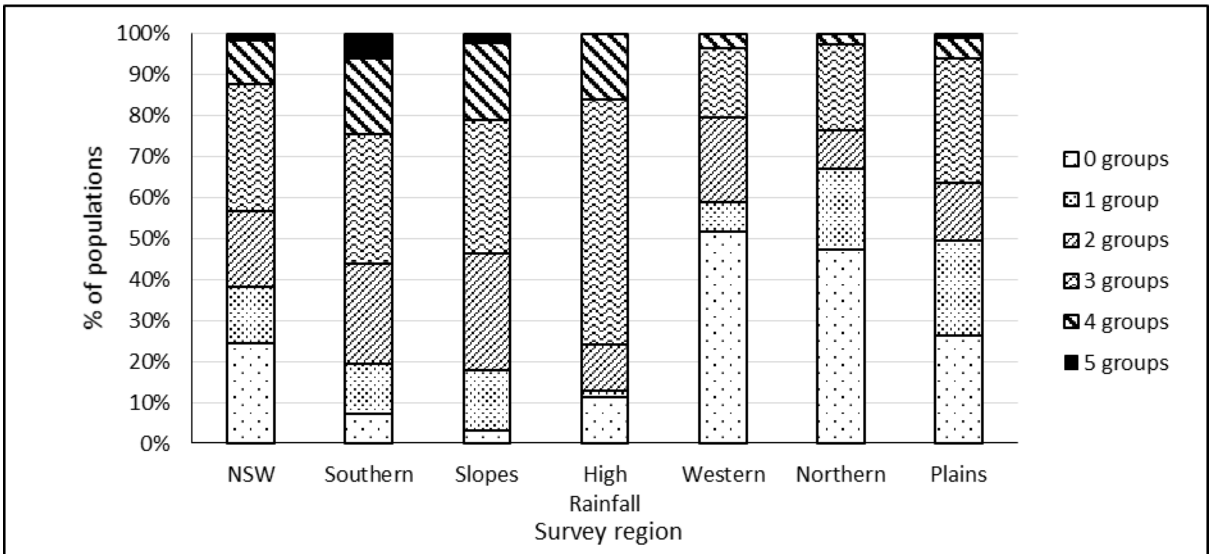

Figure 3. Level of cross resistance for ryegrass populations screened to five herbicide groups in NSW resistance surveys

Previous research from the Charles Sturt University (CSU) herbicide resistance testing service has shown there is minimal difference between the A fop herbicides with regard to resistance development with 97% of populations tested to diclofop-methyl and haloxyfop having the same resistance status (Broster and Pratley 2006) and no difference between fops and dens (Broster and Pratley unpublished data). However, there are differences between dim herbicides with only 31% of samples screened to both tralkoxydim and clethodim having the same resistance status (Broster and Pratley unpublished data). In the surveys where samples were tested to both of these herbicides the extent of resistance was much lower to clethodim than tralkoxydim. This was also reported in the SA and Victorian surveys (Boutsalis et al. 2012).

Of the 847 ryegrass samples that were tested to both SU and Imi herbicides 686 (81%) had the same resistance status, slightly higher than the 70% of samples having the same resistance status when tested to both by the CSU herbicide resistance testing service. These results show that when resistance occurs to both dims and Group B herbicides there may still be options within those groups to successfully control the weeds.

Wild oats

The extent of herbicide resistance in wild oats is much lower than the ryegrass with 37% of populations resistant to group A fops across NSW. Only two wild oat populations collected in the surveys were classed as resistant to clethodim, however in a previous survey where no samples were resistant to clethodim, 14% of populations tested to tralkoxydim were resistant. The CSU herbicide resistance testing service has found 2% of wild oat populations (16/718) tested to clethodim to be resistant, compared to 40% (32/81) to tralkoxydim. This shows resistance is developing to dim herbicides and care needs to be taken to maximise the effective use of clethodim. Similar to ryegrass there are differences regarding the extent of herbicide resistant wild oat population for the survey regions with the higher rainfall, more intensively cropped regions having the higher resistance levels (Table 3).

A greater proportion of wild oat populations from the central west region were resistant to group A fop than for NSW overall (54% compared with 38%), for the other screened herbicides the extent of resistance was similar.

Table 3. Extent of herbicide resistance in ryegrass populations from the most recent surveys for various regions within NSW. Data is total of both resistant (>20% survival) and developing resistant (10-20% survival) populations.

	NSW	Southern 2010 & 2013	Slopes 2013	High rainfall 2014	Western 2015	Plains 2016
A fop	38	36	57	46	12	41
clethodim	1	0	0	0	0	2
B SU	8	0	1	53	6	0
J	0	0	0	0	0	0
Samples	336	39	98	35	94	70

Barley grass and brome grass

Eight percent of the 109 barley grass populations screened were resistant to group B SU herbicides with populations also resistant to group A fop and paraquat. The majority of the resistant populations came from the western region. A total of 88 brome grass populations have been screened for resistance with all populations from the slopes, plains or higher rainfall regions susceptible to all tested herbicides. Of the 31 populations from the Western survey, 28% were resistant to Group B SU herbicides, 13% to Group B Imi and 11% to Group A fop herbicides.

Wild radish, sow thistle and Indian hedge mustard

Forty nine wild radish populations have been collected for resistance screening with low levels of resistance found to group B SU (13%), Imi (5%), C (4%) and F (4%). This is significantly lower than reported in the most recent WA survey (Owen et al. 2015). This is most likely a reflection of the lower number of wild radish populations and plants treated with herbicides when compared to WA.

However, these results show that resistance is developing to wild radish in NSW and farmers must manage their weed control to prevent resistance reaching the extent found in WA.

Of the 212 sow thistle populations collected 51% were resistant to group B SU and 2% to group I herbicides. Resistance was highest in the plains region (69%) and lowest in the slopes (43%) with the other regions having similar resistance levels.

Resistance has been found in 44 Indian hedge mustard populations that have been collected during the resistance surveys with 16% resistant to groups B and 2% to group I herbicides. No populations were resistant to group B Imi, C, F or M.

Relationship with farming system

With increasing levels of herbicide resistance across the state, it is becoming increasingly difficult to correlate management practices with resistance, as in many regions populations are resistant to three of four herbicide groups (Figure 3). However some relationships are still noticeable.

The extent of resistance to the group M herbicides, while relatively low across NSW, is concentrated in several areas (Figure 4). The shires with the highest glyphosate resistance are those with a high potential for growing summer crops, either dryland or irrigated, with ryegrass as a common weed species. The extensive use of glyphosate in maintaining clean winter fallow has led to a greater extent of glyphosate resistance. The other shires with glyphosate resistance are those with higher rainfall, high intensity and input cropping systems in which the ryegrass populations are resistant to a large number of the selective herbicide groups.

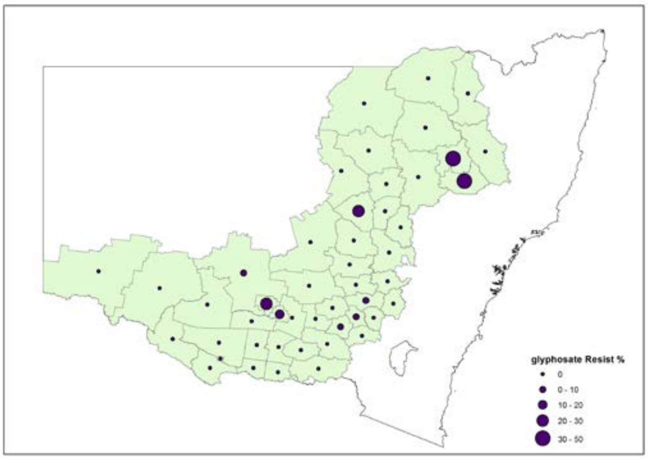

Figure 4. Extent of group M resistance across surveyed area

Shires that grew more canola were associated with higher levels of resistance, both in number of selective groups resistant and resistant to individual herbicide groups (Figures 5 and 6). This may be not directly related to the canola but that the areas that can grow canola are also those with higher rainfall and higher inputs - especially herbicides. This was most apparent in the relationship between canola and group D resistance (Figure 6).

Group B and D resistance levels were much lower in northern NSW. Wheat, barley and chick peas were the most common crops sampled during the 2016 resistance survey in northern NSW. While trifluralin can be used in all three and group B SU herbicides in wheat and barley, these are areas with summer cropping growing sorghum, cotton, sunflower and maize. The plantback period for both trifluralin and the sulfonylurea herbicides for both maize and sorghum is 12 months (Fleming et al. 2012). This would limit their use in this region where these summer crops are grown.

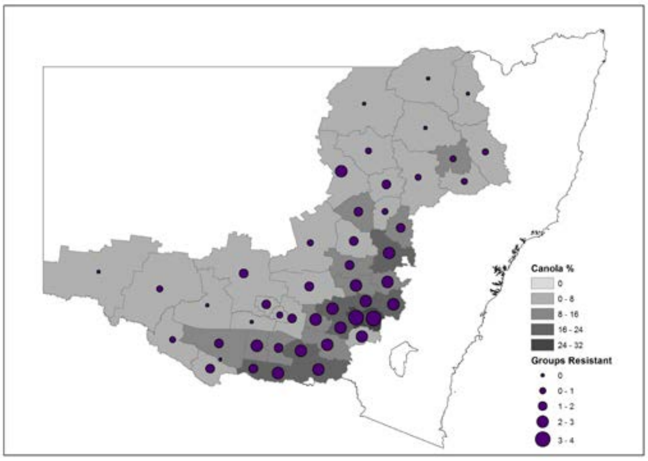

Figure 5. Map showing annual percentage of each shire sown to canola and average number of resistant selective herbicide groups (A fop, A dim, B SU, B Imi and D) for ryegrass

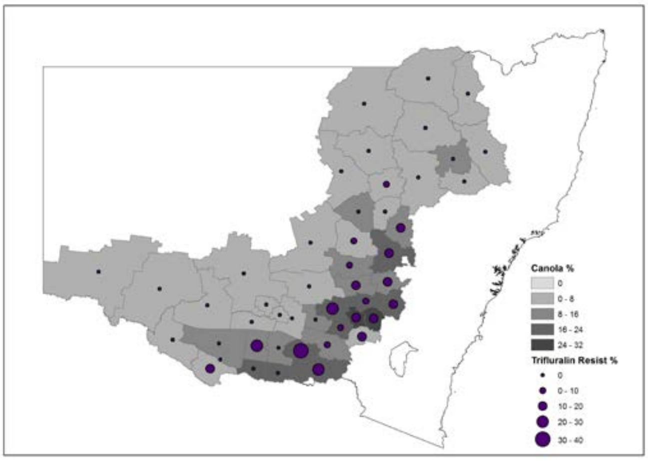

Figure 6. Map showing annual percentage of each shire sown to canola and extent of trifluralin resistance in each shire

As trifluralin requires incorporation and binds to organic matter it would be expected that shires with higher levels of trifluralin resistance would also have higher levels of cultivation and stubble burning. While most of the shires with higher level of trifluralin resistance are also shires with the greatest proportion of stubble burning, they do have higher levels of crop sown with no cultivation before sowing. These high stubble burning with zero cultivation shires with high trifluralin resistance also have the highest Group A fop and B resistance and canola and this combination may be a reflection of cropping intensity and therefore selection pressure for resistance development.

Conclusion

Over 70% of ryegrass populations in NSW are resistant to a minimum of one selective herbicide group. Resistance is highest to the group A fop and group B herbicides. However, no resistance was found to the newer pre-emergent herbicides, Boxer® Gold and Sakura®. For the other species, while significant levels of resistance were found to one or two herbicide groups, the extent of resistance varied greatly between regions. The differences between the survey regions reflected differences in rainfall pattern, crop types, rotation and intensity and the prevalence and importance of the various weed species in each region. However because of the overall high levels of resistance in some areas it is very difficult to assign these differences to cropping practices.

Acknowledgements

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. The work of numerous students and casual staff at Charles Sturt University who have assisted in both the surveys and the resistance screening is much appreciated. The assistance of Neil Clark and Associates who provided the ABS data is acknowledged.

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Alternate second knock herbicides for broadleaf weeds in fallow – are there other options?

Richard Daniel, Anthony Mitchell, Linda Bailey, Denielle Kilby and Branko Duric, Northern Grower Alliance

Key words

common sowthistle, flaxleaf fleabane, double knock

GRDC code

NGA00004 GRDC Grower Solutions for Northern NSW and Southern Qld

Call to action/take home messages

- A series of 8 trials has shown that saflufenacil (Sharpen®) may have a useful role as a 2nd knock treatment for key broadleaf weeds.
- Level of control was at least equivalent to paraquat at 1.6-2.4L/ha of the 240 g ai/L formulation in these trials.
- However poor control was achieved from both paraquat and saflufenacil when used as 2nd knock treatments on flaxleaf fleabane, following glyphosate only.
- No option provided effective management when applied as a 2nd knock on tall fleabane (*Conyza sumatrensis).*
- Paraquat did not provide acceptable levels of suppression of Canadian fleabane (*Conyza canadensis)* when applied as a 2nd knock at 1.6-2.4L/ha.
- Mixtures of saflufenacil and paraquat require further evaluation as they may provide more robust control of key fallow weeds.

Background

The sequential application of two separate herbicide treatments has become the most common 'double knock' approach used in weed management. Unfortunately these approaches have added cost, complexity and scheduling issues to weed management programs but have been required for two main reasons:

1. To control herbicide resistant weed populations, that may have been selected by prolonged use of similar mode of action chemistry; and
2. Control of weed species or stages that are unsuccessfully controlled with single herbicide applications.

Paraquat has been the key active ingredient used in the second knock situation and can provide effective management of a wide range of grass and broadleaf weeds. However, it is clear we require other options to use in this management window to:

1. Avoid the more rapid selection of paraquat resistance; and
2. Provide options that may improve weed control in situations where paraquat efficacy is not adequate.

Since winter 2016, NGA have been screening a range of herbicides, to identify options that have potential for this use pattern. The two key broadleaf weeds being targeted are common sowthistle (*Sonchus oleraceus*) and flaxleaf fleabane (*Conyza bonariensis*).

Trials conducted

Table 1 shows the key details of trials conducted during the last 12-15 months.

Table 1. Trial details

Main Weed	Location	Date of 1st knock application	Days to 2nd knock application
Common sowthistle	Tambar Springs	9/10/2016	7
Flaxleaf fleabane	Mt Tyson	17/10/2016	11
Flaxleaf fleabane	Dalby	6/12/2016	10
Common sowthistle	Moree	16/6/2017	19
Common sowthistle	Mullaley	20/9/2017	14
Tall fleabane	St Ruth	27/11/2017	9
Canadian fleabane	Cecil Plains	27/11/2017	10
Common sowthistle	Somerton	19/12/2017	8

NB Tall fleabane - *Conyza sumatrensis,* Canadian fleabane - *Conyza canadensis*

Approach

1st knock treatments were applied uniformly across the entire trial area. The most common treatment was a mixture of glyphosate and 2,4D amine, with the rates varying with the weed stage, environmental conditions and the grower/adviser recommendations.

2nd knock applications were applied between 7 and 19 days after the 1st knock treatments.

- All trials included a range of rates of paraquat for benchmarking purposes.
- Initial trials included a range of group G herbicides (all registered in fallow alone or in mixture with glyphosate or paraquat) and the group N herbicide glufosinate (Basta®).
- The most promising group G option was evaluated in all trials.
- The 'untreated' plots in all trials had the 1st knock herbicide treatment applied but did not receive a 2nd knock application.

Results to date

- Trials in 2016 on both common sowthistle and flaxleaf fleabane showed improved efficacy from saflufenacil (Sharpen) as a 2nd knock treatment compared to flumioxazin (Valor®) or carfentrazone (eg Nail®). No further evaluation has been conducted on flumioxazin or carfentrazone.
- Interestingly, the performance of saflufenacil has appeared more consistent when used in a 2nd knock application, particularly on common sowthistle.
- Glufosinate was evaluated in the initial series of trials but did not provide any consistent benefit over paraquat or saflufenacil. Performance of glufosinate has appeared similar whether used in a 1st or 2nd knock situation (data not presented).

Figures 1 and 2 show results from two of the trials evaluating double knock control of common sowthistle conducted in 2017.

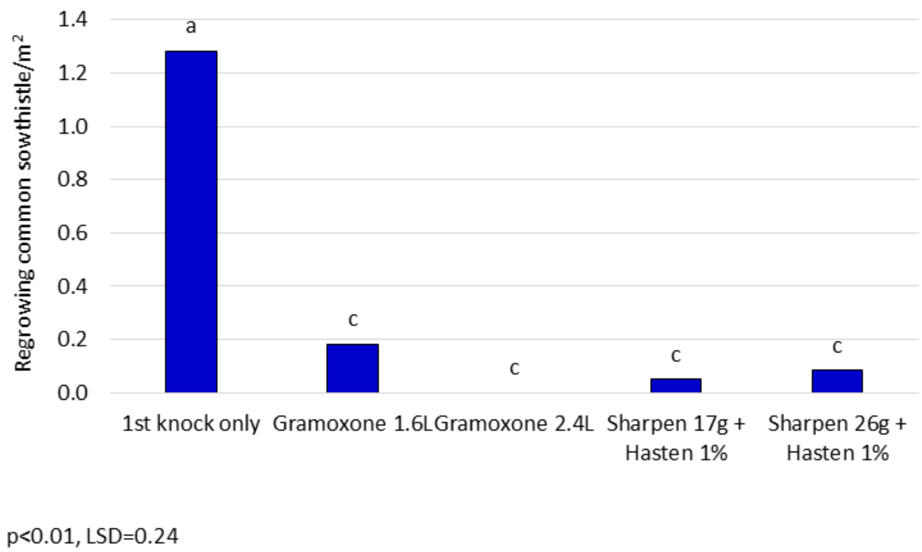

Figure 1. 2nd knock control of common sowthistle (26 days after application) at Mullaley Oct 2017
NB 1st knock application was Glyphosate 450 + Amicide® 625

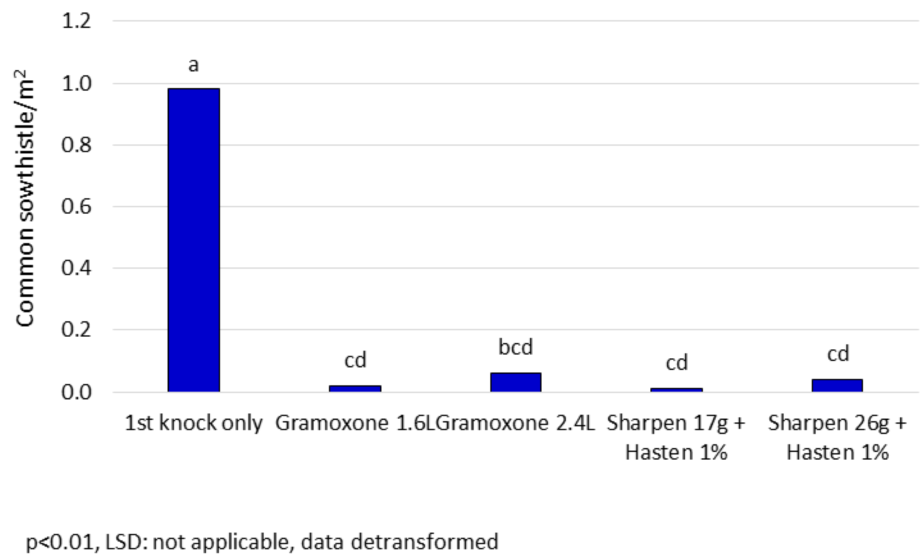

Figure 2. 2nd knock control of common sowthistle (44 days after application) at Croppa Creek Aug 2017
NB 1st knock application was Glyphosate CT + Amicide 625

Figures 3 and 4 show results from the two sites in 2016 evaluating double knock control of flaxleaf fleabane. NB Figure 4 shows the result from a site where the commercial application of a 1st knock was glyphosate alone. Previous activity has shown that the addition of 2,4D to the first spray is generally critical to achieve effective control of flaxleaf fleabane, even when double knocked with paraquat.

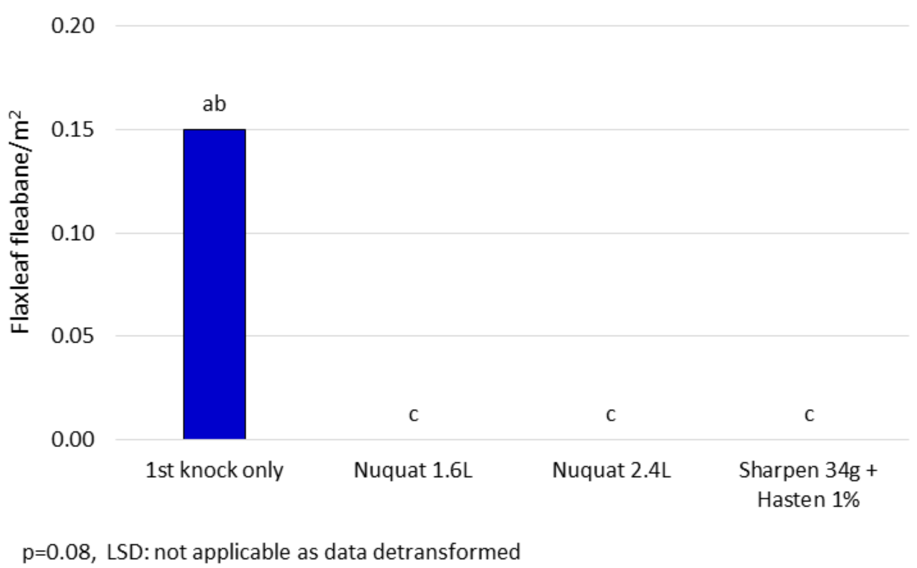

Figure 3. 2nd knock control of flaxleaf fleabane (24 days after application) at Dalby Jan 2017
NB 1st knock application was Glyphosate 450 + Amicide 720, **significant differences are only tested at the 10% level**

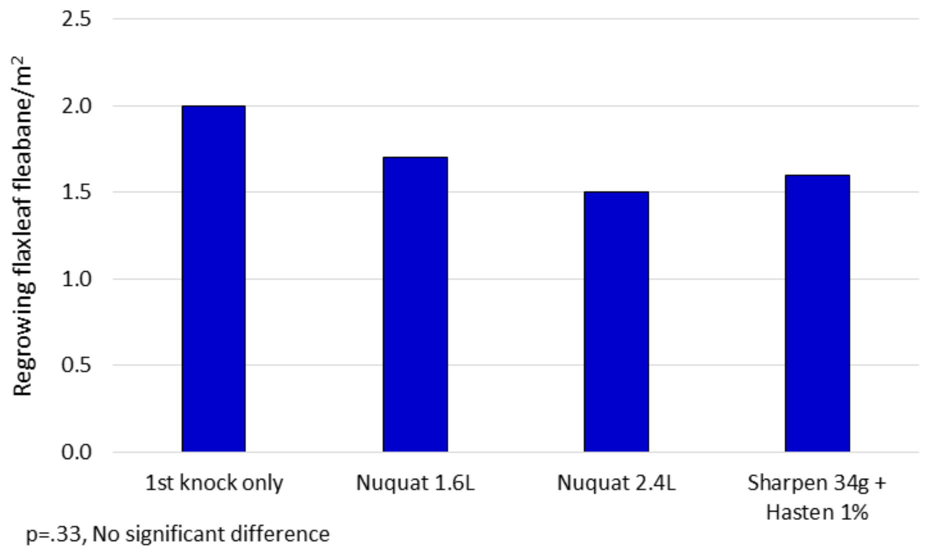

Figure 4. 2nd knock control of flaxleaf fleabane (17 days after application) at Mt Tyson Nov 2016
NB 1st knock application was Glyphosate CT only

Key points

- Sharpen (700g/kg saflufenacil) at rates of 17 and 26g/ha provided a similar level of control to paraquat at 1.6 to 2.4L/ha when applied as a 2nd knock application on common sowthistle in all 4 trials.
- Sharpen (700g/kg saflufenacil) at rates of 34g/ha provided equivalent control to paraquat at 1.6 to 2.4L/ha when applied as a 2nd knock application on flaxleaf fleabane in 2 trials.
- Poor levels of control were achieved by all 2nd knock options on flaxleaf fleabane when glyphosate only was used as the 1st knock (see Figure 4).

- No herbicide product provided useful levels of control of tall fleabane (*Conyza sumatrensis)* when applied following Roundup Ultra® Max and Amicide 625 (data not presented).
- Paraquat did not provide useful levels of control of Canadian fleabane (*Conyza canadensis)* when applied following Tordon™ 75D (data not presented)

Conclusions

The results to date indicate that the group G active ingredient saflufenacil warrants further investigation as a potential 2nd knock option for the control of a number of key broadleaf weed species. Across this series of trials, the level of control was similar to that provided by rates of paraquat of 1.6-2.4L/ha. However in situations where paraquat failed to provide useful efficacy on flaxleaf fleabane following an application of glyphosate only, there was no indication of improved benefit from saflufenacil.

Where to next?

Saflufenacil clearly may have a useful fit as a 2nd knock alternative on broadleaf weeds such as common sowthistle or flaxleaf fleabane. However the majority of fallow applications have a need for both broadleaf and grass control. Consequently part of the project activity in 2017 was to commence an evaluation of the fit of saflufenacil/paraquat mixtures to identify cost effective but more robust options for use as 2nd knocks.

Acknowledgements

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

NGA would particularly like to acknowledge the assistance from our trial co-operators during this series of trials: Terry Leerentveld, Justin Commens, Warren Myring, Ben McIntyre, Aaron Goddard, Gavin Maguire, Graeme Gall and the Strang Family.

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Impacts of residual herbicides on soil biological function

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[2]NSW Department of Primary Industries

Key words

residual herbicides, rhizobia, nodulation, N fixation, mycorrhizal colonisation

GRDC code

DAN00180

Call to action/take home messages

- Numerous factors (such as herbicide group, application rate and frequency, soil type, crop type and environmental conditions) influence the expression of herbicide persistence in soil. Results to date imply that risk to crop growth through direct phytotoxicity (plant-back) is more important than through impacts on soil biological processes.
- Herbicides with longer residual lives such as imazapic, products that contain picloram, and diuron can potentially significantly reduce chickpea shoot and root growth as well as number and dry weight of the nodules of chickpea plants when applied 90 days prior to planting. Nitrogen fixation would therefore be impacted, leading to potential N deficiency in the pulse and of the following crop. Careful adherence to recommended plant back periods for sensitive crops is critical.
- Mycorrhizal colonisation of crops does not appear to be negatively impacted by herbicide residues in soils unless major root damage has occurred.

Background

Over the last thirty years, the number of Australian grain growers using reduced-till technology has increased from around 5% to over 70%. This has dramatically improved soil structure and reduced erosion, but has also necessitated an increase in herbicide use for weed control. Little is known about how increased herbicide use might impact on soil organisms and the beneficial functions they provide. Anecdotal evidence also suggests that plant-back damage in rotational crops due to herbicide residues is a growing concern amongst growers, but the scale and cost to the Australian Grains industry remains unknown. A GRDC-funded project (DAN00180) has been benchmarking the level of herbicide residues in cropping soils and generating new knowledge about the fate, behaviour and risk of herbicides to productivity and soil biological function. The aim is to enable the Australian grains industry to better understand the risks and implement changes in management for more productive and resilient farming systems.

One part of this project has been examining the impacts of residual herbicides applied over a summer fallow on subsequent biological symbiotic associations (rhizobia and mycorrhizal) in winter crops (chickpea and wheat) and biological components (nematode communities, microbial activity) of the soil. Field trials conducted by the Regional Research Agronomy network and the weeds teams within the Sustainable Farming Systems group of Crop and Food Science, Qld DAF, have given an opportunity to viably assess the impact of some residual herbicides on certain crop associated soil biological functions and components. With the increase in glyphosate resistance and difficult to control weeds in the northern region, alternative weed management tactics are required. One such alternative is residual herbicides. Residual herbicides can provide medium to long-term control of weeds in fallow and crop by controlling several flushes of emergence. However the efficacy of residual herbicides can be affected by the environment (soil type, rainfall, temperature). Therefore, it is necessary to gather local efficacy and persistence data across a range of environments and seasons. Persistence of residual herbicides can have flow-on effects on the biological components of soils either directly or indirectly (through reduced plant and root growth).

What was done

Residual herbicide trials were conducted across Queensland over the summers of 2015/16 and 2016/17. Multiple sites operated out of Emerald, Goondiwindi and Toowoomba (15 sites in total) were established to investigate the efficacy of residual herbicides on key summer weeds. Bioassays using soil samples collected 90 days post-spraying were then conducted to study the impact on soil biota such as mycorrhizal fungi and beneficial nematodes as soil health indicators and on key biological associations such as nodulation with N fixing bacteria.

Site

Each field trial was established at a site/s where there was an expected uniform density of a minimum 30-50 plants/m^2 for each flush of emergence (often difficult to predict). This was to ensure there would be enough target weed species to distinguish between treatments either alone or in mixture.

Experimental design

- Randomised block
- 3 replications x 16 herbicide treatments (Table 1)
- Pot size: 8m x 2m

Table 1. Treatments (note not all treatments applied at all sites)

Trt No.	MOA	Product/s	Rate (/ha)	Active ingredient, grams active/L(kg)	g.a.i./ha
1	-	Untreated control	-		
2	B	Flame®	200 mL	Imazapic 240 gai/L	48
3	D	Stomp® Xtra**	3.3 L	Pendimethalin 455 gai/L	1500
4	C	Terbyne®	1.4 kg	Terbuthylazine 750 gai/kg	1050
5	H	Balance®	100 g	Isoxaflutole 750 gai/kg	75
6	K	Dual Gold®	2 L	S-metolachlor 960 gai/L	1920
7	B + H	Flame + Balance	200 mL + 100 g	Imazapic 240gai/L + Isoxaflutole 750gai/kg	48 75
8	B + K	Flame + Dual Gold	200 mL + 2L	Imazapic 240gai/L + S-metolachlor 960gai/L	48 1920
9	B + D	Flame + Stomp Xtra	200 mL + 3.3 L	Imazapic 240gai/L + Pendimethalin 455gai/L	48 1500
10	D + H	Stomp Xtra + Balance	3.3 L + 100 g	Pendimethalin 455gai/L + Isoxaflutole 750gai/kg	1500 75
11	C	Nu-trazine™**	1 kg	Atrazine 900gai/kg	900
12	C	Diuron 900 DF	1 kg	Diuron 900gai/kg	900
13	G	Sharpen®	34 g	Saflufenacil 700gai/kg	24
14	I	FallowBoss™ Tordon™	1 L	2,4-D amine at 300gai/L + picloram 75gai/L + aminopyralid 7.5gai/L	300 75 7.5
15	K	Outlook®#	1 L	Dimethenamid-P 720gai/L	720
16	D	TriflurX®#	3 L	Trifluralin 480gai/L	1440

** Please note that Stomp Xtra and Nu-trazine were used as a treatment in this trial and are no longer registered products, however other products are available containing the same active ingredients are registered. Always refer to label for rates.

Products not registered in fallow.

Application of treatments

- To start with a weed-free trial site, weeds were initially sprayed out with a non-residual knockdown herbicide (eg. glyphosate or paraquat).
- Herbicide treatments were applied at a spray volume of 100 L/ha using 015 even flat fan nozzles on a 2m shielded boom.
- At most sites, herbicides were incorporated by rain.

Bioassays

A minimum of 5 kg of soil to a depth of 10cm from each plot was collected 90 days post application. Soil from each treatment at each site was potted into 3 x 1.5 L pots and planted to either uninoculated chickpea or inoculated (with rhizobia, strain CC1192) chickpea or to wheat. Soil was also collected for a nematode community analysis at time of sampling and for soil physical characteristics. Whilst an analysis of the level of herbicide residue at this time would also be of interest, it was cost prohibitive to do all samples and so specific plots/treatments only will be analysed.

Plants were grown for 8 weeks, at which time top and root growth was assessed and nodulation due to rhizobia was scored for each of the chickpea treatments. Wheat roots were subsampled for mycorrhizal colonisation assessments.

Results

Whilst analyses are still underway, preliminary results are indicating that residual effects of imazapic (Trt 2) and the combination of imazapic and isoxaflutole(Trt 7), of diuron (Trt 12) and of picloram, 2,4-D and aminopyralid (applied as Fallow Boss Tordon) (Trt 14) have all had negative impacts on nodulation and in some cases growth of the plant. Figures 1 and 2 are examples of the impacts on nodulation and plant growth respectively at one site (Denver) in southern Qld. These effects are not surprising, as these active ingredients are all listed as being slowly degraded by microbes with average half-lives of 89 (diuron) to 232 (imazapic) days (Congreve and Cameron 2014). Furthermore plant back periods for chickpea as specified on some key product labels are 4 months for imazapic and 6 months for FallowBoss Tordon (picloram, 2,4-D and aminopyralid). Soil organic matter and the amount and frequency of rainfall will greatly influence degradation times as breakdown is primarily via microbial degradation processes. Temperature will also have an influence, as can incorporation by rainfall or tillage. In the case of imazapic, soil pH will also have an influence, soil half-life values being somewhat longer in lower pH soils. We sampled at 90 days post application, so given the dry season over the summer, several of these slower to degrade herbicides are obviously still persisting with the potential to exhibit negative impacts on plant growth and nodulation of the sensitive species chickpea.

Mycorrhizal colonisation of wheat roots completed for the Denver site have shown no impacts of the herbicides on % colonisation by arbuscular mycorrhizal fungi (AMF), with levels consistently around 50 -60%. Damaged chickpea roots however do have lower mycorrhizal colonisation levels and hence much lower lengths of mycorrhizal root. Nematode communities are also under analysis to determine impacts on soil food web structures.

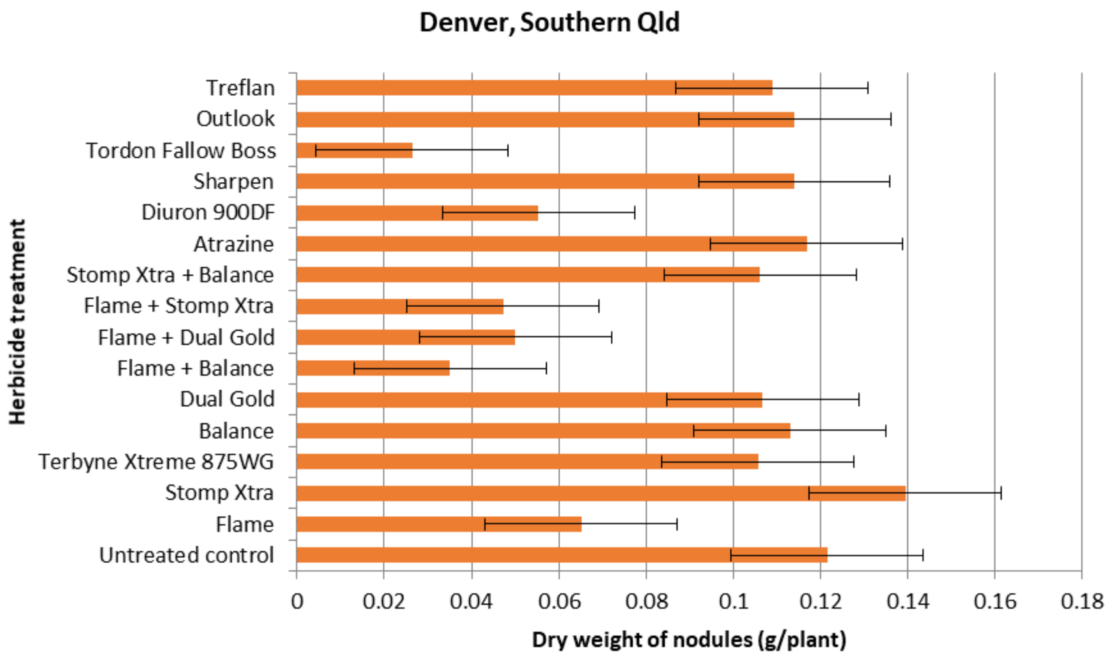

Figure 1. The dry weight of nodules on 8 week-old chickpea plants grown in pots of a vertosol that was collected from a paddock in southern Qld 90 days post application of various residual herbicides.

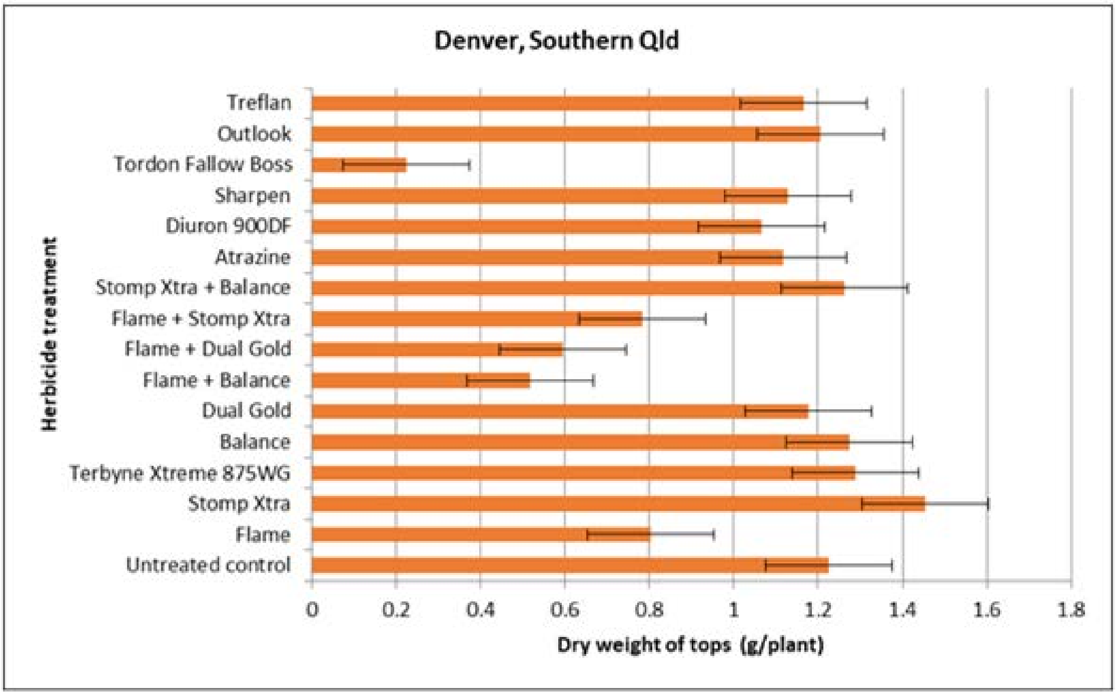

Figure 2. The dry weight of shoots of 8 week-old chickpea plants grown in pots of a vertosol that was collected from a paddock in southern Qld 90 days post application of various residual herbicides

Implications for growers

Growers should carefully adhere to recommended plant back periods for sensitive crops and be especially careful if the seasonal weather conditions have not been conducive to complete herbicide breakdown. Not only will growth of the crops be reduced but damage due to the presence of residual herbicide in the soil may also lead to reduced nodulation and hence reduced nitrogen fixation in a following chickpea crop leading to potential N deficiency in the pulse and of the following cereal crop. Severe root and shoot damage leading to poor crop performance has the potential to reduce mycorrhizal colonisation in following crops.

Acknowledgements

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. Many thanks especially to the DAF Regional Research Agronomy Network team especially Andrew Erbacher, Darren Aisthorpe and Duncan Weir for conducting the trials along with Michael Widderick and his weeds research team.

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New data on the integrated Harrington seed destructor and its efficacy on a broad range of weed species, including fleabane and sow thistle

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Key words

harvest weed seed control, HWSC, integrated Harrington seed destructor, iHSD

GRDC code

US00084

Call to action/take home messages

- Harvest weed seed control (HWSC) can reduce weed seed inputs into the seed bank.
- Many common annual weeds have high levels of seeds present at wheat crop maturity.
- Over 95% of weed seeds were destroyed after passing through the integrated Harrington seed destructor (iHSD®).

Introduction

A large proportion of Australian cropping paddocks contain weeds that are resistant to some of the herbicides used for their control. This both reduces the herbicide options for their control and limits crop yields if the weeds are unable to be controlled in a timely manner. Many annual weeds in Australian cropping regions retain their seed at maturity and thus are able to be captured by the harvester. Harvest weed seed control (HWSC) is a suite of management practices all of which target the seed of weeds at harvest time. HWSC systems include narrow windrow burning, chaff lining, chaff carts, bale direct and seed destruction.

The integrated Harrington seed destructor (iHSD®) is the first system developed to destroy weed seeds during the harvesting process. The iHSD does not crush or grind the weed seeds; rather it is an impact mill where the seeds are broken through numerous high speed impacts. An advantage of this system over other HWSC is that all harvest residues are retained and spread across the paddock.

Two factors influence the level of control provided by the iHSD. Firstly, the weed seeds must enter the front of the harvester; and secondly, they must be destroyed by the HWSC system used.

Seed retention

On average 93% of ryegrass seed was retained at the time of wheat crop maturity. The amount of ryegrass seed above 15cm differed between two experiments (Table 1). A greater percentage of ryegrass seed was found above 15cm in wheat crops with low numbers of large ryegrass plants with high seed production (Broster et al. 2015). Wild oat seed retention was also found to be high, however if harvest was delayed for 28 days seed retention had fallen to 39% (Walsh and Powles 2014).

Seed retention levels for flaxleaf fleabane were high although there was a large range in the proportion of seeds above 15cm in a wheat crop, while sow thistle had much lower and more variable seed retention and more of the retained seed was above 15cm (Table 1).

Table 1. Average seed retention for weed species at wheat harvest and percentage of retained seed above 15cm

Weed species	% seed retained		% of total retained seed
	Above 15cm	Total (range)	above 15cm
Annual ryegrass	75[a] or 85[b]	93[a]	
Wild oats	84[b]	69[c]	100[c]
Brome grass	77[b]		
Awnless barnyard grass		95[c]	100[c]
Flaxleaf fleabane		93 (81-100)[c]	40-100[c]
Sow thistle		53 (12-84)[c]	80-100[c]
Wild radish	99[b]		

References: a - (Broster et al. 2015), b - (Walsh and Powles 2014); c - (Widderick et al. 2014)

Seed destruction

To evaluate the efficacy of the iHSD on different weed species, a specific number of weed seeds were added (larger species were dyed for subsequent identification) to 2kg samples of wheat chaff. 11 weed species were tested at two different times. The samples were then introduced to a iHSD test stand by spreading the wheat chaff evenly across a conveyor belt. The chaff was fed into the mill at 1.5kg/sec equivalent to that processed by a twin-mill iHSD system with a wheat harvest rate of 35t/hr (Walsh et al. 2017).

All of the tested weed species had more than 95% of seeds introduced into the iHSD destroyed. For the majority of species seed kill was greater than 99%, annual ryegrass at 96% seed kill was the lowest ($P<0.005$) (Table 2).

Table 2. Number of weed seeds placed in wheat chaff and percentage destruction of seed from 11 weed species using the iHSD test stand (adapted from Walsh et al. 2017)

Weed species	Seed No.	Seed kill (%)
Annual ryegrass	1000	96
Wild oats	200	99
Brome grass	200	98
Awnless barnyard grass	1000	99
Flaxleaf fleabane	25000	99
Sow thistle	3000	99
Wild radish	200	99
Indian hedge mustard	2000	99
Windmill grass	3000	97
Barley grass	500	99
Feathertop Rhodes grass	3000	98

Acknowledgements

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. The work of Allison Chambers and Charles Sturt University students in assisting with the test stand operation and sorting through processed chaff samples is much appreciated.

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General plenary day 2

Connecting to our farming future

David Lamb, Precision Agriculture Research Group, University of New England

Key words

SMART farm, sensors, telecommunications, technology, future

Call to action/take home messages

The progression of telecommunications and technology must be accompanied by education and extension. A recent survey identified that more that 60% of Australian farmers did not know of on-farm connectivity options or who to talk to about getting connected. And 'connectivity is king'. Lack of connectivity is identified as one of THE constraints to adopting tools that improve productivity, safety and workflow. There are many challenges and opportunities of getting connected into a SMART farming future that, in 5-10 years, will just be farming. Farmers need to understand the basics of how connectivity works to be able to make informed decisions when getting connected. Government, policy makers and telco providers need to understand what farmers need and why.

Introduction

The role of the internet in agriculture is fast approaching a 'third wave.' The first wave was connecting people to data via the World Wide Web (1990s); the second wave was about connecting people to people e.g. through Facebook and Twitter (2000s). The third wave will connect people to 'things' (2010 onwards). These waves are not specific to agriculture. Developments in the agricultural field are contained within and mirror wider technological progressions that have led us to a place where every part of our lives relies on an internet connection.

In terms of on-farm developments, advances in wireless sensor networks coupled with in-situ, low-cost machine, crop, animal and asset sensors; the so-called 'internet of things' means our farms and fields will become sources of high-quality, real-time management data. Big data is really made up of lots of small data, and will become increasingly useful in day-to-day and long-term management decisions. Some of this data will be utilised alongside intelligent and autonomous systems operating both on ground and in the air.

The SMART Farm

I lead the University of New England's SMART Farm project (Sustainable Manageable Accessible Rural Technologies Farm). UNE has transformed a 2,900 ha, predominantly sheep farm into a SMART Farm which showcases the latest technologies aimed at improving productivity, environmental sustainability, safety, workflow and social/business support networks on Australian farms (www.une.edu.au/smartfarm, 2018). Buts is a CONNECTED farm; linked via AARNet and the national broadband network (fibre, terrestrial wireless AND satellite) because the predominantly grazing SMART Farm is a national demonstrator site.

Examples of the types of sensors we use include 100 soil moisture probes, which create a living map of soil moisture. The farm also has another telemetry network that allows devices to be 'plug-and-played' ranging from monitoring water use in trees, pasture growth through to honey accumulation in beehives.

We are also working with livestock tracking and are investigating opportunities around developing fingerprints of animal behaviour ranging from when they're attacked, if they're calving, whether they have internal parasites and also how much pasture is left behind from grazing.

Live satellite derived pasture data is available through the Pastures from Space™ program. This provides estimates of pasture production during the growing season by means of remote sensing. Satellite data is used to accurately and quantitatively estimate pasture biomass or feed on offer, or combined with climate and soil data is used to produce estimates of pasture growth rate (https://pfs.landgate.wa.gov.au/).

The SMART Farm is just an example of what the future of farming will look like- buts it's connected to the hilt. In order for that future to be realised across 137,000 Australian farms, action is required in the telecommunications sector.

Telecommunications

As well as sensor technology and big data, telecommunications is a key enabling part of the SMART Farming future. In 2016, the Commonwealth Department on Agriculture and Water Resources initiated a Rural R&D for Profit Research Project entitled 'Accelerating Precision Agriculture to Decision Agriculture' or 'P2D'. One of the aims the project was to deliver 'recommendations for data communications to improve decision making - or decision agriculture'; effectively to undertake a 'telecommunications review' for agriculture. During the period of August 2016 – June 2017, a series of eight workshops, numerous phone interviews and site visitations around Australia sought to understand the current status of on-farm telecommunications at the farm level in support of a big data future for agriculture. This review sought a 'producer-eye' view, seeking to understand the dimensions of key enabling telecommunications utilised by producers, factors constraining the uptake or adoption of available enabling technologies, as well as investigating the future telecommunications needs and opportunities. Information was solicited from not only producers, but also developers and providers of technologies and data services, as well as looking at the developments 'top-down' such as the ACCC Inquiry into Domestic Mobile Roaming and the Productivity Commission Review of the Universal Services Obligation (USO).

In the last couple of years the notion of telecommunications as a 'critical infrastructure' for rural and regional Australia, and in particular in agriculture, has at last well and truly taken root. Over this period there has also been a significant increase in the development of end-to-end telecommunications technologies and services offered to producers. These so-called 'second-tier' telecommunications providers (as distinct from the 'big telcos'), also offer their own transmission backhaul capability and in some cases associated cloud based services. Moreover they seek to 'guarantee' speeds. Second tier providers will help extend the value and potential of existing NBN and mobile telecommunication networks. The role of telecommunications in supporting a big data future in agriculture is not necessarily technology constrained; if a farm has access to the mobile network somewhere on the farm, or NBN into the farm house then there is invariably technology available to beam it to where it is needed. But the external connectivity MUST be stable 24/7. There is little value having high speed internet for only short periods of the day. If this is the case, as it often is, then at least we should be able to know IN ADVANCE when that will be so we can work to get the best out of it. Reliability is as important as absolute speed, and speed is different from signal 'strength' or 'reception'. The other real constraint is around service and price. Entirely new innovative methods of extending connectivity over remote regions are in the R&D pipeline; some are even surfacing now. Others have been around for some time and overlooked. It is time to visit or revisit them. Business models are evolving, and need to evolve further to support the types of connectivity functionality that farmers need.

The on-farm telecommunications market is rapidly evolving but like with all things in precision agriculture, education is one of the biggest challenges faced by both those looking for solutions and those offering solutions. Industry needs well-curated case studies and education/educators must target not only consumers of telecommunications services but also technology developers and service providers seeking to put something in the market place.

Conclusion

The progression of telecommunications and technology must be accompanied by education and extension. A recent survey identified that more that 60% of Australian farmers did not know of on-farm connectivity options or who to talk to about getting connected. There are many challenges and opportunities of getting connected into the SMART farming future that, in 5-10 years, will just be farming.

Acknowledgements

The project that delivered the 'telecommunications review' referred to in this presentation was led by Cotton Research and Development Corporation (CRDC). The 'P2D' project was jointly funded by the Department of Agriculture and Water Resources Rural Research and Development (R&D) for Profit Program and all 15 rural Research and Development Corporations including the Grains Research and Development Corporation (GRDC). A copy of the full report "A review of on-farm telecommunications challenges and opportunities in supporting a digital agriculture future for Australia" (ISBN 978-921597-75-6 Electronic) is available for free download on the Australian Farm Institute website (http://www.farminstitute.org.au/p2dproject).

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At what stages are wheat, barley, canola, chickpea and field pea most sensitive to temperature and water stress?

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[3]South Australian Research and Development Institute

Key words

critical growth stages, wheat, barley, canola, chickpea, field pea, temperature, water stress

GRDC code

JPA00003

Call to action/take home messages

- Analysis of Australian national variety trials demonstrates impact of climate on wheat, barley, canola, chickpea and field pea grain yield.
- In all crops, higher temperature in the non-stressful range is associated with yield reduction when it occurs before flowering in the north, east and south and in all regions after flowering.
- In cereals, yield loss was greater when high temperature or water stress occurred during stem elongation.
- In canola and pulses, yield loss was greater when high temperature or water stress occurred from shortly before flowering and into pod filling.
- Canola was overall the most sensitive to water stress.
- The interaction between temperature and water stress had a regional pattern.

Background

The purpose of this study was to explore the relationship between weather and grain yield in the Australian cropping belt and identify the stages of vulnerability of winter sown crops with emphasis on temperature and water stress. This paper was part of a GRDC initiative aiming to inform research investment to breed more resilient crops in the face of higher temperatures (2017 third warmest year on record, annual national mean +0.95°C above average), increasing frequency of heat events and declining growing season rainfall (e.g. 11% since the mid-1990s in the southeast) (www.bom.gov.au).

Our work aimed to fill two gaps. First, we focused not only on wheat, but also on crops that have received little attention including barley, canola, chickpea and field pea. Second, we used a comparative approach to illuminate aspects that are overlooked in single-crop studies about the adaptive potential of crops as they are exposed to a variety of weather and soil conditions across the continent in comparable stages of development. Here we present a summary of a full paper [1].

What we did

We asked the question: which weather variables can help differentiate high vs low yielding situations (90th and 10th yield percentile respectively) in wheat, barley, canola, chickpea and field pea and at which crop stage by region?

To answer this question we linked three sources of information:

1. Grain yield (oil yield for canola) measured in Australia's national variety trials between 2009 and 2013 in the north, east, south and west regions (Figure 1),

2. weather records (www.bom.gov.au) and
3. flowering time for a mid-season maturity type predicted by the crop simulation model APSIM[2].

The weather variables studied in relation to temperature were average, maximum (T^{max}) and minimum (T^{min}) temperature (°C), number of days with potential for damage by frost (Days<=0°C) or heat (Days>=30°C). In relation to water availability, we considered rainfall (mm), vapour pressure deficit (VPD, kPa), which encapsulates how dry and hot the air is, and the water supply vs. demand ratio, or water stress index, based on the plant-soil water balance [3].

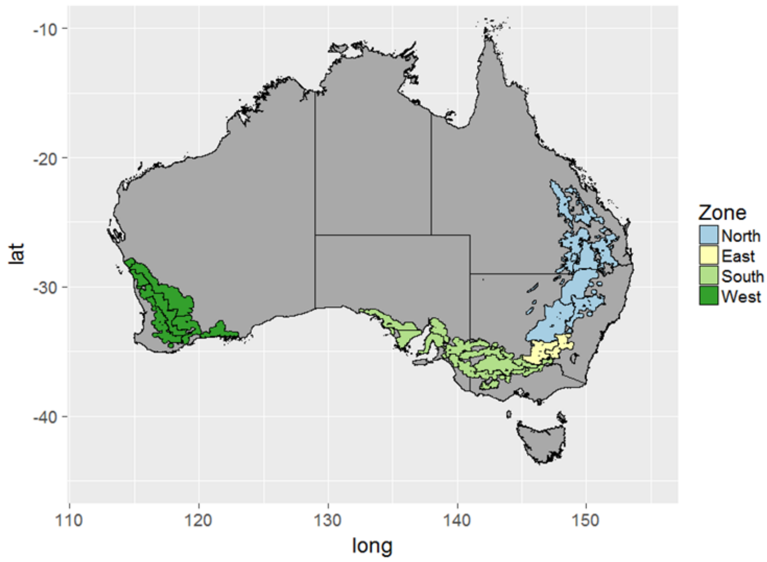

Figure 1. Geographical regions as defined in http://www.nvtonline.com.au/

Linking yield and weather using chronological time does not allow us to exploit our current knowledge on the physiology of crops regarding the definition of yield components, therefore, we used degree days (°Cd). Degree days are the units of the plant biological clock, combining time and temperature into a single number. Using this basis allows us to compare weather events in relation to crop stages across regions of widely different temperature regimes. For example, a 100°Cd interval will last 10 days if the average temperature is 10°C and half that time at 20°C, but at the end of the 100°Cd period the crop would have achieved the same developmental stage.

What we found

Is it OK to work with NVT data to learn about crop adaptation?

GRDC National Variety Trials (NVT) are an extensive source of data (combination of years and sites) that can be used to explore the relation between recently released germplasm and vulnerability to weather conditions because, as a whole, they represent relevant conditions in the cropping belt, even when timely operations can be challenging in particular locations. We found that in the 2009-2013 period, the sowing dates did not significantly differ between the lowest (10th percentile) and highest (90th percentile) yields, except for wheat in the west and canola in the south. This makes more reliable the interpretation of the influence of climate variables. In addition, the range of yields in each crop (Table 1) was consistent with reported agronomy yield gap studies. The magnitude of yield variation between trials far outweighed the genotypic variation within a trial; therefore we used site averages to represent a site, except for canola and chickpea, where the average of the best germplasm type for a particular site (e.g. desi instead of kabuli chickpea) was used. Crop presence in a region represents current practices. Note that the number of NVT trials varies per crop and region, wheat and barley and south and west having the highest numbers.

Table 1. Number of trials analysed and mean, median, 10th and 90th percentile grain yield of wheat, barley, chickpea, field pea and oil yield of canola per region.

Crop	NVT Region	Number of trials	Yield ($t\ ha^{-1}$)			
			Mean	Median	10th percentile	90th percentile
Wheat	North	130	3.4	3.4	2.1	4.7
	East	36	3.5	3.6	2.0	5.2
	South	230	3.4	3.3	1.5	5.0
	West	200	2.8	2.7	1.3	4.0
	Total	623				
Barley	North	42	3.7	3.8	2.7	4.9
	East	39	3.3	3.3	1.7	4.7
	South	146	3.6	5.1	2.1	5.1
	West	75	3.5	3.0	1.5	4.5
	Total	302				
Canola	North	-[1]	-	-	-	-
	East	33	0.8	0.8	0.6	1.2
	South	71	0.9	0.9	0.6	1.3
	West	81	0.8	0.8	0.4	1.2
	Total	185				
Chickpea	North	47	2.1	1.9	1.0	3.3
	East	-[1]	-	-	-	-
	South	77	1.9	1.7	0.9	3.1
	West	33	1.3	1.0	0.6	2.6
	Total	157				
Field pea	North	-[1]	-	-	-	-
	East	27	2.0	2.0	1.2	2.8
	South	107	2.5	2.4	1.4	3.5
	West	51	1.9	1.8	0.7	3.0
	Total	185				

[1] insufficient data

Which environmental factors worked better at separating low from high yielding crops? Were all crops equally sensitive?

From a water stress perspective, cumulative rainfall was the least and the water supply/demand ratio was the most reliable at discriminating high and low yielding conditions. The water supply/demand ratio (1=no water stress) was able to reconcile differences among crops and regions by integrating the calculated water demand by the crop, differences in rainfall amount and seasonality and soil water storage capacity and plant available water at sowing.

As expected, water stress increased during the season, particularly in low yielding situations, but different patterns of association with yield emerged across regions and crops (Figure 2). In the north and east, summer rainfall and stored soil moisture are an important source of water for crops, whereas crops in south and west depend primarily on in-season rainfall. Accordingly, the association between yield and water stress was stronger in the south and west, than in the north and east.

The timing of onset of water stress separating high and low yielding situations and the sensitivity to water stress differed amongst crops (0°C days represents flowering time in all figures). Regarding the timing, water stress started at tillering in wheat and barley, close to flowering in canola and in mid to late grain filling in chickpea. Regarding the sensitivity, in any region, canola crops experienced the highest water stress (lowest water supply/demand ratio) and high yielding wheat crops were the least stressed. Low yielding wheat crops were more water stressed in the west than in the east or north. Water stress in field pea was low for this data set and unrelated to yield.

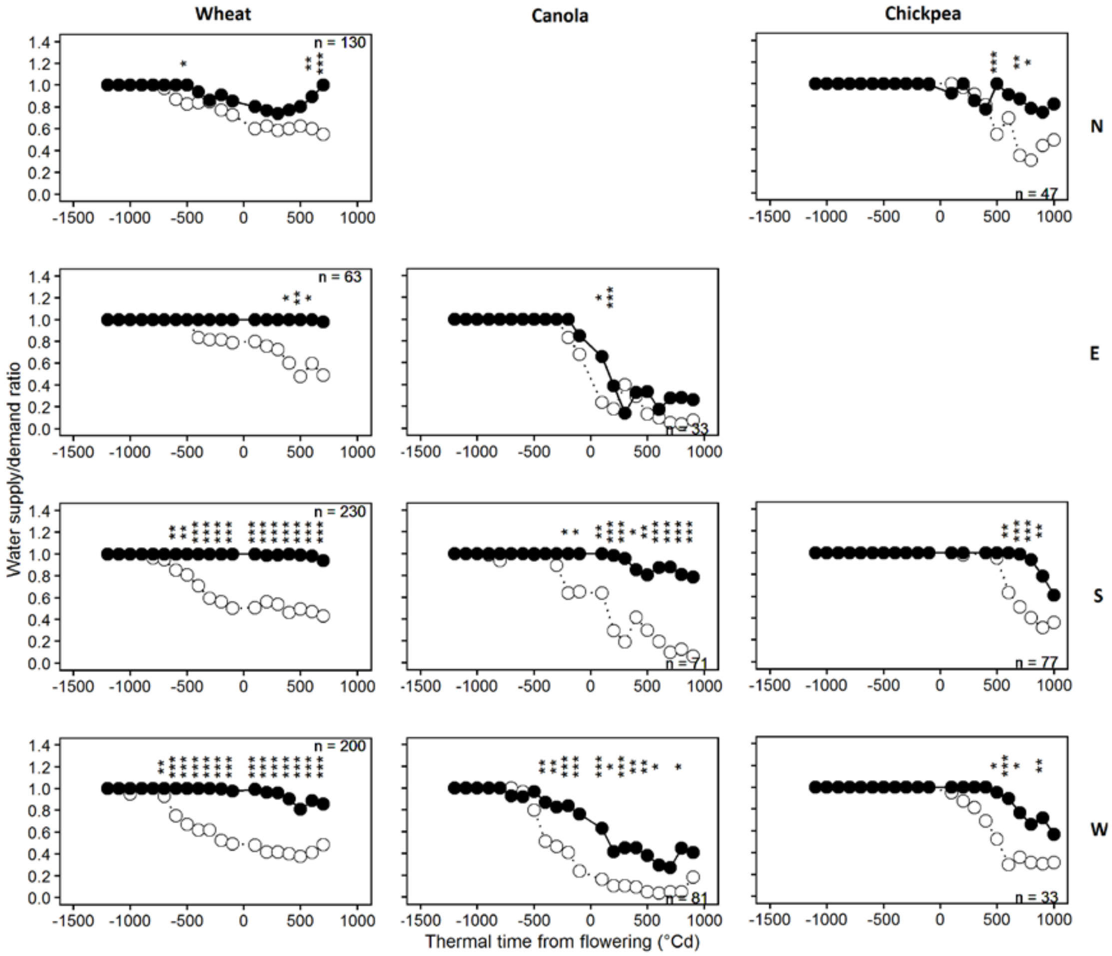

Figure 2. Water supply/demand ratio associated with high (90th percentile, black symbols) and low (10th percentile, white symbols) yielding wheat, canola and chickpea crops in the north, east, south and west regions as a function of thermal time centred at flowering (x=0°Cd). Water supply/demand ratio=1 represents no stress. Asterisks indicate significant differences at P<0.0001 (***), P < 0.01 (**) and P < 0.05 (*).

From a *temperature* perspective, it is worth distinguishing two aspects of warming with different consequences for the crop: an increase in temperature within the non-stressful or benign range that accelerates plant growth and development (e.g. 15 to 16°C), from the stressful or extreme temperatures (e.g. above 30-35 °C), which disrupt processes such as starch synthesis in wheat or oil synthesis in canola.

Our expectation was that high maximum temperature (Tmax), particularly in the stressful range, e.g. above 30°C, would be associated with low yields. More generally, the findings indicated that there was a strong and consistent association between high Tmax, even in the non-stressful range, and lower yields (Figure 3). Wheat and barley conformed to a pattern where higher Tmax was related to low yields in the north, practically unrelated in the east, strongly throughout the cycle in the south and more influential towards flowering and grain filling in the west. Canola had an association between low yield and higher Tmax during grain filling in the east, and was similar to wheat and barley in the south and west, whereas chickpea was affected little and late in grain filling.

The findings regarding minimum temperature (Tmin) were different between regions and crop stages (Figure 4). Before flowering, specifically during early growth stages for wheat and barley in the north and the east and canola in the east, a higher Tmin was often associated with lower yields. Warmer nights shorten the crop's cycle, and as less resources are captured, there is a lower potential for yield. By contrast, for all crops in the west, a higher Tmin during tillering and stem elongation in the cereals and before flowering in canola, chickpea and field pea, was associated with higher yields. We expect this is the result of an interaction with water supply. Crops experiencing higher Tmin early in the season, cover the ground quickly and reduce direct evaporation from soils with limited water holding capacity, resulting in a more favourable water balance compared to low yielding crops. In the case of chickpea, higher Tmin may also reduce flower abortion.

By contrast, after flowering, higher Tmin was associated with lower yields across crops and regions where a significant effect was detected, as expected from warmer nights shortening the calendar time for grain filling [4].

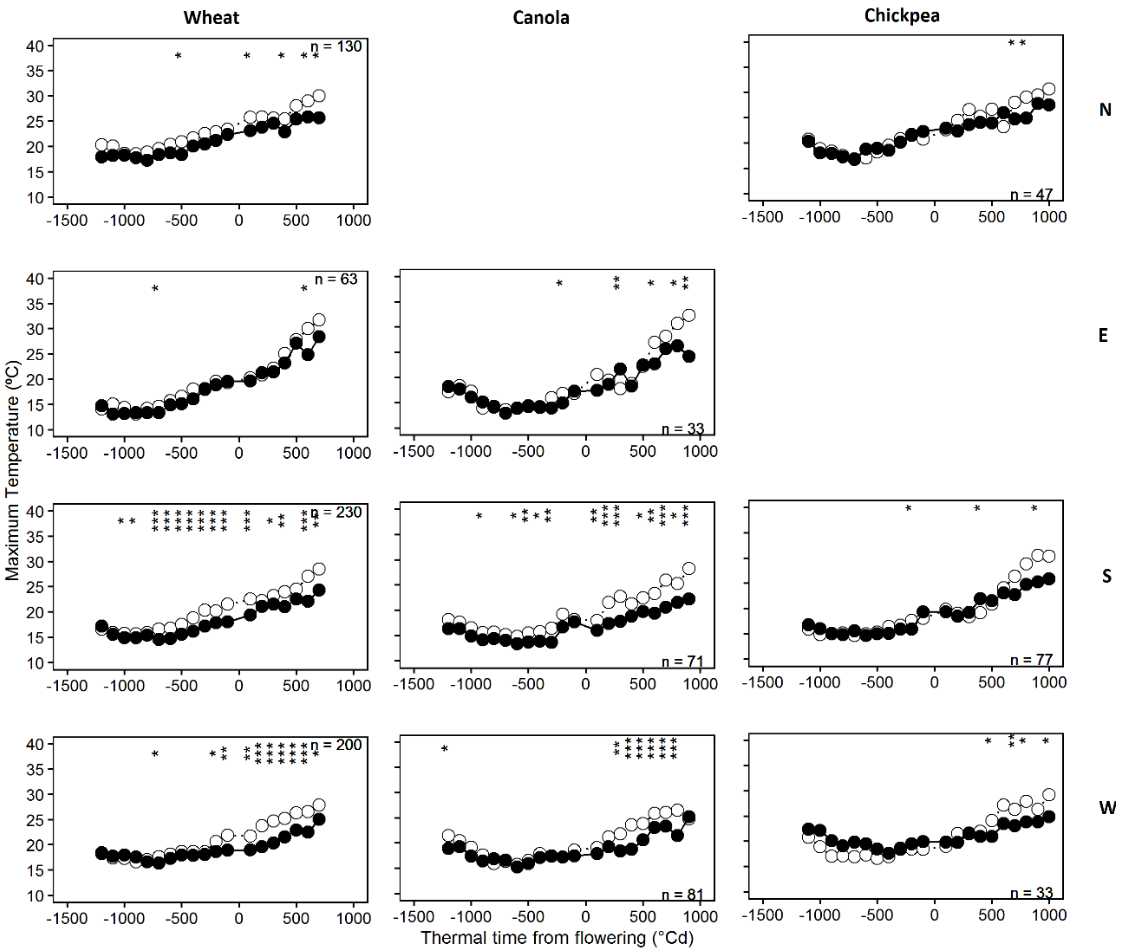

Figure 3. Maximum temperature associated with high (90th percentile, black symbols) and low (10th percentile, white symbols) yielding wheat, canola and chickpea crops in the north, east, south and west regions as a function of thermal time centred at flowering (x=0°Cd). Asterisks indicate significant differences at P<0.0001 (***), P < 0.01 (**) and P < 0.05 (*).

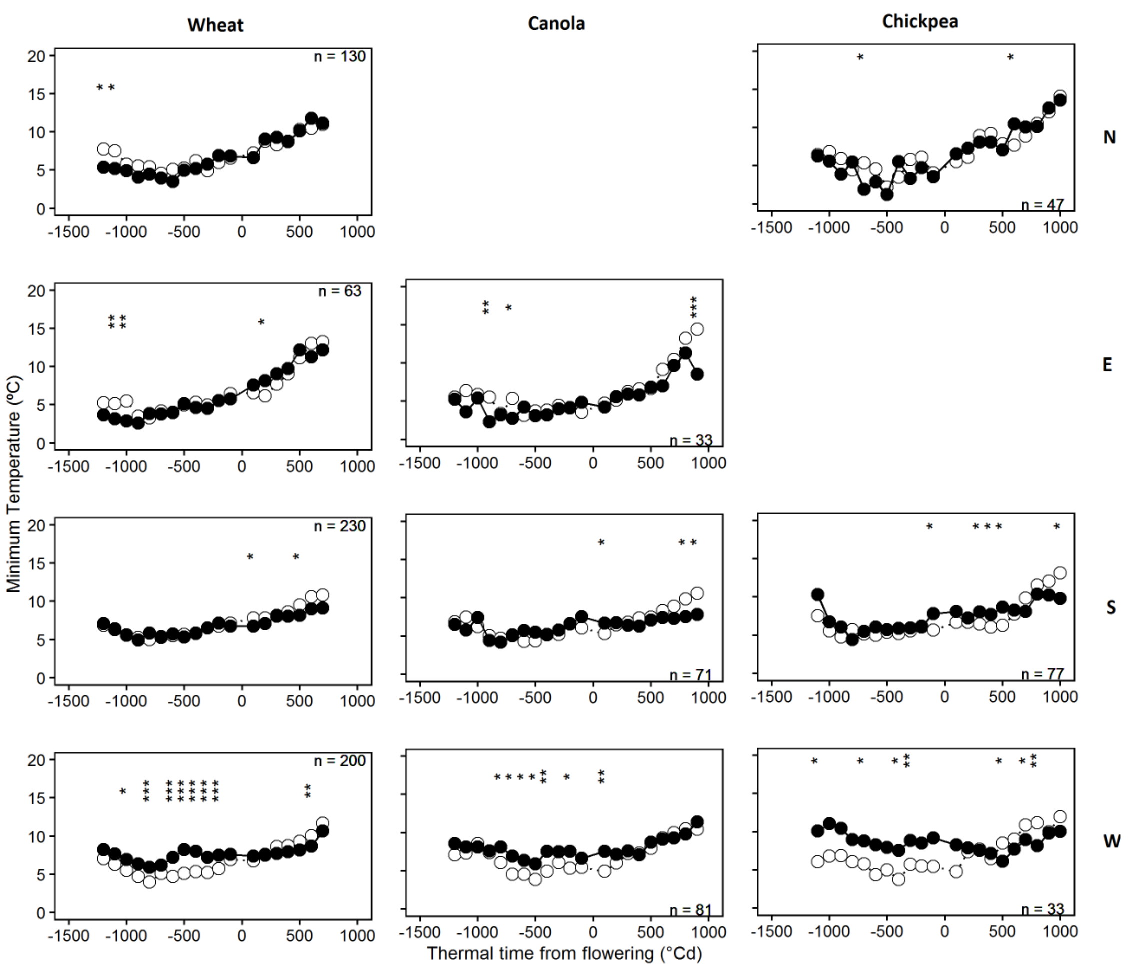

Figure 4. Minimum temperature associated with high (90th percentile, black symbols) and low (10th percentile, white symbols) yielding wheat, canola, chickpea and field pea crops in the North, East, South and West regions as a function of thermal time centred at flowering (x=0°Cd). Asterisks indicate significant differences at P<0.0001 (***), P < 0.01 (**) and P < 0.05 (*).

Conclusions

Our comparative approach revealed that the most sensitive stage to temperature and water stress coincided with the window when the grain number is being formed, the most important component of yield. In wheat and barley, it was confirmed as the period during stem elongation when the spike is growing and forming fertile florets (precursors of grains), extending to shortly after flowering during grain set. In canola and chickpea, the critical window for yield formation started shortly before flowering and extended further into grain filling as flowering and pod growth overlap.

Our study supports that in all crops, higher temperature in the non-stressful range is associated with yield reduction when it occurs before flowering in the north, east and south and in all regions after flowering. While wheat and chickpea were sensitive to temperatures above 30°C from early and late in grain filling respectively, chickpea was sensitive to low temperatures from flowering and canola was overall the most sensitive to water stress. Furthermore, the interaction between early growth and drought has regional relevance.

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Managing insecticide resistance (*Helicoverpa armigera*, green peach aphid, redlegged earth mite) and an update on Russian wheat aphid

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Keywords

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GRDC codes

CES00003, UM00057, CES00004, UM00048

Call to action/take home messages

Insecticide resistance issues continue to outpace availability of novel control options.

Aphids:

- Green peach aphid (GPA) has acquired resistance to neonicotinoids.
- Pirimicarb is now mostly ineffective against GPA due to resistance, but remains effective against other crop aphids, highlighting the importance of correct species identification.
- A variety of insecticide seed treatments have been shown to control Russian wheat aphid, with the length of protection differing between products. No seed treatments are registered, however use of products containing 600 g/L imidacloprid as their only active constituent are allowed under permit PER82304.

Helicoverpa armigera:

- Insecticide control of *H. armigera* is complicated due to field resistances and increased selection pressure to important insecticide products.
- The implementation of a recently published Resistance Management Strategy is vital to maximising the long-term viability of chemical options.

Redlegged earth mite (RLEM):

- Insecticide resistance in RLEM has been detected for first time in eastern Australia.
- Synthetic pyrethroids (SPs) are completely ineffective against SP-resistant RLEM populations, while some efficacy remains for organophosphates (OPs) against OP-resistant RLEM populations.

Background

Insecticide resistance issues in broadacre cropping continue to outpace the availability of novel control options. In this paper, we discuss the latest findings on two major pest species that have developed resistance to key chemical groups, the green peach aphid (*Myzus persicae*, GPA) and the redlegged earth mite (*Halotydeus destructor*, RLEM), and present a new Resistance Management Strategy developed specifically for *Helicoverpa armigera* in grains. We also provide new research on the efficacy of seed treatments against Russian wheat aphid (*Diuraphis noxia,* RWA).

Green peach aphid acquires new resistances

Green peach aphid is a widespread and damaging pest of canola and a range of pulse crops, causing damage by feeding and transmitting viruses. Five chemical subgroups are registered to control GPA in grain crops: carbamates (group 1A); synthetic pyrethroids (SPs - group 3A); organophosphates (OPs - group 1B); neonicotinoids (group 4A); and sulfoxaflor (group 4C). Paraffinic spray oils are also registered for suppression of GPA.

Together with CSIRO, cesar have been mapping the extent of insecticide resistance in GPA across Australia for the past few years with strategic investment from GRDC. This ongoing resistance surveillance has continued to show high levels of resistance to carbamates and SPs that are widespread across Australia. Moderate levels of resistance to OPs have been observed in many populations, and there is evidence that resistance to neonicotinoids is spreading.

Despite widespread resistance to the carbamate, pirimicarb, in GPA populations (Figure 1), this insecticide remains important to the control of other canola aphids of similar appearance (e.g. cabbage aphid). Thus, it is important to properly identify aphids before spray decisions are made. Figure 2 highlights some key features that can be used to distinguish GPA from other similar species found on canola (with a hand lens). If a hand lens is unavailable, GPA will usually be found on lowest, oldest leaves, typically in sparse family groups, while turnip aphid & cabbage aphid are more commonly found in large colonies on flowering spikes.

Neonicotinoid resistance conferred by enhanced expression of the P450 CYP6CY3 gene was discovered in Australian GPA populations in 2016 by cesar and CSIRO researchers. Laboratory bioassays revealed these aphids to be ~10 times more resistant to a topical application of a neonicotinoid compared to a susceptible population. However, overseas GPA are known to carry an R81T gene mutation of the nicotinic acetylcholine receptor that confers ~1000 times resistance to neonicotinoids resulting in field control failures, as well as cross-resistance with group 4C chemicals such as sulfoxaflor. Australian GPA may acquire this high-level resistance if neonicotinoid selection pressures remain high, or if there is an incursion of overseas GPA carrying the R81T mutation.

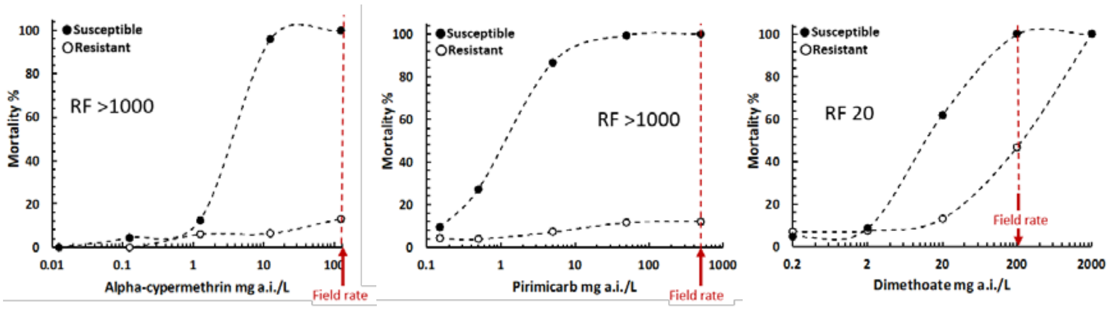

Figure 1. Sensitivity of a typical Australian susceptible and resistant green peach aphid population to the synthetic pyrethroid, alpha-cypermethrin (left panel), the carbamate, pirimicarb (middle panel) and the organophosphate, dimethoate (right panel). RF = Resistance Factor

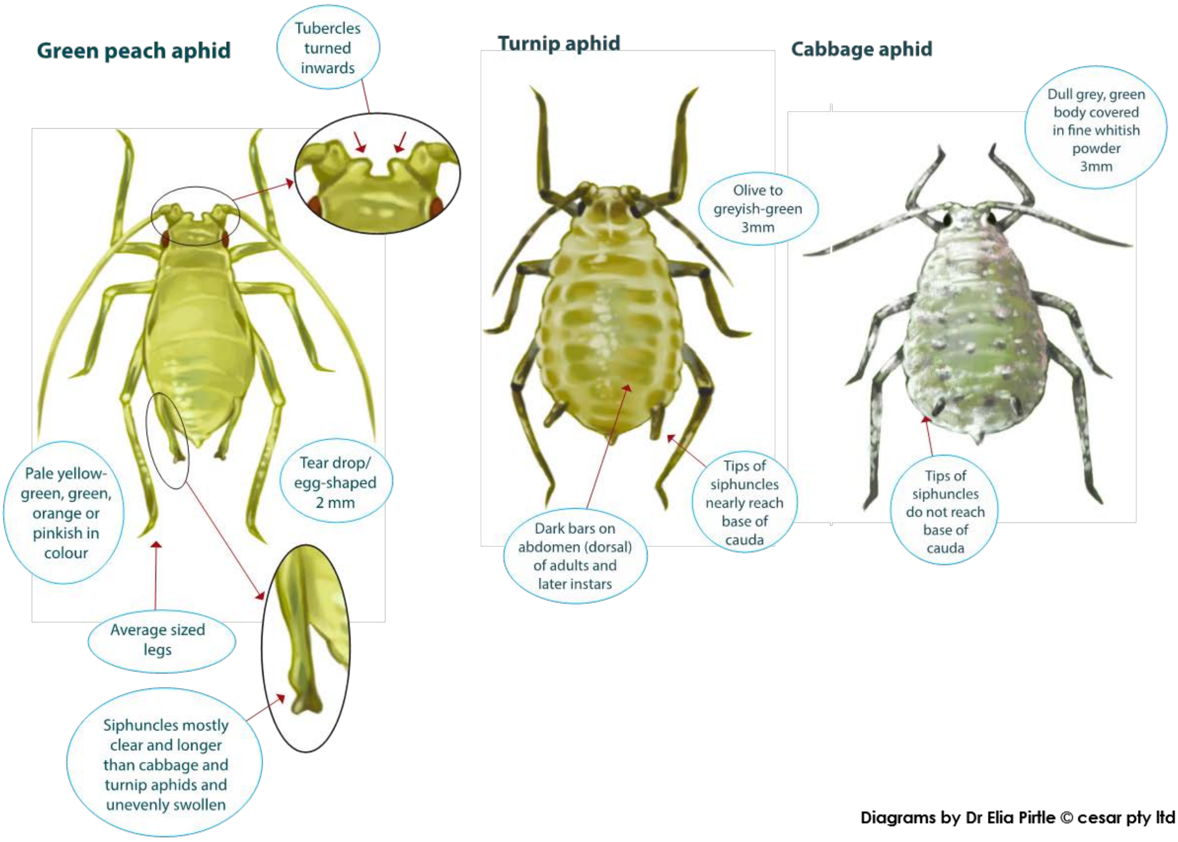

Figure 2. To assess the applicability of pirimicarb to other non-resistance aphid species of similar appearance, green peach aphid should be distinguished using diagnostic traits.

New resistance management strategy for *Helicoverpa armigera*

Helicoverpa armigera is a major pest of grains crops. Direct feeding by *H. armigera* reduces yield of pulses, oilseeds, coarse grains and, occasionally, winter cereals. Losses come from direct weight loss through seeds being wholly or partly eaten. Grain quality may also be downgraded through unacceptable levels of chewed grain. Although widely distributed and recorded in all states and territories within Australia, *H. armigera* is more common in the northern or coastal regions of eastern Australia, particularly in warmer regions. In cooler regions, they are generally only problematic in summer.

There are over 200 insecticide products registered in Australia against *H. armigera* for grains, cotton and vegetable crops. The majority are from 3 chemical sub-groups with broad-spectrum activity: carbamates (group 1A); organophosphates (group 1B); and synthetic pyrethroids (group 3A). However, insecticides from group 6 (emamectin benzoate), group 22A (indoxacarb) and group 28 (chlorantraniliprole) are become more widely used in pulses due to high efficacy and low impact on natural enemies. Control is complicated because field populations are resistant to numerous insecticide groups (Table 1). Due to these factors, timing of chemical applications and coverage are critical, and growers need to understand how to minimise yield loss without furthering resistance levels.

Table 1. Products with label claims for Helicoverpa armigera (and Helicoverpa spp. generally) in Australian grain crops and current resistance status

IRAC MoA Group	Insecticide category	Active ingredient(s)	Example trade name(s)	Resistance in Australia
1A	Carbamates	methomyl, thiodicarb	Lannate®, Marlin®, Larvin®	✓ Moderate – high (30-50%)
1B	Organophosphates*	chlorpyrifos	Chlorpos, Lorsban™, Chlorpyrifos	✓ Low – moderate (1-10%)
3A	Pyrethroids	alpha-cypermethrin, beta-cypermethrin, cypermethrin, deltamethrin, gamma-cyhalothrin, lambda-cyhalothrin, esfenvalerate, permethrin, bifenthrin	Alpha-Scud®, Astound®, Trojan®, Talstar®, Sumi-Alpha® Flex	✓ Metabolic resistance is high (50-100%) Target site resistance is low (<5%)
5	Spinosyns	spinetoram	Success™ Neo	✓ Very low (<2%)
6	Avermectins	emamectin benzoate	Affirm®	×
11C	*Bacillus thuringiensis*	B.t. subsp. Kurstaki, B.t. subsp. aizawai	DiPel®, Delfin®, Costar®, Bacchus®	✓ Low (<5%)
22A	Oxadiazines	indoxacarb	Steward®	✓ Low, but increasing (5-12%)
28	Diamides	chlorantraniliprole	Altacor®	✓ Very low (<1%)
No Group	Nuclear polyhedrosis virus	nuclear polyhedrosis virus	Gemstar®, Vivus® Max/Gold	×
No Group	Paraffinic spray oils	paraffinic oil	Canopy®	×

* Not registered to control *H. armigera* in grain crops.

Table adapted from: *Science behind the Resistance Management Strategy for* Helicoverpa armigera *in Australian grains* (NIRM, 2018). Data provided by NSW Department of Primary Industries with support from the Cotton Research and Development Corporation (CRDC) and the Grains Research and Development Corporation (GRDC).

A new Resistance Management Strategy (RMS) has recently been produced for *H. armigera* in Australian grain crops and will be available for the 2018 field season. This RMS was developed by the National Insecticide Resistance Management (NIRM) working group of the Grains Pest Advisory Committee (GPAC), and is endorsed by CropLife Australia.

The general rationale for the design of the strategy is that chickpeas and mung beans are currently, and for the foreseeable future, the crops in which the use of insecticides is most likely to have the greatest impact on the management of resistance in *H. armigera* populations. Therefore, the strategy is primarily focused on insecticide modes of action (MoA) rotation in these systems and is built around product windows for Altacor and Steward because:

1. Altacor is at risk from dangerously high levels of over-reliance in pulses, but resistance frequencies are currently low.
2. Steward is at risk due to genetic predisposition (high level genetic dominance and a metabolic mechanism). Pre-existing levels of resistance in NSW and QLD are present (with elevated levels in CQ during 2016-17). In addition, Steward is now off-patent in Australia which provides the opportunity for lower priced products to enter the market, which may further increase frequency of applications.

There are two RMS regions:

1. Northern grains region (Belyando, Callide, Central Highlands & Dawson); and
2. Central grains region (Balonne, Bourke, Burnett, Darling Downs, Gwydir, Lachlan, Macintyre, Macquarie & Namoi).
    - The RMS provides window-based recommendations common to Southern QLD, Central & Northern NSW because *H. armigera* moths are highly mobile and have the capacity to move between these regions, potentially increasing the risk of further exposing cohorts of insects previously selected for resistance.
    - We have limited knowledge of the likely risk of *H. armigera* occurrence in winter crops in the southern and western grains regions (Victoria, South Australia and Western Australia) because there has been little formal monitoring for this species in these regions. However, there is some historical data, and anecdotal records of *H. armigera* outbreaks in the southern region, which suggests that in some years and regions there is a risk of control failure and/or selection of resistance in the *Helicoverpa* population because of the presence of *H. armigera*.
    - No RMS is currently proposed for the southern and western grains regions. Biological indicators are that the risk of *H. armigera* occurring in winter crops, at densities where control failures may occur, is presently considered low. However, if required, the Central Grains region RMS may be adapted for *H. armigera* management in summer crops in these regions.

The new RMS for grain crops is not intended to 'sync' with the cotton IRMS. Recommended windows for use in the two industries do not align, and the level of insecticide used for *Helicoverpa* control in cotton is relatively small in comparison with the areas of winter and summer pulses potentially treated each year. It is considered that insecticide use patterns in cotton pose little risk to the ongoing management of resistance, relative to the risk posed by year-round, high level use in grains.

For further information on the cotton IRMS go to:
http://www.cottoninfo.com.au/publications/cotton-pest-management-guide

Resistance in redlegged earth mites spreads to eastern Australia

The redlegged earth mite (*Halotydeus destructor*, RLEM) is an important pest of germinating crops and pastures across southern Australia. Four chemical sub-groups are registered to control RLEM in grain crops: organophosphates (OPs) (group 1B); synthetic pyrethroids (SPs) (group 3A); phenylpyrazoles (group 2B); and neonicotinoids (group 4A). The latter two are registered only for use as seed treatments (Umina *et al.*, 2016).

After remaining confined to WA for a decade, insecticide resistance in RLEM was detected for the first time in eastern Australia in 2016 (Maino, Binns and Umina, 2017). In WA, resistance to SPs is widespread, while OP resistance is comparatively more restricted (Figure 3). In 2016, following reports of a field control failure in the upper south-east district in South Australia; resistance testing determined this South Australian population was resistant to SPs and OPs (Figure 4). In 2017, two additional SP resistant populations were confirmed on the Fleurieu peninsula (~30 km apart from each other, and ~200km from the 2016 detection).

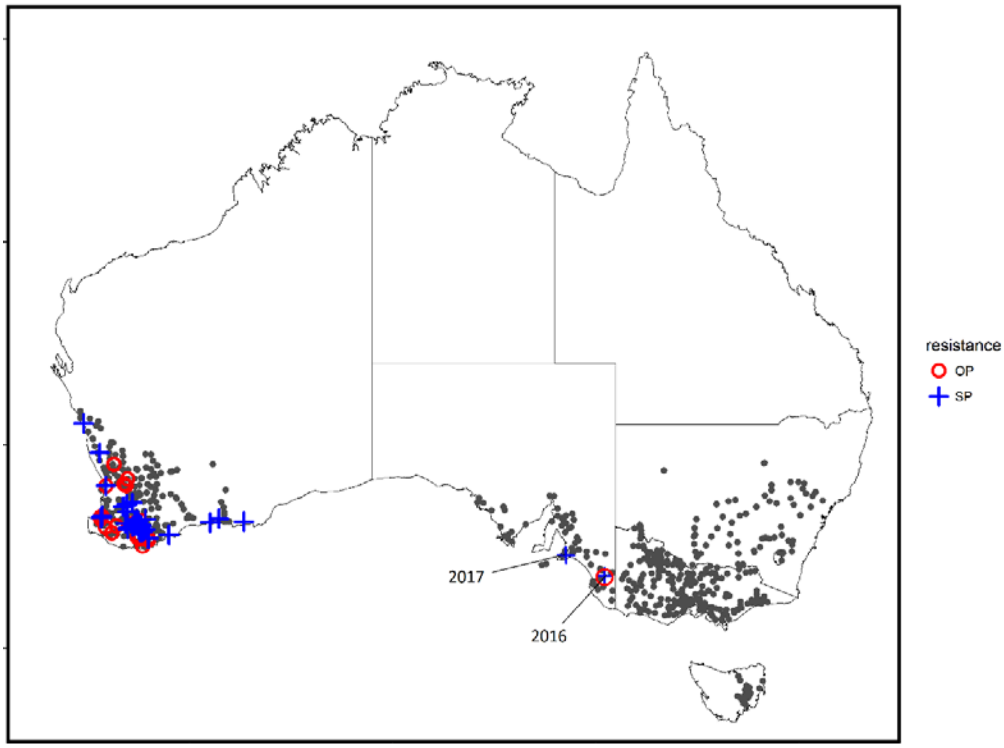

Figure 3. The current known distribution of redlegged earth mite in Australia (adapted from Hill et al. 2012) shown as filled circles, overlaid with the known distribution of synthetic pyrethroid (SP) and organophosphate (OP) resistance across Australia at 2017

All SP resistant populations tested to date have been found to possess a target site mutation on the para-sodium channel (Edwards *et al.*, 2017). This mutation confers high level SP resistance (~200,000 times the resistance of a susceptible population) leading to complete spray failures (Figure 4). In contrast, the mechanism conferring OP resistance has not yet been resolved, but resistance is comparatively less than SP resistance, such that OP efficacy will be reduced but not lost entirely.

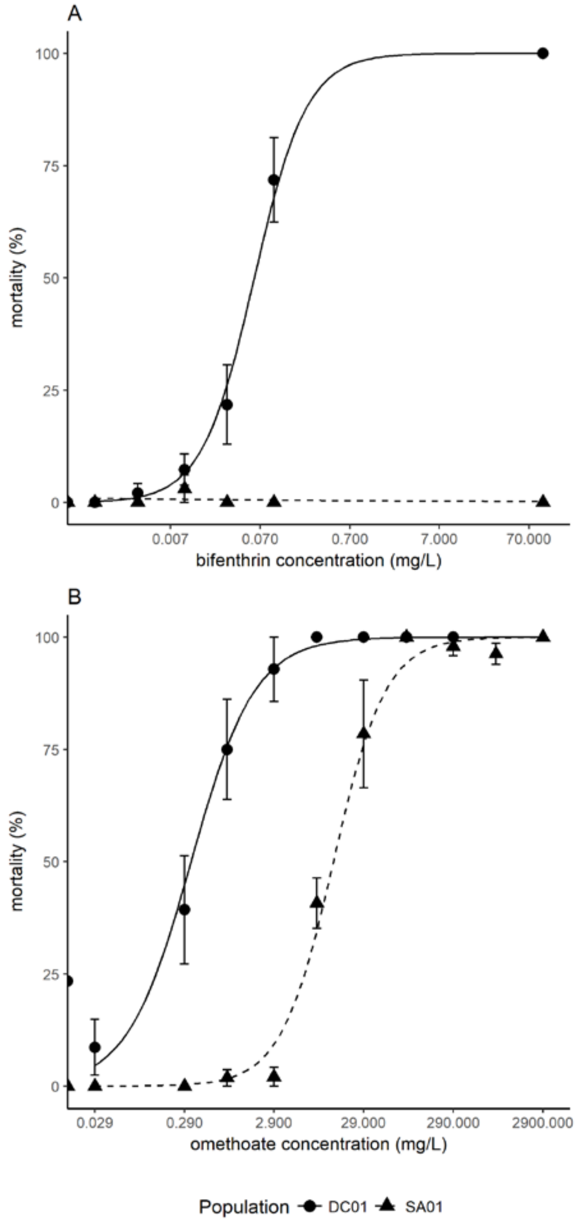

Figure 4. Concentration-mortality curves for redlegged earth mite from susceptible (DC01) and resistant (SA01) populations when exposed to a synthetic pyrethroid - bifenthrin (A) - and an organophosphate - omethoate (B) - after 8 h exposure. Vertical bars denote standard errors. Lines represent fitted values from fitted logistic regression models

Testing control methods for Russian wheat aphid

Russian wheat aphid (*Diuraphis noxia*, RWA) was first detected in Australia in 2016. The host range of RWA includes more than 140 species of cultivated and wild plants within the family Gramineae (grasses). These include wheat, barley, triticale, rye, oats, pasture grasses and wild genera including *Poa*, *Bromus*, *Hordeum*, *Lolium*, *Phalaris* and others. Wheat and barley are most susceptible, while triticale, rye and oats are less susceptible.

Unlike other cereal aphids that damage plants by removing nutrients, RWA also injects salivary toxins during feeding that cause rapid, systemic phytotoxic effects on plants, resulting in acute plant symptoms and potentially significant yield losses. Even a few aphids can cause plant damage symptoms to appear as early as 7 days after infestation. These include:

- white and purple longitudinal streaks on leaves;
- curled, rolled or hollow tube leaves;
- stunted growth or flattened appearance;
- discolored leaves;
- hooked-shaped head growth from awns trapped in curling flag leaf; and
- bleached heads.

Insecticide seed dressings[ϕ] can be effective to combat RWA infestations in establishing cereal crops. cesar have tested the relative efficacy and length of activity of various insecticide seed dressings in wheat against RWA, and compared this with another important cereal aphid pest, the oat aphid (*Rhopalosiphum padi*).

Seed dressings tested provided effective aphid control up to 5 weeks after emergence, with higher rates generally providing several weeks extra protection over lower rates of the same product. Oat aphids generally persisted and reproduced on wheat at an earlier time-point than RWA, suggesting that RWA is less tolerant to the insecticide seed dressings tested. This suggests that management of cereal aphids in Australia using insecticide seed dressings is likely to achieve similar, if not better, control of RWA as oat aphid.

[ϕ]No insecticides(seed dressings or in-crop application) are currently registered for use in Australia, but use is permitted under the following permits: PER81133, PER82304 and PER83140.

Useful resources

www.grdc.com.au/GPAResistanceStrategy

https://grdc.com.au/TT-RWA

https://grdc.com.au/FS-RLEM-Resistance-strategy-West

https://grdc.com.au/FS-RLEM-Resistance-strategy-South

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