GRAINS RESEARCH UPDATE

STRATEGIC STEPS – ENDURING PROFIT

Bendigo

Ulumbarra Theatre, Gaol Road
27 & 28 February 2018

#GRDCUpdates

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GRDC Welcome

Welcome to the 2018 Bendigo GRDC Grains Research Update

On behalf of the Grains Research and Development Corporation, I welcome you to the 2018 Bendigo Grains Research Update.

A new year brings with it new opportunities and challenges for our grain growers and the broader industry, and this forum is an important platform for building knowledge regarding the latest in grains research & development as well as raising awareness to inform tactical decision-making for the coming season.

For the GRDC, the arrival of 2018 marks the beginning of what will perhaps be the most transformational period of grains research, development and extension (RD&E) investment in the corporation's history.

The GRDC has commenced development of the Strategic Research, Development and Extension Plan for 2018-23, with the plan's overarching objective mirroring the GRDC's sole purpose of creating enduring profitability for Australian grain growers. Pivotal to the plan's development and its investment thrust will be the feedback we have received from growers and other industry stakeholders.

That feedback is now being fed into construction and finalisation of the 2018-23 RD&E Plan which will provide industry with a sound and strategic framework for future investments – well beyond the next five years – that are geared to deliver profit-building outcomes for growers.

The drivers of grower profitability – yield, price, costs and risk – anchor the strategic plan and will be at the cornerstone of future RD&E investment considerations which factor in the varying levels of importance of these profit drivers depending on a grower's environment, farming system and business structure. Such considerations will determine the shape and nature of activities and approaches required to support adoption of RD&E outputs, particularly at a local level.

Taking calculated risk to achieve transformational change is a bold, new focus for the GRDC as it embarks on a revised strategy for investment over the coming years. Targeting high-reward opportunities, which carry inherent risk, is a key to unlocking profit growth for growers in the face of increasing costs and market volatility. The GRDC will pursue these opportunities through strategic investments, but with management of risk, based on well informed assumptions, very much front of mind.

Improving yield remains a fundamentally important component and key driver of the profitability equation. The need to close the gap between actual and potential yield (http://www.yieldgapaustralia.com.au/wordpress/) has long been recognised and we, as an industry, must continue to strive towards achieving that objective. But should we be satisfied with simply closing the yield gap as it stands? Whilst this is critically important, we must also aggressively pursue transformational RD&E opportunities to raise the potential yield ceiling in order to future proof the profitability of Australian growers.

GRDC Welcome

In order to start to close the yield gap we must first of all address the very real need for improved implementation of required practice change and effective adoption of relevant new technologies. In many instances, the means of bridging the yield gap exists, but we have faltered in implementation and uptake of the knowledge, tools and technologies at our disposal.

Which brings us to why we are here today. The GRDC Grains Research Updates are an incredibly important platform to equip growers and advisers with the findings and knowledge generated from GRDC investment in relevant, targeted and high-impact RD&E.

New knowledge and technologies emerge from these investments on a continuing basis so it is imperative that these learnings and advances are extended to growers and advisors as quickly as possible to ensure rapid practice change and adoption of new technologies for improved profitability. The GRDC Updates are intended to facilitate that process of adoption and change.

This year's Update features a line-up of agronomic and technical experts who will present the latest findings from their respective areas of research and development. Extending this cutting-edge information to growers is of paramount importance, and the GRDC recognises the important and influential role that advisers play in this process.

The GRDC also recognises the need for the corporation itself to have a much greater regional presence and outreach to support growers, advisers, researchers and other stakeholders, and to that end it has now established a highly skilled team of regionally-based staff. The skills, expertise, experience and knowledge of the regional staff we now have on board enables the GRDC to be more responsive and agile in identifying and responding to key issues affecting grain grower profitability.

With regional staff in place, backed by the Southern Regional Panel and the Regional Cropping Solutions Network whose members span this State and beyond, we have the industry networks, capacity and capability to ensure the GRDC has the check and balances in place to ensure relevance and impact of R,D&E investments to Victorian growers.

Although the opportunity for formal feedback on the 2018-23 Strategic RD&E Plan has now closed, I encourage all of you attending this Update to seek out the GRDC staff, Panel and RCSN members present and have a chat to them about any ideas or concerns you may have.

The GRDC undertakes regular reviews of its strategic investment plan and investment priorities so maintaining an open dialogue is vital in ensuring we leave no stone unturned as we build the path to enduring grower profitability.

Craig Ruchs

Senior Regional Manager - South

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Ulumbarra Theatre

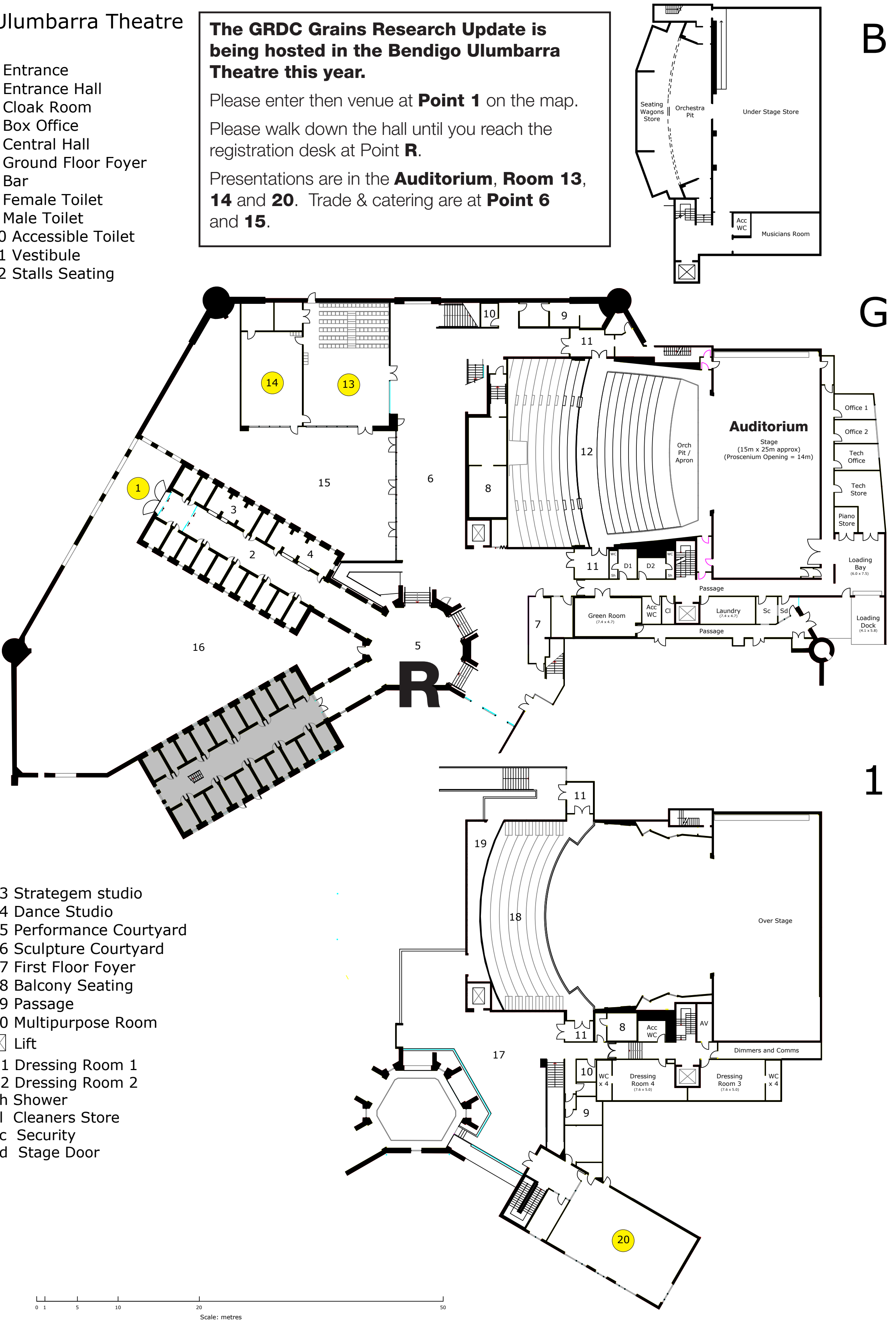
1 Entrance
2 Entrance Hall
3 Cloak Room
4 Box Office
5 Central Hall
6 Ground Floor Foyer
7 Bar
8 Female Toilet
9 Male Toilet
10 Accessible Toilet
11 Vestibule
12 Stalls Seating

The GRDC Grains Research Update is being hosted in the Bendigo Ulumbarra Theatre this year.

Please enter then venue at **Point 1** on the map.

Please walk down the hall until you reach the registration desk at Point **R**.

Presentations are in the **Auditorium**, **Room 13**, **14** and **20**. Trade & catering are at **Point 6** and **15**.



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15 Performance Courtyard
16 Sculpture Courtyard
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18 Balcony Seating
19 Passage
20 Multipurpose Room
☒ Lift
D1 Dressing Room 1
D2 Dressing Room 2
Sh Shower
Cl Cleaners Store
Sc Security
Sd Stage Door


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GRDC values the contributions made by its research partners during the 2018 series of Grains Research Updates.

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STRATEGIC STEPS – ENDURING PROFIT

PROGRAM DAY 1 - FEBRUARY 27th

8.55 am	**Announcements**	*ORM*
9.00 am	**Welcome and GRDC update**	*GRDC representative*
9.20 am	**The pulsating pulse – expansion of high value pulse crops** - P15	***Ron Storey,*** *Pulse Australia*
9.55 am	**Collating and analysing small data to make big decisions. Can it improve farm productivity and profitability?** - P21	***Terry Griffin,*** *Kansas State University*
10.35 am	**Morning tea**	

CONCURRENT SESSIONS (40 minutes including time for room change) (R = session to be repeated)

	Ulumbarra Auditorium	Ulumbarra Dance Studio	Ulumbarra Strategem Studio	Ulumbarra Multipurpose Room
11.00 am	**Are the Russian forces building – what are our spies telling us (R)** - P27 ***Maarten van Helden,*** *SARDI*	**Septoria tritici update and latest developments in powdery mildew (R)** - P35 ***Nick Poole,*** *FAR Australia*	**Pulses - technical research supporting the expansion of pulses (R)** - P43 ***Jason Brand,*** *Agriculture Victoria*	**High rainfall wheat and barley review (R)** - P57 ***Jon Midwood and Claudia Gebert,*** *SFS*
11.40 am	**Cereal disease update (R)** - P65 ***Grant Hollaway,*** *Agriculture Victoria*	**Fungicide resistance: recent discoveries pave way to better understanding the resistance mechanisms (R)** - P89 ***Katherine Zulak,*** *Curtin University, Centre for Crop and Disease*	**Best options for optimal performance from inoculants (R)** - P75 ***Matt Denton,*** *The University of Adelaide*	**Weather and seasonal forecasting - science or fiction? (R)** - P83 ***Dale Grey,*** *Agriculture Victoria*
12.20 pm	**Septoria tritici update and latest developments in powdery mildew** - P35 ***Nick Poole,*** *FAR Australia*	**'On the couch' session** *Ron Storey and Terry Griffin*	**Are the Russian forces building – what are our spies telling us** - P27 ***Maarten van Helden,*** *SARDI*	**The effects of stubble on nitrogen tie up and supply (R)** - P97 ***Gupta Vadakkatu,*** *CSIRO*

1.00 pm **LUNCH**

CONCURRENT SESSIONS (40 minutes including time for room change) (R = session to be repeated)

	Ulumbarra Auditorium	Ulumbarra Dance Studio	Ulumbarra Strategem Studio	Ulumbarra Multipurpose Room
2.00 pm	**Canola - blackleg management update** - P107 ***Steve Marcroft,*** *Marcroft Grains Pathology*	**Best options for optimal performance from inoculants** - P75 ***Matt Denton,*** *The University of Adelaide*	**Weed warriors - update on brome grass and other emerging problems (R)** - P119 ***Sam Kleemann,*** *The University of Adelaide*	**High rainfall wheat and barley review** - P57 ***Jon Midwood and Claudia Gebert,*** *SFS*
2.40 pm	**Weather and seasonal forecasting - science or fiction?** - P83 ***Dale Grey,*** *Agriculture Victoria*	**Pulses - technical research supporting the expansion of pulses** - P43 ***Jason Brand,*** *Agriculture Victoria*	**Cereal disease update** - P65 ***Grant Hollaway,*** *Agriculture Victoria*	**Improving barley performance in the low rainfall zone** - P125 ***Linda Walters,*** *BCG*
3.20 pm	**Fungicide resistance: recent discoveries pave way to better understanding the resistance mechanisms** - P89 ***Katherine Zulak,*** *Curtin University, Centre for Crop and Disease*	**'On the couch' session** ***Steve Marcroft,*** *Marcroft Grains Pathology*	**The effects of stubble on nitrogen tie up and supply** - P97 ***Gupta Vadakkatu,*** *CSIRO*	**Weed warriors - update on brome grass and other emerging problems** - P119 ***Sam Kleemann,*** *The University of Adelaide*

4.00 pm	**AFTERNOON TEA**	
4.30 pm	**NVT Online update** - P137	***Rob Wheeler,*** *GRDC*
4.45 pm	**Long fallows maintain whole-farm profit and reduce risk in semi-arid south eastern Australia** - P141	***David Cann,*** *student*
4.55 pm	**Physiological and biochemical responses of lentils to silicon mediated drought tolerance** - P147	***Sajitha Biju,*** *student*
5.05 pm	**How to keep yourself at peak performance the majority of the time** - P163	***Mark McKeon,*** *MMA TEAM Pty Ltd*
5.50 pm	**Close and evaluation**	
5.55 pm	**COMPLIMENTARY DRINKS AND FINGER FOOD**	

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GRDC Grains Research Update **BENDIGO**

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PROGRAM DAY 2 - FEBRUARY 28th

CONCURRENT SESSIONS (40 minutes including time for room change) (R = session to be repeated)

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9.00 am	**Canola diseases - sclerotinia in the spotlight (R)** - P175 ***Kurt Lindbeck,*** *NSW DPI*	**Refining nitrogen placement in cereals - mid row banding (R)** - P181 ***Ash Wallace,*** *Agriculture Victoria*	**Insects, resistance and control (R)** - P187 ***James Maino,*** *cesar*	**Glyphosate update (R)** - P195 ***Peter Boutsalis,*** *Plant Science Consulting*
9.40 am	**Achieving the best blend of HWSC methods for your situation (R)** - P201 ***Greg Condon,*** *AHRI, Grassroots Agronomy*	**Critical agronomy management points for optimal canola growth (R)** - P207 ***Rohan Brill,*** *NSW DPI*	**Agricultural machine technology – practical uses now and into the future (R)** - P215 ***Steven Rees,*** *The University of Southern Queensland*	**Mice - learning from 2017? Looking to 2018 (R)** - P217 ***Peter Brown,*** *CSIRO*
10.20 am	**MORNING TEA**			
10.50 am	**Canola harvest management - new data busts myths (R)** - P223 ***Maurie Street,*** *Grain Orana Alliance*	**Refining nitrogen placement in cereals - mid row banding** - P181 ***Ash Wallace,*** *Agriculture Victoria*	**Filling the yield gap - Optimising yield and economic potential of high input cropping systems in the high rainfall zone (R)** - P231 ***Malcolm McCaskill,*** *Agriculture Victoria*	**Canola diseases - sclerotinia in the spotlight** - P175 ***Kurt Lindbeck,*** *NSW DPI*
11.30 am	**Critical agronomy management points for optimal canola growth** - P207 ***Rohan Brill,*** *NSW DPI*	**Mice - learning from 2017? Looking to 2018** - P217 ***Peter Brown,*** *CSIRO*	**Insects, resistance and control** - P187 ***James Maino,*** *cesar*	**Agricultural machine technology – practical uses now and into the future** - P215 ***Steven Rees,*** *The University of Southern Queensland*

CONCURRENT SESSIONS (40 minutes including time for room change) (R = session to be repeated)

	Ulumbarra Auditorium	Ulumbarra Dance Studio	Ulumbarra Strategem Studio	Ulumbarra Multipurpose Room
12.10 pm	**Glyphosate update** - P195 ***Peter Boutsalis,*** *Plant Science Consulting*	**Achieving the best blend of HWSC methods for your situation** - P201 ***Greg Condon,*** *AHRI, Grassroots Agronomy*	**Canola harvest management - new data busts myths** - P223 ***Maurie Street,*** *Grain Orana Alliance*	**Filling the yield gap - Optimising yield and economic potential of high input cropping systems in the high rainfall zone** - P231 ***Malcolm McCaskill,*** *Agriculture Victoria*

12.50 pm **LUNCH**

1.30 pm **The art of communicating science and recognising the 'snake oil'** - P241 ***Jenni Metcalfe,*** *Econnect Communication*

2.10 pm **Herbicide resistance - where we are, where we are going and what can we do about it** - P249 ***Chris Preston,*** *The University of Adelaide*

2.50 pm **Wrap up**

3.00 pm **CLOSE**

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Pulsating pulses - expanding pulse crops

Ron Storey.

Storey Marketing Services & Chairman, Pulse Australia.

Keywords

- pulses, protein, sustainability, global diets.

Take home messages

- Record Australian production and exports of lentil and chick pea in 2016 and 2017 — is it sustainable?
- Global demand and dietary shift towards better nutrition and sustainability is undeniable, but the commercial journey is not without bumps in the road — it requires patience.
- Underlying fundamentals for pulse products are very positive however this needs to be tempered by the short-term volatility in markets arising from significant government intervention, at times, to meet domestic political realities in the major pulse markets of the Indian sub-continent.
- **NOTE: At the time of preparing this synopsis of the paper (early January 2018), there is significant market uncertainty due to recent announcements of import tariffs on pulses by the Indian Government. By necessity therefore, this paper will outline some key messages but a range of data and information will need to be updated to be current at the time of the presentation during February 2018.**

Background

There has been a consistent theme over the past decade around rising populations, declining arable land and safe water, and the challenge to produce sufficient food. In grain markets, this has shown its face in rapidly rising demand for feed grains and protein meals to meet animal protein demand (poultry, pork, beef, dairy, etc.). Does this mean Australian grain growers can just hitch a ride on this 'gravy train'? After all, with lentil and chick pea prices at A$700+ over the 2016/2017 seasons, it looked pretty straightforward! But by early 2018, we are back to $400 lentil prices — if there is a buyer! The answer is far more complex, and this applies especially to pulses. The future is bright but will require patience, and like anything that is worthwhile, it will require us to be the best in the business.

The emerging story — from protein, to health, to pulses

The 'protein story' is now quite well-worn. Rising populations and rising incomes drive demand for a shift to animal proteins (poultry, pork, dairy, beef, seafood, etc.), away from rice and noodles as staples. While this western diet trend is touted as 'better', it is also evident that the diseases of the West (diabetes, obesity, cancers, heart disease, etc.) are coming under increasing scrutiny as the link between diet and disease becomes better understood. So the 'health and nutrition story' is gaining prominence over the protein story in terms of food demand. Developing countries are not content to just see a McDonalds or KFC outlet as evidence of their rising incomes and prosperity; they are very concerned about food safety and provenance and the longer term impacts on health budgets as their populations grow older. It is in this context that pulses have an exciting future role to play in satisfying global food demand, not so much in a quantity sense, but more-so in the quality and nutrition of future foods. Quite apart from the growth in raw commodity pulses for the pulse market engine room of the Indian sub-continent (primarily India, Pakistan and Bangladesh), global food companies are starting to introduce pulses as ingredients into mainstream products and beverages. Will the 'pulse story' have a happy ending?

Reconciling the bright outlook with current market realities?

How does the positive future indicated by the above fundamentals line up with current market trends?

As one example, how do we go from $800/t (decile 9) lentil price in 2016/17, as per Figure 1.

....to $400/t (decile 1) lentil prices in 2017/18, as per Figure 2?

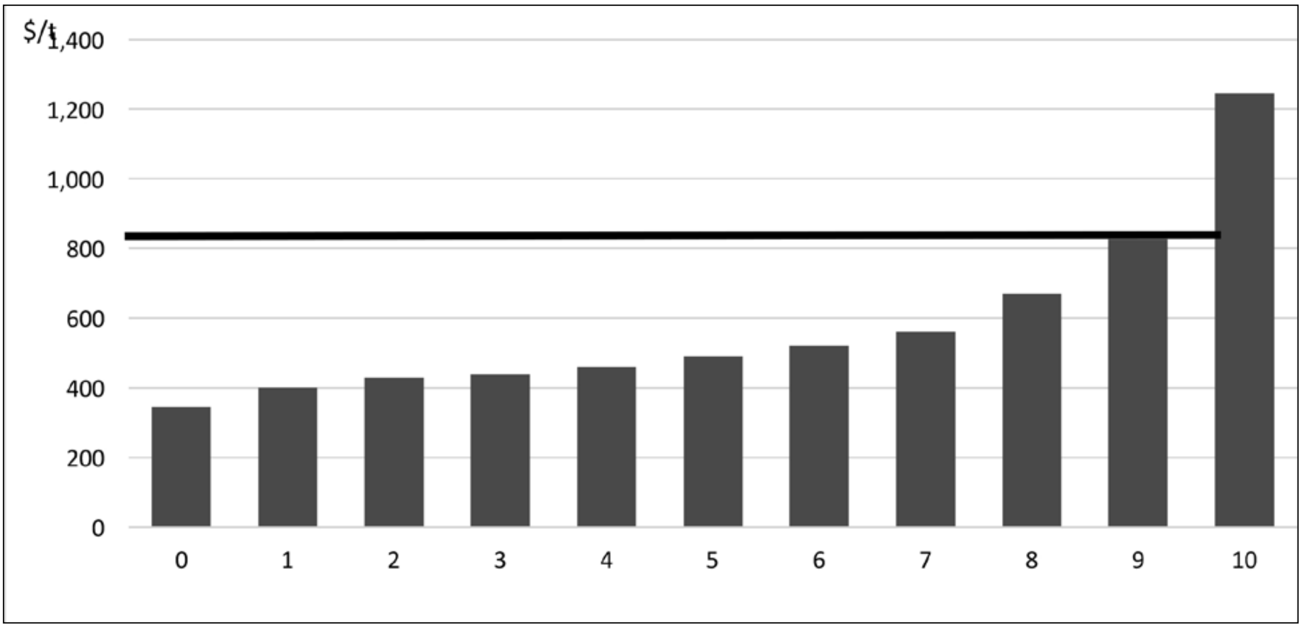

Figure 1. Port Adelaide NIP1 lentil decile, January 2017.

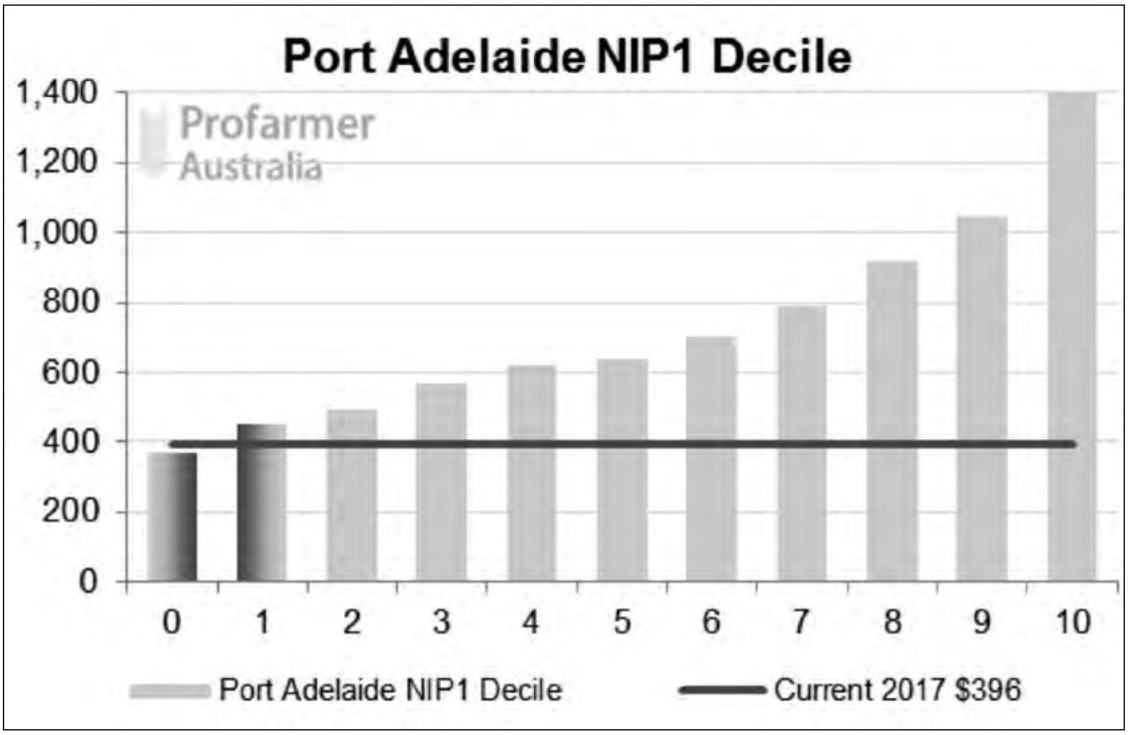

Figure 2. Port Adelaide NIP1 lentil decile 1, January 2018 (Source: Profarmer Australia).

The answer is a combination of seasons (failed 2015 and 2016 monsoons in India, coupled with an all-time record 2016 yields and production in Australia), followed by large Indian Government tariff duties to protect their local growers in late 2017. This level of price volatility helps no-one and we have to look past these short term spikes (both up and down), and ask whether there is a more sustainable, more certain future to justify the investments in varieties, standards and supply chains to sustain both reliable producers and importers?

We also need to appreciate the current market structures, where Australia may have a significant export position, but this can be more than overshadowed by the dependence on a single market.

For example, in chick pea, Australia is the world's largest exporter, but the overall chick pea market is dominated by India which produces about ten times Australia's average production (Figure 3).

So, where to from here? — it's a long term game

In the face of these current market realities (aka, typical commodity boom/bust scenarios) what are the prospects of sustainable, high value pulse crop options for Australian growers and exporters? If we were to be reliant on the general commodity cycle, then life will continue to be a challenge in terms of retaining pulses as a regular profitable option in the farming system. BUT, the reasons to be confident are compelling because the diet shift is not just a hope; it is consumer driven and the trend is under way. That is…

- What we eat matters; the demand for food origin and content will only increase.
- Millennials (18-35 year olds) are driving the change.
- Consumption of 'better For you' foods is outstripping traditional foods.
- Pulses are a stellar converter of water to protein — sustainability.

Additionally, the diet shift (gradual) is being played out in the food sector with traditional uses making way for novel and functional innovations (Table 1).

These trends in the food industry will require pulse supply chains which are targeted and sophisticated, capable of meeting demands of food processors for functionality, traceability and sustainability — not your typical commodity supply chain where lowest price wins. For Australia, this

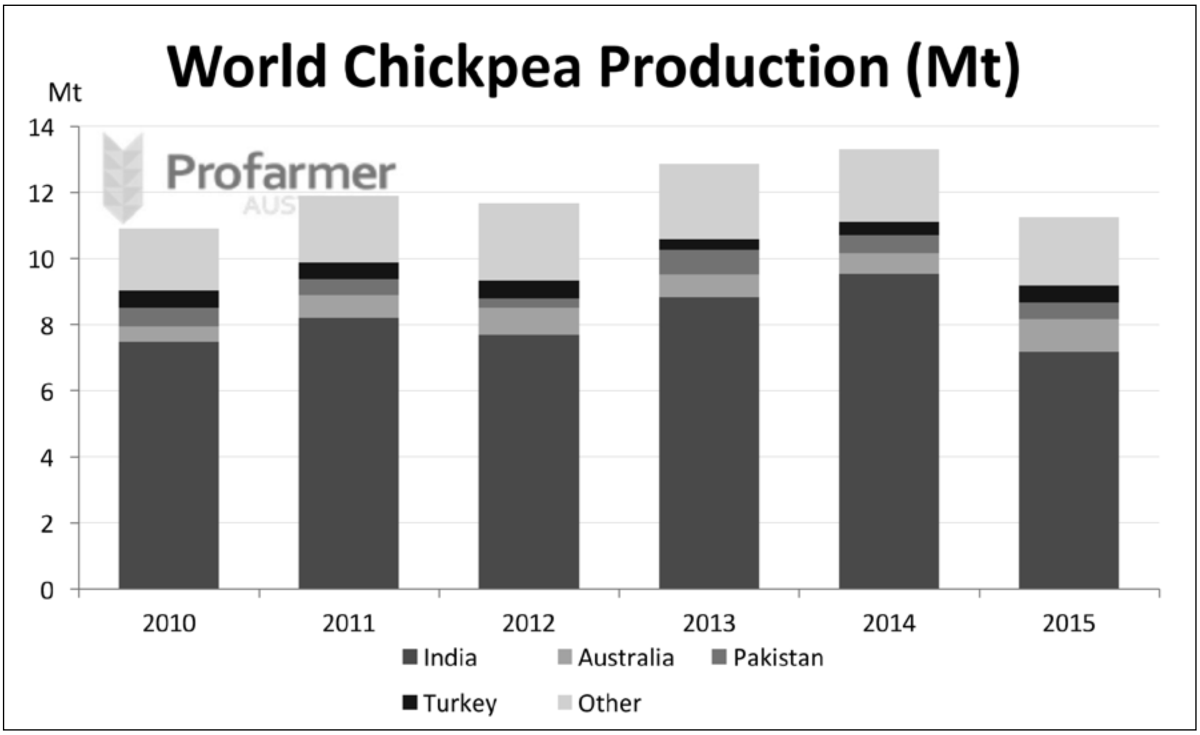

Figure 3. Chickpea – Australia (second bar from bottom of the column) is the largest exporter but India (first bar from bottom of the column) dominates production *(Source: Profarmer Aus)*.

is good news as we are better suited to position ourselves for the 'deli market', not the 'hypermarket'. But it does require time and patience to stay the course.

Table 1. The diet shift

From Traditional	To Novel
Whole pulses	Flours, fractions
Soups, sauces	Batters, breading, bakery
Dips, spreads	Beverages
Cook at home	Snacks, salads — ready to eat

Conclusion

The 20+ year journey to introduce and successfully grow pulses by Australian growers seems to be well embedded and accepted as a good and sustainable practice from a farming systems point of view. Growers have the confidence to grow them. The marketplace for pulses however, continues to throw up the volatility challenge, with highly profitable prices at times and unprofitable prices at other times. The opportunity however, based on some pretty striking global fundamentals on what and how the next generations want to consume food looks particularly positive. Family farming, being a multi-generational pursuit, is well suited to keeping its finger on the pulse.

References

Data drawn from ABS, Profarmer Australia, Australian Crop Forecasters, Pulse Australia

Acknowledgements

Ron Storey acknowledges the support of GRDC and its panel networks in requesting this input to the GRDC 2018 Grains Research Updates.

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Notes

Notes

Collating and analysing small data to make big decisions — can it improve farm productivity and profitability?

Terry Griffin.

Kansas State University.

Keywords

- precision, farm data, on-farm research, profitability.

Take home messages

- On-farm, automated technologies tend to have a faster adoption rate and quicker financial payback than data intensive counterparts in precision.
- Data intensive technologies have great opportunity for improved profitability, if those data are used to their fullest extent.
- One of the most profitable uses of precision agriculture (PA) and farm data is conducting on-farm experiments.

Background

Precision agriculture (PA) technology has been commercially on the market for several decades. Global Navigation Satellite Systems (GNSS, formerly referred to as GPS), Geographic Information Systems (GIS), yield monitors, variable rate technologies (VRT) and other spatial management technologies have been used by growers across the globe, but questions remain about the profitability of these technologies and the future of farm data. This paper summarises: 1) Adoption of PA technology in Kansas, USA, 2) Review of how growers have made profitable use of PA, and 3) Barriers to moving forward including wireless infrastructure and other farm data issues. Adoption estimates are based on empirical evidence from the Kansas Farm Management Association (KFMA) and the United States Department of Agriculture Agricultural Resource Management Surveys (USDA ARMS). The data analysis section focuses on growers' use of the yield monitor and other data that they are collecting routinely, including spatial analysis of on-farm comparisons and alternative on-farm trial designs that take advantage of PA technology. Conclusions outline our vision of the future of PA and the role of farm management extension.

Method

In this study, KFMA growers were queried regarding their utilisation of 10 PA technologies on-farm. The KFMA databank includes detailed farm-level agronomic and financial information from 1973 to 2015. Beginning in 2015, the KFMA dataset was appended with growers' use of PA technology. Currently, more than 500 grain producing farms reported their historic adoption and utilisation of 10 PA technologies

Results and discussion

This paper reports the adoption and the abandonment of PA in Kansas, USA, with a brief comparison to the USDA ARMS dataset. Using the ARMS data, the most common uses of precision technology are presented. Finally, current and future impediments to further adoption are presented.

Adoption of technology

Historically, the adoption of yield monitors was the yardstick with which PA adoption was measured. Today, nearly all new combine harvesters are equipped with yield monitors from the manufacturer — existence does not necessarily imply utilisation at the farm level. Less than half of farms have adopted yield monitors which is consistent with USDA ARMS estimates.

Abandonment of technology

Farms that adopt PA technology typically do not abandon the technology, except for obsolescence or anticipated replacement. In the Kansas example, 40% of farms transitioned to a combine harvester with a GNSS from one without site-specific logging capability. Manual control GNSS guidance(light bars) was expected to eventually become obsolete with the introduction of automated control guidance. Nearly a third of farms using light bars abandoned manual control technology for automated guidance. Farms do not typically abandon automated section control or automated guidance. For the remaining technologies, it was less clear whether the abandonment was for obsolescence reasons or if the technology was abandoned for performance reasons. Farms that abandoned grid soil sampling may have done so by replacing with on-the-go sensing or reverted back to sampling at field regions of more than five acres.

Making the most of data intensive technology

Griffin (2010) reported that USDA ARMS data indicated that growers use PA technologies, especially yield monitors, to conduct their own on-farm experiments. Given the plethora of untested products and wide variability in environmental response to input rates, obtaining local knowledge of how products perform at the farm-level has a very high profitability potential. Private and university services are available to assist growers with conducting their own on-farm trials, however there are some steps that every grower should consider when planning and executing their research (Griffin et al. 2008). At the very least, it is advised that the grower has an interest in the research question and result, not just going through the motions of another person's project. Data quality is paramount, from recording the actual experiment that was implemented to yield monitor calibration to post processing of data by flagging erroneously measured observations.

Barriers to full utilisation of precision technology

Several reasons for lack of full adoption of precision technology are likely. One major issue is the presence of wireless communication infrastructure suitable for transmitting near real time data (Mark et al. 2016). PA and specifically farm data have the potential to change the structure of the agricultural industry, but only with adequate wireless connectivity sufficient to enable telematics and other precision technologies. Until wireless connectivity is improved in rural areas, these failures may lead to differentiation in farmland values, however it is expected that connectivity issues will be solved in the not so distant future. Wireless connectivity may be a primary driver in the adoption of both data intensive and automated technologies as it applied to telematics.

In the USA and Australia, one of the most discussed aspects of PA revolves around the farm data generated, especially in the context of 'big data'. Coble et al. (2018) describe the current landscape of agricultural big data along with the challenges and opportunities for agriculturalists. Among the challenges they describe is the uncertainty regarding data privacy and security — the notion of who 'owns' the data and how growers can protect themselves and their data from misappropriation.

Conclusion

PA technologies have been put into farm-level service around the world. Some technologies have been adopted more readily than others — these typically have the information technology embodied into the product, such as automated guidance or automated section control. Data intensive technologies such as yield monitors, soil sampling, and other sensor data have been adopted less than the automated counterparts and usually have less certain payback periods. Growers who use PA tools for conducting their own on-farm experiments are likely to enjoy improved whole-farm profitability. Even in developed nations, the lack of wireless connectivity is impeding the full utilisation of precision technologies.

Useful resources

https://www.agmanager.info/machinery/precision-agriculture

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Acknowledgements

The author is thankful to GRDC for making this presentation possible. The author deeply appreciates Chris Sounness from the Birchip Cropping Group, and the Victorian Endowment for Science Knowledge & Innovation (veski) for providing funding and effort for the opportunity to visit Bendigo and other locations in Australia.

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Concurrent sessions Day 1

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Are the Russian forces building – what are our spies telling us

Maarten van Helden, Thomas Heddle, Farah Al-Jawahiri and Greg Baker.

South Australian Research and Development Institute, Waite Campus, Adelaide, SA.

GRDC project codes: DAS00170 SA 9174815; **SAGIT project code:** CARASA

Keywords

- Russian wheat aphid, South Australia, population dynamics, management.

Take home messages

- Russian wheat aphid (RWA) is now present all over SA and Victoria, and expanding in Tasmania and NSW.
- Although the aphids are present everywhere, damaging populations have only occurred only in low rainfall areas (e.g. Loxton — <400mm).
- RWA survives summer on volunteer cereals, so management of the 'green bridge' is essential.
- In 2017, RWA autumn migration flights occurred in March and April.
- Early sowing in low rainfall areas increases the risk of autumn infestations.
- Spring migration occurs during warms days of August till the end of November.
- Well established vigorous crops in later development stages(>GS35) are not attractive to RWA.
- Seed treatments can prevent early autumn RWA infestation of crops, but are not always necessary.

Occurrence and current distribution in Australia

Russian wheat aphid (*Diuraphis noxia*, RWA), first reported in SA in May 2016, is now present all over SA, including the Eyre Peninsula, throughout Victoria, and expanding in Tasmania and NSW. So far there are no reports from WA. It is considered that RWA can invade and maintain itself in all of the cereal growing areas of Australia (Avila et al. 2017). In the 2017 season, most SA reports of high populations came from low rainfall areas such as the Mallee and upper Eyre Peninsula.

2017 time of sowing trials

In the 2017 season, South Australian Grains Industry Trust (SAGIT) funding was obtained to run time of sowing (TOS) trials in three regions — Bool Lagoon, Roseworthy and Loxton (high, medium and low rainfall districts, respectively). Sowing was done in April, May, June and July and aphid infestation occurred naturally. Barley (LaTrobe$^{\phi}$), wheat (Scepter$^{\phi}$ and RAC 2388) and durum wheat (Aurora$^{\phi}$) and imidacloprid (Gaucho® 600) seed treatments (Scepter$^{\phi}$ wheat) at 1.2L/1000kg and 2.4L/1000kg were used in the trials.

Observations were done fortnightly, counting aphids and symptoms. Trials were harvested in December 2017 and January 2018.

In each site, a yellow pan trap (YPT) was used to monitor aphid migration activity from mid-May onwards. Elsewhere, YPTs (Loxton Research Centre, Keith) and aphid suction traps at Kapunda (since 2016) and Loxton research centre (since August 2017) were also operating.

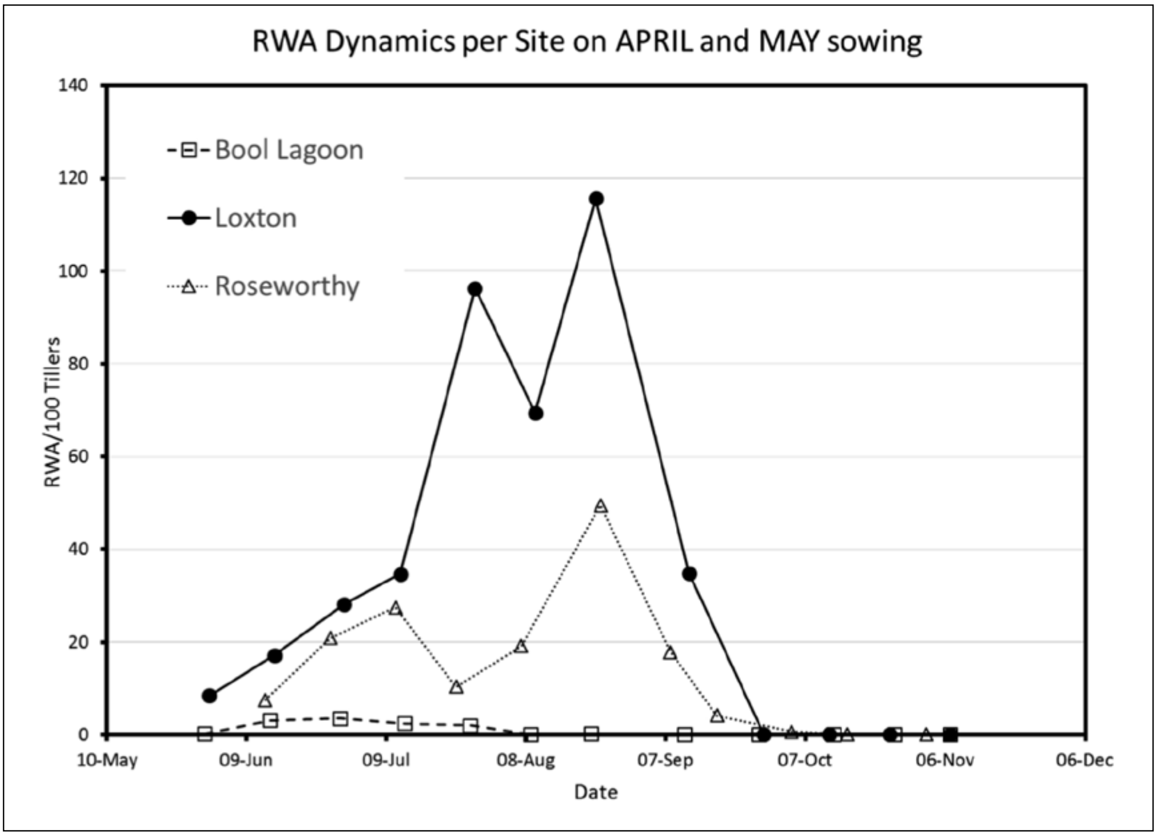

Figure 1. RWA dynamics on the three sites for April and May 2017 sown crops.

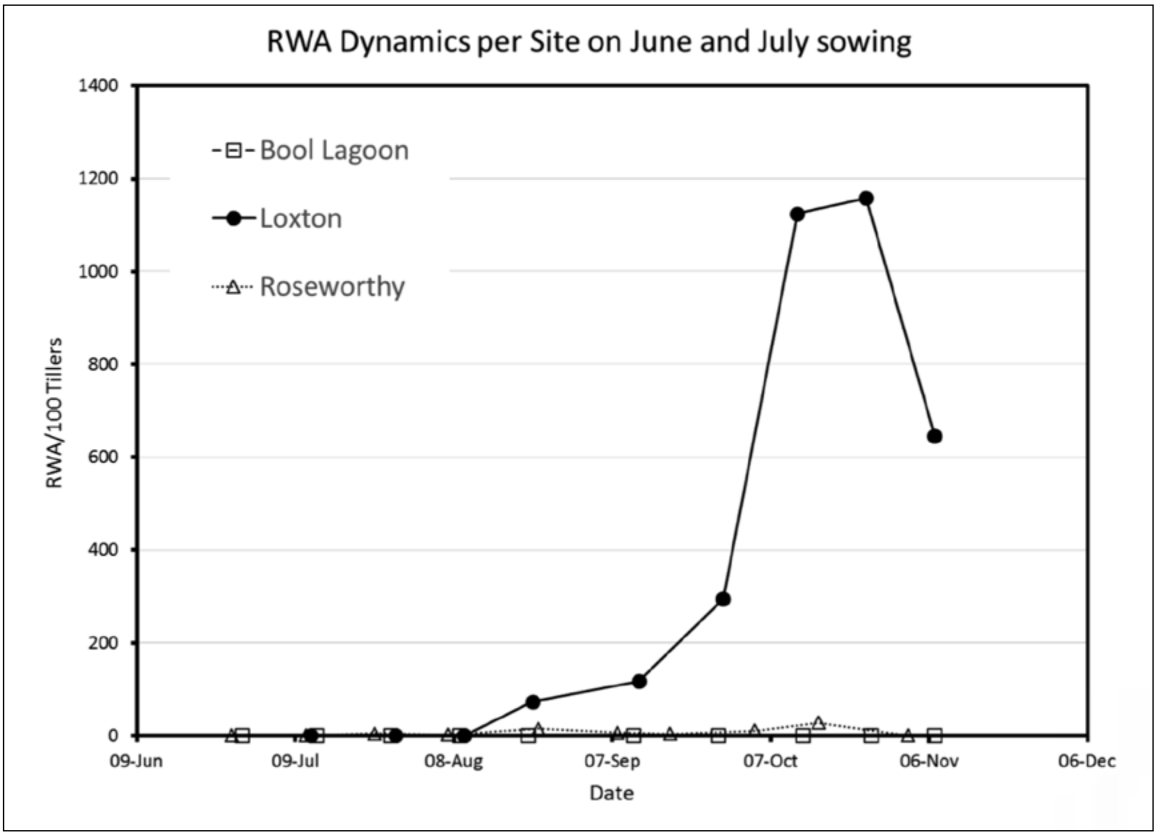

Figure 2. RWA dynamics on the three sites for June and July 2017 sown crops.

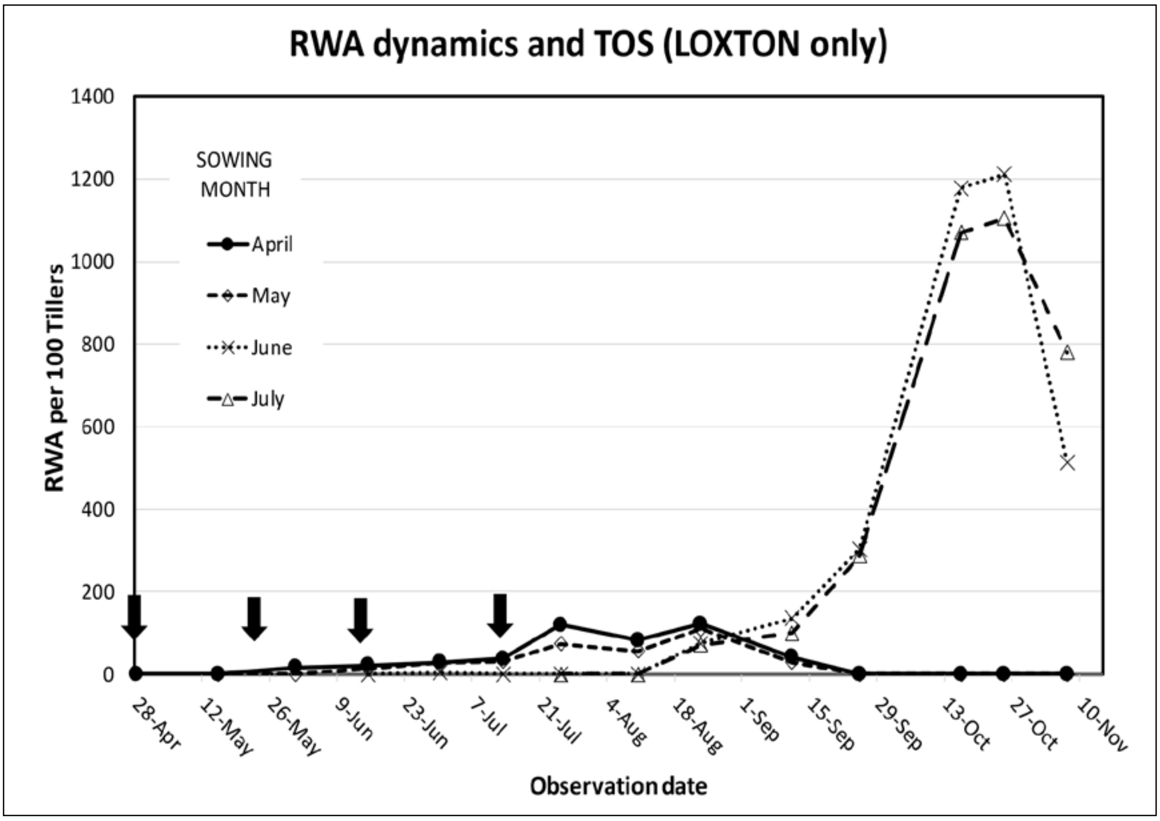

Figure 3. RWA dynamics and time of sowing in Loxton 2017. Arrows indicate sowing dates.

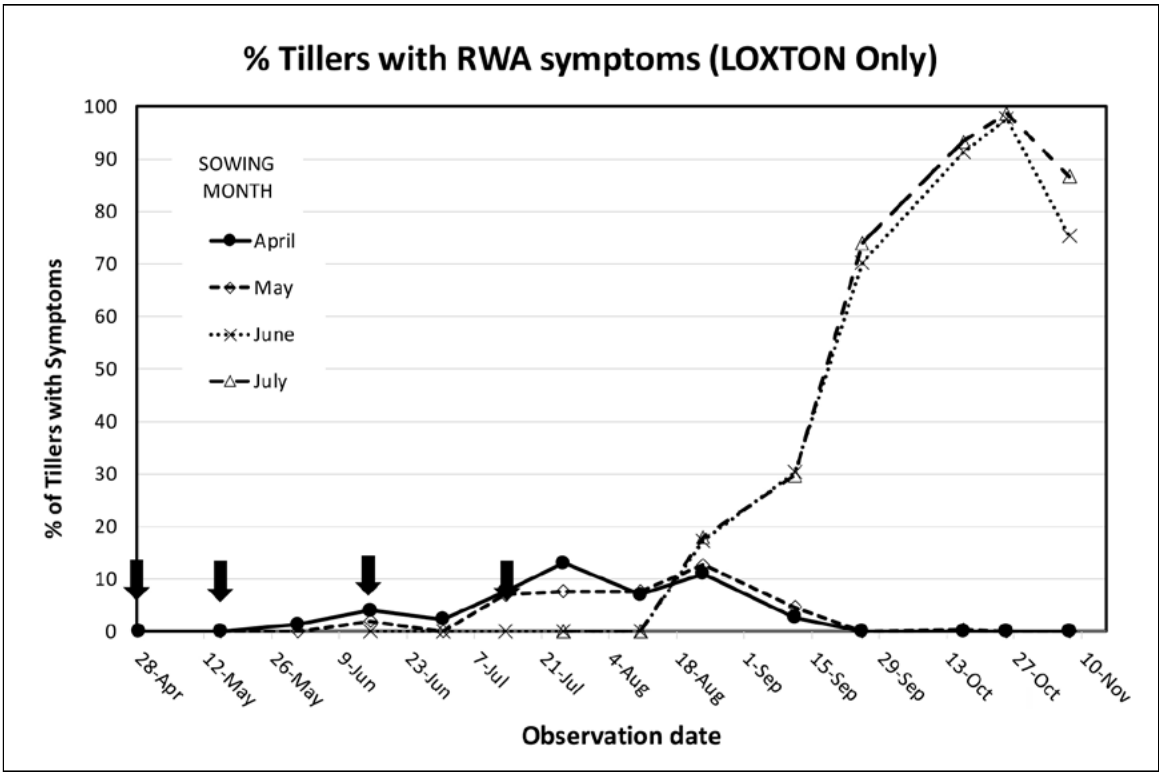

Figure 4. Percentage of tillers with symptoms, Loxton 2017. Arrows indicate sowing dates.

Results and discussion

Regional differences

RWA dynamics per site (non seed-treated plots only) are shown separately on April and May sown crops (Figure 1) and June and July sown crops (Figure 2). Note that the left axes' scales differ between Figure 1 and 2 by a factor of 10.

Although RWA is present in each site, the population density is very different among regions. In the Bool Lagoon area, a total of only 58 over the whole season were observed, while in Roseworthy 1150 were observed. Loxton showed by far the highest populations (23 000 RWA counted).

However, when looking at the April and May sowings (Figure 1), Roseworthy showed populations that were roughly one third of the Loxton population.

The big difference between Roseworthy and Loxton is observed on the June and July sowings that were very heavily infested in Loxton and hardly at all elsewhere.

Time of sowing

Detailed data for all sowing dates are shown only for Loxton in Figure 3. The April sowing was slightly more infested (40% more) than the May sowing. The early (April) sowing caused a slightly earlier and higher initial colonisation that had more time to build up on the crop before less favourable conditions set in, compared to the May sowing. The June and July sowings suffered severe water stress, causing reduced growth. These crops were colonised in August while still in early growth stage (GS 12-14) and aphids then developed to extremely high populations in October before falling in November due to plant death.

Figure 4 shows changes in the percentage of tillers with symptoms per sowing date in Loxton. In the April and May sowings, the percentage of tillers with symptoms never exceeded 15% (July and August) and decreased later in season. The heavily infested June and July sowings reached 100% at the end of October

Differences among crop varieties

The number of aphids on the different cereals on the April and May sowings for Roseworthy and Loxton (average over the whole season) is shown in Figure 5 and the percentage of symptoms in Figure 6. Again we see more aphids in Loxton, but the number of aphids is similar for the wheat and durum wheat varieties, and only the barley (LaTrobe$^{(l)}$) has about half the aphid numbers in Loxton, compared to the wheat and durum varieties.

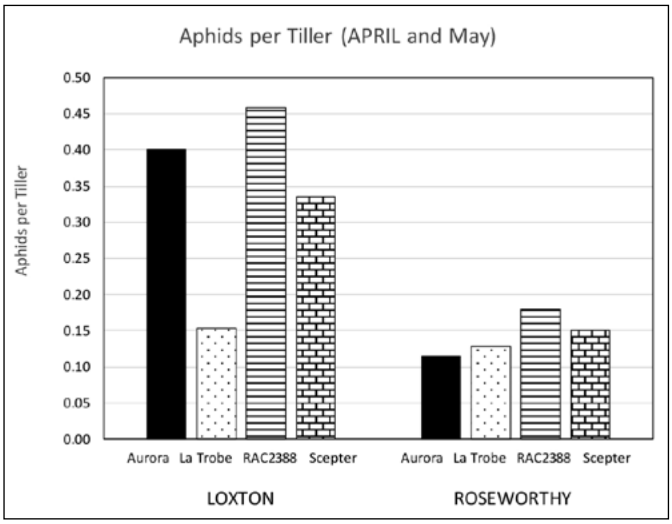

Figure 5. Aphids per tiller per variety. (April and May sowing of Loxton and Roseworthy)

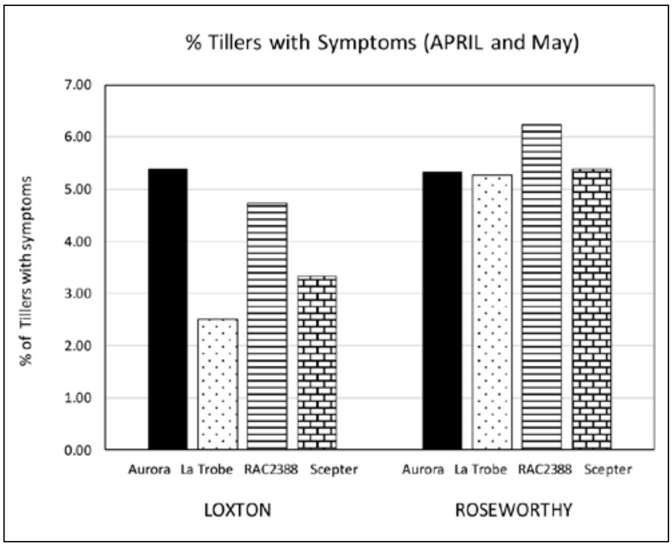

Figure 6. % tillers with symptoms. (April and May sowing of Loxton and Roseworthy)

Surprisingly, this difference in aphid numbers between these two sites is not reflected in the number of tillers showing symptoms, since this is actually higher in Roseworthy than in Loxton for wheat and barley and similar only for durum wheat. Overall, the same ratio of aphids/symptomatic tiller is maintained on each site. This suggests that there is not much difference in sensitivity between accessions to either aphids or symptoms, but that environmental factors, such as climate, water stress and fertilisation seem to be able to influence aphid numbers and symptom expression.

Seed treatments

Table 1 shows the effect of seed treatment on the number of tillers with symptoms.

In the April and May sowings, the seed treatments almost completely prevent aphid infestation (96%

Table 1. Effect of seed treatments on aphid numbers and symptoms in Loxton, separated for April/May and June/July sowings.

Seed treatment	Loxton April + May		Loxton June + July	
Imidacloprid	RWA/100T	% Symptoms	RWA/100T	% Symptoms
UTC	33.61	3.33	377.18	47.14
1.2l/1000kg	0.39	0.72	53.49	27.14
2.4l/1000kg	1.94	0.50	19.84	21.41

No clear difference was observed between the low and high rate of seed treatment.

reduction) and reduce symptom expression by 80%. In the June and July sowings, the reduction in aphids is still greater than 90%, but symptoms are only halved compared to the untreated control treatment (UTC). This suggests that symptoms can occur through aphid probing even when the aphids cannot establish and develop on the plants.

Aphid migration

The capture of RWA in different traps is shown in Figure 7 (suction trap, Kapunda) and Figure 8 (YPT, four locations). As can be seen, some autumn migratory activity of the RWA occurred in March, April and early May. Early sown crops that will be just emerging are at risk of colonisation by RWA during that period.

Following autumn, there were no captures till the first warmer days in August. The number of RWA trapped was then high from mid-September to mid-November.

The overall trapping of RWA in the Kapunda suction trap was 10 times higher in 2017 compared to 2016 suggesting that populations were considerably higher in that area in 2017.

Regional differences in trapping (Figure 8) are very large with no RWA trapped at all in Bool Lagoon (South-East SA), low numbers in Keith and Roseworthy (+/- 50 over the whole season) and high numbers near Loxton (>500 RWA) in the YPTs. This seems to reflect overall differences in RWA pressure per region.

Early spring migrations occurred in early August in Loxton, slightly later in the other regions, and migrations continued during almost three months. These migrations could potentially invade crops, and symptoms have been observed in many paddocks during that period (see peaks in aphid numbers and symptoms for all sowing dates in mid-August (Figures 3 and 4). However, we have seen aphids settle and symptoms and damage occur only in the crops that were still in early growth stage (June and July sowings). This clearly shows that RWA will not settle in well-established and vigorous crops (GS>35).

Yield

As at January 2018, all plots have been harvested and the grain yield and quality data are being analysed. These will be presented at the Updates

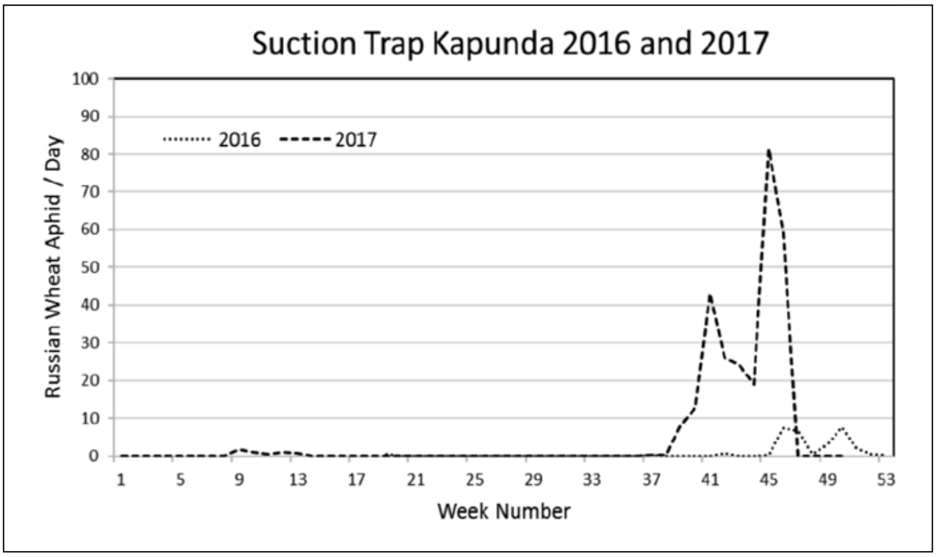

Figure 7. Suction trap data from Kapunda trap 2016 and 2017. Data shows average of RWA per day over a week period.

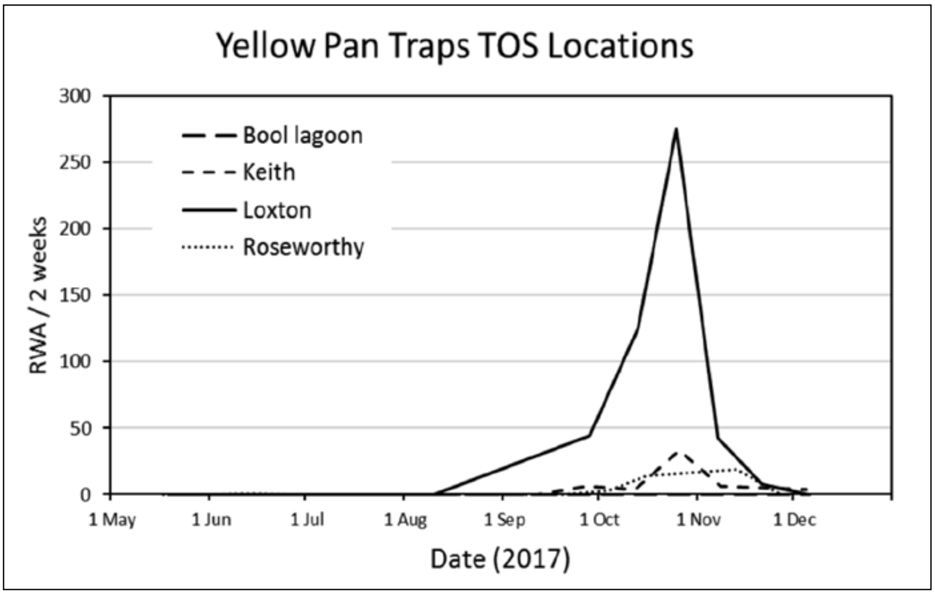

Figure 8. YPT data from TOS locations (+ Keith) in 2017. Data shows average of RWA per two week trapping period.

and are expected to provide a better understanding of actual damage and economic thresholds.

Conclusions

The results show that:

- RWA population dynamics are very different between regions, with generally more aphids in low rainfall areas.
- Autumn colonisation can be aggravated by early sowing. However, we have not seen RWA populations develop above the current intervention threshold (20% of plants infested) during the trial on April or May sown crops.
- RWA numbers on April and May sown crops build up slowly over autumn and winter, but aphids seem to leave these plants during stem elongation in early spring.
- Spring migration of RWA is important, but the migrating winged aphids will only settle in very young crops (GS<30), while the older plants (GS>35) are not colonised by the aphids in spring.
- Seed treatments are very effective in reducing aphid populations and symptoms in April and May sown crops, but it is unclear if this has improved yields.
- Seed treatments are less effective in spring on June and July sown crops (GS<30). Aphid numbers will still be reduced compared to UTC, but symptoms expression can be strong. The effect of the seed treatment on later sown crops appears to decline while the plants are still attractive to RWA.

This TOS experiment will be repeated in 2018 to see if the same trends can be observed.

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.

The work presented here was also funded through the SAGIT project CARASA. The authors would like to thank Maryam Barati and Clare Svilans for technical assistance.

Useful resources

GRDC: Russian Wheat Aphids: tactics for Future Control:

https://grdc.com.au/rwa-tacticsfuturecontrol

GRDC : Tips & Tactics: Russian Wheat Aphid

https://grdc.com.au/TT-RWA

PIRSA (2016/2017). Cereal Aphid dynamics

http://pir.sa.gov.au/research/services/reports_and_newsletters/cereal_aphid_observations_in_south_australia

PIRSA Russian wheat aphid information

http://www.pir.sa.gov.au/biosecurity/plant_health/exotic_plant_pest_emergency_response/ russian_wheat_aphid

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Septoria tritici update and latest developments in powdery mildew management

Nick Poole and Tracey Wylie.

FAR Australia.

ΦExtra technical comment by Protech Consulting Pty Ltd

GRDC project codes: FAR00004-a, FAR00002 and CCDM Programme 9

Keywords

- Septoria tritici blotch (STB) *Zymoseptoria tritici*, powdery mildew *Blumeria graminis f. sp. tritici*, fungicide resistance, integrated disease management (IDM), Quinone outside Inhibitors (QoIs), strobilurins, triazoles.

Take home messages

- Reduced sensitivity of the septoria tritici blotch (STB) pathogen *Zymoseptoria tritici* to triazole fungicides is likely to be an increasing problem, following the discovery of more resistant biotypes (R8 strain or Isoform 11) on the mainland in 2016.
- The presence of this strain and its proportion in the population will influence disease management strategies differentially.
- In Tasmania, early season disease control in the field with flutriafol (2017 trials) and tebuconazole (2016 trials) has been reduced by more resistant biotypes of the pathogen (R8 strain or Isoform 11), whilst on the mainland, STB activity of flutriafol appears to have been maintained in 2017.
- The performance of a new Succinate Dehydrogenase Inhibitor (SDHI) based seed treatment and to a lesser extent fluquinconazole (Jockey®) has been better than flutriafol in Tasmanian trials.
- Following the discovery of wheat powdery mildew (WPM) resistant to strobilurin fungicides in 2016 and 2017 collectively, we should aim to minimise the use of fungicides containing QoIs to one per season.
- Use integrated disease management (IDM) measures such as more resistant cultivars, rotating out of wheat where wheat stubbles were infected with WPM in 2016 and removing the green bridge volunteers to further prevent infection.
- Where more than one fungicide is used in wheat, avoid using the same triazole active ingredient twice, irrespective of diseases to be controlled.

Background

Septoria tritici blotch (STB) continued to be a problem in 2017 despite the drier conditions encountered compared to 2016. This was likely the result of stubble infection from 2016 and cultivar susceptibility. Whilst the adoption of integrated disease management (IDM) remains central to prolonging the activity of fungicides, 2017 research results illustrated geographic region was a key consideration in the adoption of fungicide management strategies. In Tasmania, where the use of fungicides is more intensive as a result of a longer more disease prone season, the field performance of commonly used fungicides, such as flutriafol and tebuconazole, is being compromised by more resistant strains of the STB pathogen. These more resistant strains show reduced sensitivity to fungicide applied in the field, meaning that although they still give some control, they are not as effective as they once were. It was confirmed at the 2017 Wagga Wagga GRDC Grains Research Updates that the more resistant strains found in Tasmania are now being found on the mainland at low levels in the population. As a result, FAR Australia, working with Southern Farming Systems and Mackillop Farm Management Group, has been evaluating the performance of these fungicides on both the mainland and in Tasmania. This paper builds on the paper presented at the 2017 GRDC Updates looking at the 2017 results from the GRDC funded project FAR00004-a that was set up to look at the control of STB and leaf rust in the field.

For the first time in 2016, wheat powdery mildew (WPM) samples from both southern Victoria and Tasmania were confirmed as being resistant to QoI fungicides (FRAC Group 11) commonly referred to as the strobilurins e.g. azoxystrobin, pyraclostrobin. At present, it is difficult to comment on how widespread these resistant mutations are within the mildew population, however it is the same mutation that was found in Europe and New Zealand (G143A mutation). In this paper, we look at the consequences of this resistance mutation spreading in the WPM pathogen population.

Research conducted on STB in 2017

Field research was conducted at four sites in the 2017 season: Hesse and Westmere in southern Victoria, Hagley in Tasmania and Conmurra in south east South Australia. In contrast to 2016, growing season rainfall (April-November) for 2017 was lower in all of these regions, a factor which would have restricted the ability of the disease to be as damaging.

Table 1. Growing season rainfall at the research locations where control of STB is being assessed.

Trial site region	2016	2017
Hesse, Victoria	430	379
Hagley, Tasmania	827	430
Conmurra, South Australia	675	476
Westmere, Victoria	561	436

At the time of writing this paper, 2017 harvest data was in the process of being analysed or trials were not yet ready for harvest (Tasmania), therefore the following paper is primarily based on disease data collected from the FAR Disease Management Centre at Hesse in southern Victoria, where yield data was available.

Results and discussion

Fungicide performance against STB - Zymoseptoria tritici

Influence of at 'sowing' fungicide products on the mainland and in Tasmania

Work in southern Victoria, where STB has been problematic since 2010, has shown that flutriafol applied in furrow is still giving relatively good control despite the discovery of STB strains that reduce the performance of flutriafol. Results at FAR Australia's Disease Management Centre in 2016 and 2017 revealed field control from flutriafol was similar (or superior, data not shown) to fluquinconazole (Jockey®)$^{\Phi}$ (Figure 1).

$^{\Phi}$ *Registered for suppression not control.*

At present, it is thought that the level of the R8 strain or isoform 11 strain (the strain that carries one of the more serious mutations for reduced sensitivity to triazoles) is at relatively low levels in the mainland population of STB. This may help explain why flutriafol's field performance still appears reasonably good. However, assuming that this strain of the disease is equally fit (adapted to the environment) as other strains of the STB pathogen, it is likely that this strain will increase in importance and as a result increasingly reduce the efficacy of triazole fungicides, in particular flutriafol and tebuconazole. This is what looks to have happened in Tasmania where the frequency of the R8 or Isoform 11 strain in the STB population is much higher than it is on the mainland. This strain in Tasmania is at such high levels in the population that the performance of triazoles in the field is now being compromised. However, the reduction in the performance of triazoles is not occurring equally. In trial data, flutriafol and tebuconazole are affected to a greater extent than other triazoles, such as the seed

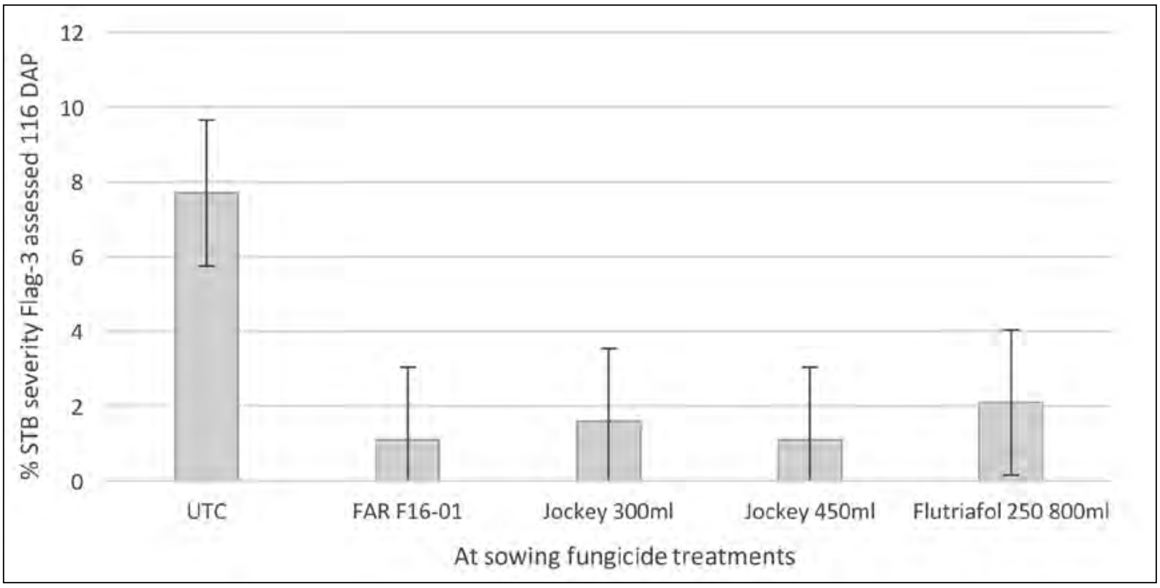

Figure 1. Influence of 'at sowing' fungicide applications on % STB infection recorded on F-3 at GS37-39 on 31 August 116 days after planting – cv Bolac⦶, Gnarwarre, southern Victoria 2016 FAR F16-01 (Experimental seed treatment), Jockey® 300mL$^{\Phi}$ (/100kg of seed), Flutriafol 250 800ml/ha (applied to MAP).

$^{\Phi}$ *This is below the label rate of 450mL/100kg.*

treatment fluquinconazole (Jockey®) or the foliar applied triazole epoxiconazole (Opus®). Fungicides with an alternative mode of action, such as the SDHI seed treatment FAR F17-01, are also unaffected by this mutant strain and have performed extremely well in 2017 at the Tasmanian site (Figure 2).

It should be emphasised that the fungicide products tested are all approved for use in wheat$^{\Phi}$ and were tested for control of STB and leaf rust that occurred together in this experimentation. It should also be emphasised that not all products tested have an individual label recommendation for STB control, even though they are all approved for use in wheat. The infection of leaf rust was not noted to be as severe in 2017 and therefore is unlikely to have influenced the yield results to the same extent as it did in 2016.

$^{\Phi}$ *All products tested except FAR F16-01*

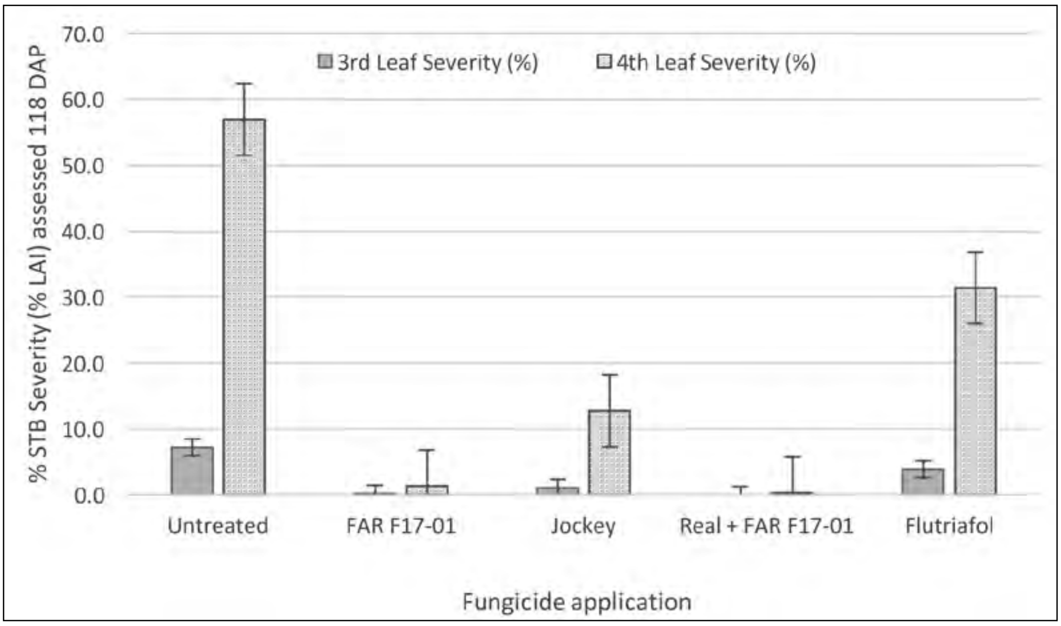

Figure 2. Influence of 'at sowing' fungicide applications and Opus® 500mL/ha applied at GS24 on % STB infection severity recorded on third and fourth oldest leaf at the late tillering stage (GS25) on 23 August 118 days after planting – cv SQP Revenue⦶, Hagley, Tasmania.

Overall, from the trial locations where testing is taking place, it would appear that disease management strategies in Tasmania need to be modified to take account of changes that have already occurred in the STB pathogen population. However, on the mainland if the proportion of more resistant isolates increases, then changes in disease management strategies will be forced upon growers and advisers as some active ingredients become less effective. For now though, whilst we are not seeing the effects of changes in the STB population to the same degree on the mainland, it is important that we collectively act by adopting as many IDM options as possible before resorting to fungicide use and wherever possible, alternating our fungicide strategies so we do not depend on the same active ingredients.

Foliar fungicide performance against STB

The significant differences in product performance resembled results generated in 2016 under higher disease pressure with triazole and strobilurin mixtures (Radial®, Amistar Xtra® based on the strobilurin azoxystrobin) and SDHIs performing more strongly than some of the triazoles applied alone. Of the triazoles used in wheat, Opus 125 SC® (epoxiconazole) and Prosaro 420 SC® (tebuconazole and prothioconazole) were significantly superior to tebuconazole and the coded triazole FAR F1-16. In terms of yield response, all fungicides applied at their full rate gave a significant yield response, however there were no significant yield advantages to the strobilurin and SDHI triazole mixtures over Opus® and Prosaro® in 2017 as there had been in 2016 when both yields and disease pressure were higher.

It should be emphasised that although Opus® and Prosaro® are approved for use in wheat, there is currently no label recommendation for STB control.

Integrated Disease Management (IDM) - influence of cultivar resistance on fungicide strategy

Adopting better genetic resistance is a key strategy for reducing STB infection in wheat and reducing the exposure of fungicides to the further development of pathogen resistance. 2017 results from GRDC project FAR00004-A illustrated the positive impact of genetic resistance on disease management strategies. Beaufort$^{\Phi}$ (rated susceptible STB), Accroc (moderately susceptible STB) and SQP Revenue$^{\Phi}$ (moderately susceptible STB) were evaluated with nine different levels of fungicide management. The results illustrated that Accroc and Revenue$^{\Phi}$ significantly reduced disease

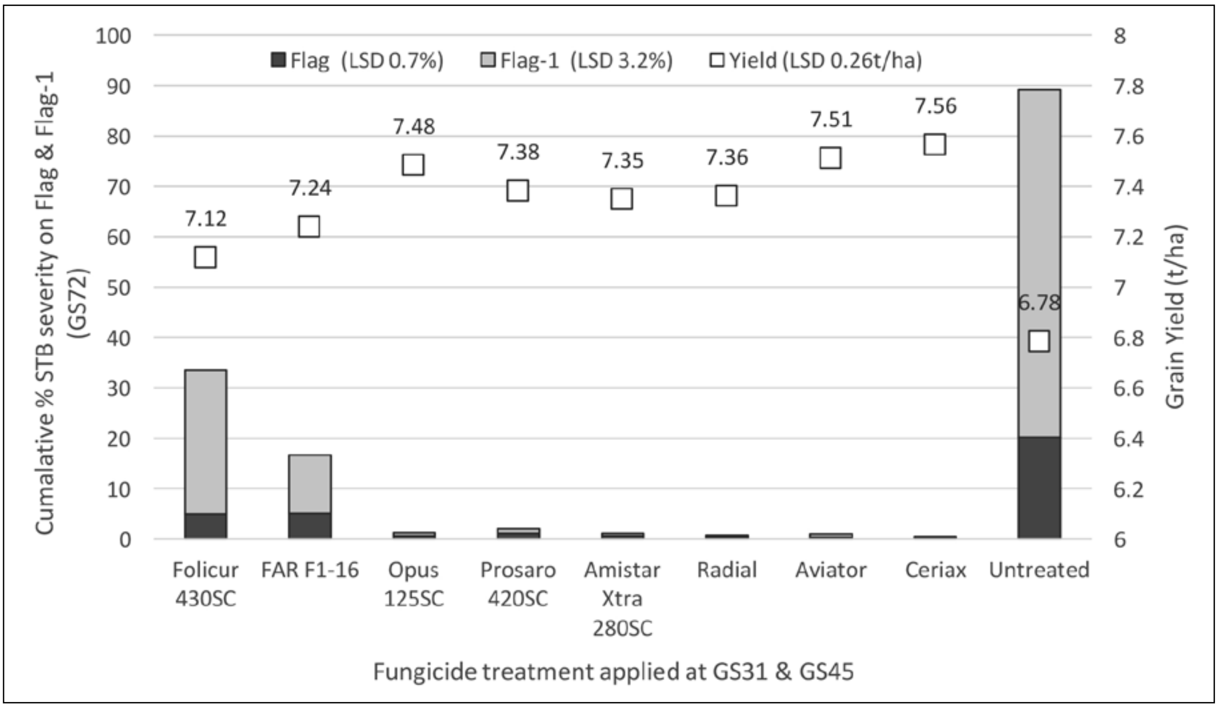

Figure 3. Influence of foliar fungicides (full label rate) on STB % severity and yield (t/ha) of wheat – cv SQP Revenue$^{\Phi}$, FAR Disease Management Centre, Hesse, Southern Victoria.

$^{\Phi}$ *Of the products listed in Figure 3 the only Aviator product registered is Aviator XPro and it is not registered in wheat. Ceriax is not registered and Folicur is no longer registered. These products are used for research purposes only.*

pressure in relation to Beaufort$^{\phi}$ and produced no significant differences in STB infection whether one, two and three spray fungicide programs were applied (Figure 3). However, with Beaufort$^{\phi}$ under higher disease pressure, increasing the number of foliar fungicides progressively reduced STB infection in the lower canopy, particularly with the GS31 and GS39 sprays. With Accroc and SQP Revenue$^{\phi}$ the slight improvement in genetic resistance resulted in lower disease pressure and no significant differences in disease control between one, two and three spray fungicide programs, whilst with Beaufort$^{\phi}$ there was a clear advantage in the lower and upper canopy disease control between one and two spray programs.

With the slightly more resistant cultivars SQP Revenue$^{\phi}$ and Accroc, there was an indication that disease development was delayed compared to Beaufort$^{\phi}$ and that severity increased later in the season, since there were significant advantages to two sprays over one on Flag-1 at the later assessment taken on 17 November during grain fill (data not shown). The increased STB genetic resistance of SQP Revenue$^{\phi}$ and Accroc over Beaufort$^{\phi}$ was manifest in the yield responses obtained in the trial (Figure 5). The level of yield response in Accroc and SQP Revenue$^{\phi}$ was approximately half of that observed in Beaufort$^{\phi}$, however all three cultivars gave the optimum economic response from two fungicide applications applied at GS31 (1st node) and GS39-45 (flag leaf emergence - booting). In part this result is thought to be related to rainfall events favourable for STB infection in September that occurred after the first fungicide was applied on 10 September and before the second spray was applied on 3 October (Figure 6).

Fungicide activity against powdery mildew and strobilurin resistance

Product performance against powdery mildew – Blumeria graminis

Early in 2017, researchers at the Centre for Crop and Disease Management (CCDM) led by Dr Fran Lopez discovered strobilurin (Quinone outside Inhibitors (QoI) – FRAC Group 11) resistance in wheat powdery mildew (WPM) *Blumeria graminis f. sp. tritici*. The resistance was discovered in samples from susceptible cultivars grown in southern Victoria and Tasmania. This was the first case of QoI resistance in broadacre cereal crops in Australia. The single point mutation that confers this resistance (G143A mutation) is exactly the same mutation that exists in the WPM resistant populations in Europe, discovered two years after these products were introduced in 1996. It is a single step to resistance and means that QoI or strobilurins, irrespective of active ingredient, will not give control. In Australia, the greatest of the unknowns is how prevalent this mutant is in the pathogen populations in these regions. At present, this resistance has not been

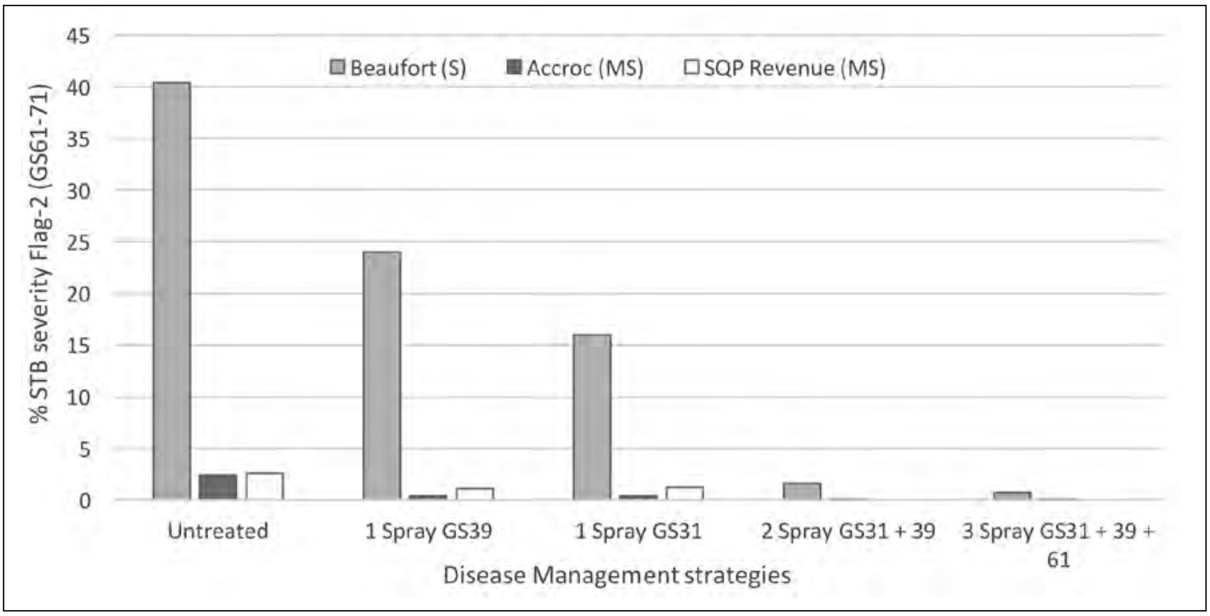

Figure 4. Influence of cultivar resistance and number of foliar fungicides on % STB infection on the lower crop canopy (Flag-2) assessed at flowering (GS61-71 3 November) – FAR Disease Management Centre, Hesse, Southern Victoria.

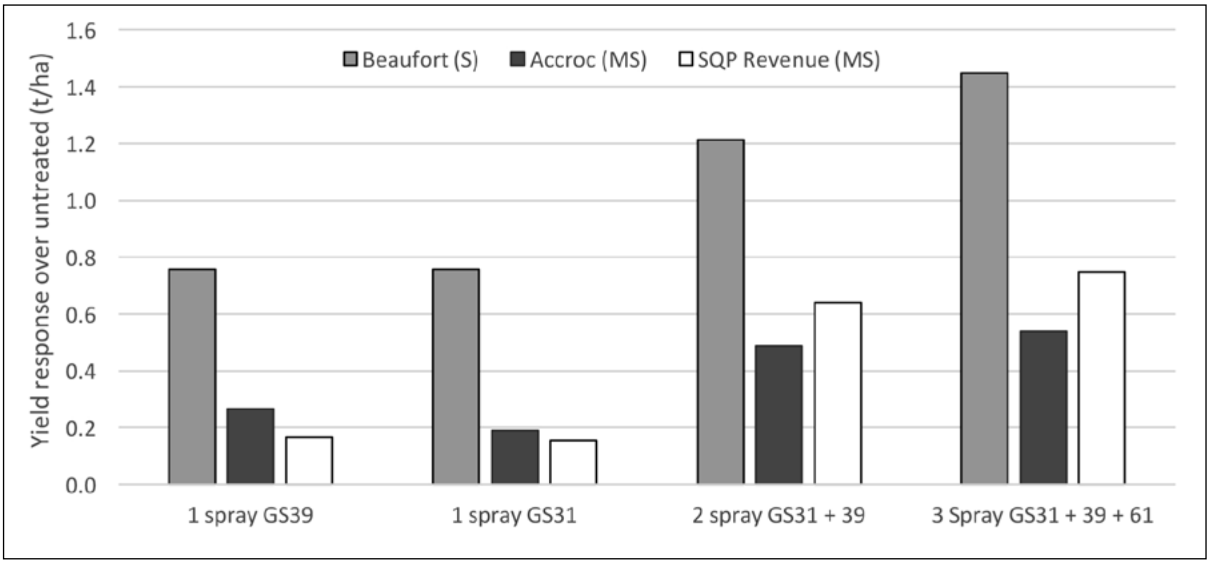

Figure 5. Influence of cultivar resistance and number of foliar fungicides on yield response (t/ha) in three cultivars (Beaufort$^{(\phi)}$, Accroc and SQP Revenue$^{(\phi)}$) of differing disease resistance – FAR Disease Management Centre, Hesse, Southern Victoria.

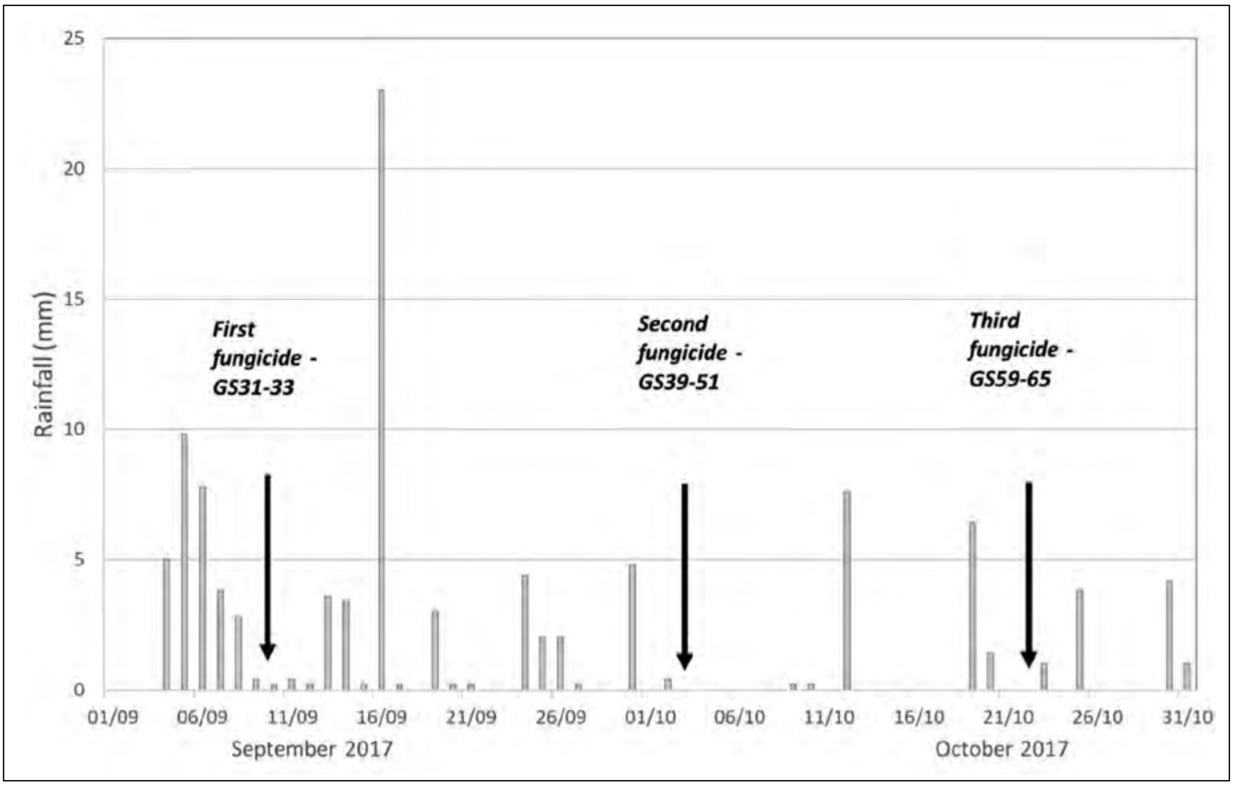

Figure 6. September and October rainfall in relation to fungicide application and development stage – FAR Disease Management Centre, Hesse, southern Victoria.

discovered in any other regions. At those locations where it was discovered, the frequency of the mutation in the mildew samples was moderate in Tasmania with up to 40% of the population affected. If the population dynamics follow what happened in Europe, it is likely that the WPM population will become more and more resistant to strobilurin fungicides (azoxystrobin (e.g. Radial®, Tazer Xpert®, Amistar Xtra®) and pyraclostrobin (Opera®) relatively quickly (two to three years). In Australia, only two modes of action are registered for WPM control Group 3 (DMI triazoles e.g. epoxiconazole, tebuconazole) and group 11 (QoI strobilurins). However, be aware that strobilurins in broadacre cereal crops are only available in mixtures with triazoles so one might expect that these mixtures will become more dependent on the triazole (Group 3) element in the mixture for the control of the disease if the proportion of mutants in the population increases.

However, with the triazoles, there is a further complication in that in Victoria, NSW and Tasmania, the 'gateway' mutation Y136F has also been discovered in WPM populations. This is a mutation that whilst it is unlikely to affect the field performance of triazole fungicides against WPM, it will enable the population to develop more serious mutations (hence the term gateway). As a result, resistance in the WPM population to triazoles is likely to develop albeit quite slowly in comparison to QoI resistance since it is a multistep resistance based on accumulating multiple mutations (multistep resistance).

So what can growers do to control WPM and minimise further fungicide resistance issues?

- If this disease is prevalent in your region, look to reduce disease pressure by adopting cultivars with good resistance to WPM.
- Use other IDM methods for controlling WPM such as rotating crops where there are infected stubbles, removing the green bridge and using clean seed sources.
- Minimise the use of QoI containing fungicides to one per season, particularly in regions where resistance has not been discovered.
- In regions where QoI resistance has been confirmed, alternate the triazole fungicide used to control powdery mildew since this will assist in preventing the build-up of multi mutations in the pathogen to WPM.
- Please consider sending a sample of active disease to the CCDM since the results inform the research community about the geographic spread of fungicide resistance and the adviser about the appropriate fungicide strategy to adopt.

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.

We also would like to acknowledge the work of our co-workers and collaborators in these projects. For the STB research FAR00004-a Amanda Pearce and her colleagues in SARDI, Charlie Crozier at Mackillop Farm Management Group, and Jon Midwood and his colleagues at Southern Farming Systems in Victoria and Tasmania. Dr Fran Lopez and his team at the CCDM covering powdery mildew resistance and the collaboration on 'baiting' trial research under Programme 9 of the Grains Research and Development Corporation and Curtin University bilateral.

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Notes

Southern region pulse performance and agronomy update 2018

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GRDC project codes: DAV00150, DAV00154, DAN00212, UA00163, DAS00131, DAS00139, CUR0023, DAV00129, DAV00128, DAV00144

Keywords

- pulse varieties, lentils, field peas, sowing dates, herbicide tolerance, disease management, grain quality, ascochyta blight, bacterial blight, root diseases.

Take home messages

- The area sown to pulses in South Australia (SA) and Victoria (VIC) continued to increase, particularly lentils and chickpeas and in Mallee regions in response to highly profitable crops in 2016. Similar to previous seasons, the lentil variety, PBA Jumbo2$^{\phi}$ performed extremely well in 2017, highlighting its yield stability across a range of regions and through a range of seasonal conditions. It is a variety that reduces disease risks and benefits from sowing early to maximise yield potential.
- Delayed sowing in field trials generally resulted in significant yield losses in pulses in VIC across all sites and rainfall zones in 2017, with losses in gross margin ranging from $200/ha to $250/ha in lentils and $100to $600/ha in chickpeas. Significant varietal variation in response to sowing date was observed with losses in lentils greater than 50% from delayed sowing observed at Curyo. In field peas, early disease control with new fungicide actives is important for reducing initial ascochyta blight (AB) infection levels with a yield potential above 1.5t/ha. A late fungicide spray is important to control AB in spring when rainfall is conducive to disease spread and pod and seed infection. Early sowing into a high disease risk window with these improved new fungicide actives was demonstrated to have better yield benefits over later sowing in the 2017 season.
- Timely harvest is important for retaining grain quality attributes such as seed coat colour, seed coat wrinkling and screenings within the allowable maximum limit for total defective material and delivery of premium quality (grade 1) crops. Significant quality variation exists among genotypes in response to harvest time. Frost in 2017 caused significant yield and quality loss, with variation in quality noted among different varieties.
- Disease severity was low to moderate in pulses in 2017. Variety reactions to AB remain the same as previous seasons, although the pathotype of *Ascochyta fabae*, which is aggressive on Farah$^{\phi}$, is becoming more frequent and more widespread. AB lesions were observed on some PBA Hurricane XT$^{\phi}$ lentil crops and AB was common in chickpea crops. Bacterial blight infected field peas in VIC following hailstorms and frosts. Root rot (potentially *Phytophthora* sp.) has caused significant yield losses in irrigated chickpea crops sown in late winter to spring in south eastern SA.

2017 seasonal snapshot

The area sown to pulses in SA and VIC continued to increase in 2017 on the back of a record breaking 2016 season. Estimates indicate that more than 825,000ha was sown — a 5% increase on 2016 (ABARE Australian Crop Report, December 2017). Lentils and chickpeas drove most of this expansion, particularly in the low rainfall zone in response to high grain prices and highly profitable crops from the 2016 harvest.

In 2017, pulse grain yields were variable across the region, ranging from slightly above average to below average. For some regions, 2017 could be termed a 'reality check', after the excellent yields, prices and profitability observed in 2016. For example, in some lower rainfall zone areas, lentil yields were lower than 0.5t/ha combined with prices less than $500/ha. Despite the lower returns from pulses in some areas, we continue to see their value in the whole cropping system with higher yields in cereals observed following the pulse phase.

The environment, combined with a challenging period around sowing and having to control mice, played a crucial role in the variability of the pulse industry in 2017. For example, one of the Southern Pulse Agronomy (SPA) sites was baited 10 times to minimise crop damage. As a general observation in VIC, a majority of the early sown crops (late April to early May) were sown into a moist seed bed, ensuring good initial establishment, particularly following good summer rain. Crops sown from mid to late May were often sown into drying topsoil, which meant slow or staggered establishment. In contrast, sowing conditions were dry throughout most of SA, with some locations not experiencing significant rain events until late June.

Despite the challenging conditions, establishment and growth were generally adequate during the winter period which experienced average to above average rainfall. Annual growing season rainfall was generally close to long term averages in VIC and up to 15% below average in SA at SPA research sites. During late winter and early spring, several frost events resulted in crop damage, particularly in lentils, but there was also an outbreak of bacterial blight in field peas in some regions. Generally, disease levels in pulses were low and well managed, due to dry spring conditions. Drying spring conditions, combined with high temperatures in some of the lower rainfall zones, contributed to lower yields in lower rainfall zones. High winds, just after maturity, also caused significant losses in lentils throughout many regions. A late spring frost throughout parts of the medium rainfall zone (Wimmera) caused significant yield and grain quality loss in lentils and chickpeas.

New variety release

Field peas

PBA Butler$^{\phi}$ (tested as OZP1101) is a superior yielding 'Kaspa$^{\phi}$ type' field pea. It is distinctly more vigorous than popular semi-leafless pea varieties such as Kaspa$^{\phi}$, PBA Oura$^{\phi}$ and PBA Gunyah$^{\phi}$. PBA Butler$^{\phi}$ combines resistance to the economically important diseases, bacterial blight and downy mildew. Although it is rated as moderately susceptible to black spot, it is one of the better performing field peas in this regard. PBA Butler$^{\phi}$ has a broad adaptation and it is suitable to grow across all field pea production zones in southern Australia. PBA Butler$^{\phi}$ has significant advantages in regions prone to bacterial blight and downy mildew.

Agronomic research highlights

SPA is a collaborative agronomic research program with investment by GRDC, DEDJTR and SARDI, with agronomic trials across SA and VIC. Some key findings from 2017 are highlighted here and previous research related to key research areas of herbicide tolerance, disease management, canopy management (biomass and architecture) and harvest quality. Further research and details relating to agronomy and new varieties will be discussed during the updates. A complete summary of trials will be available later in 2018.

Herbicide tolerance

SPA has been evaluating an elite Plant Breeding Australia (PBA) faba bean breeding line incorporating Group B tolerance traits (developed through project DAS00131), in parallel to the Group B tolerant lentil variety PBA Hurricane XT$^{\phi}$, in a range of agronomic trials over the past few years with promising results. DAS00131, along with project DAS00113, has also explored a range of other traits in lentils, including group C tolerance, and more recently has started trait development work in chickpeas and field peas. However, extensive characterisation, genetic understanding, and evaluation of the commercial potential of all these traits are still required to deliver all of these traits to market. DAS00131 is also working closely with PBA to rapidly incorporate any useful tolerance traits into elite backgrounds, and once validated, the best of these lines will be evaluated more broadly across a range of agronomic trials to ensure best management packages are available to growers for potential new varieties which incorporate herbicide tolerance traits.

Sowing dates

A range of higher yielding pulse varieties have been released with improvements in agronomic traits including biomass production, lodging resistance, disease resistance, herbicide tolerance, maturity and pod retention. In addition, growers are sowing crops earlier to maximise yield potential and reduce risks of heat and terminal drought stress. Research in 2017, similar to 2016, focused on understanding the variability in varieties and breeding lines in response to sowing dates.

At all trial sites and for all crops assessed, there was a reduction in yields from delayed sowing ranging from 2% to 37% (Table 1). For chickpeas at Curyo, this equated to a reduction in a gross margin of more than $500/ha (up to $900/ha in kabulis). The magnitude of response was related to a number of environmental factors including moisture at sowing, and timing of frost and heat events. Due to the relatively dry spring conditions and active management, disease was not an issue in all trials in 2017 except field peas at Rupanyup, where bacterial blight was observed at low levels following frost in early spring. As indicated previously, in VIC moisture was generally optimal at the earlier 'standard' sowing date and drier at the delayed sowing. This, combined with the warmer air and soil temperatures, meant that the establishment and early growth of the earlier sown treatments were much more vigorous and advanced than the delayed treatments. For much of the season, growth of the earlier 'standard' treatments was approximately four to six nodes ahead of the delayed treatments for all crops. The differential growth stages associated with sowing dates meant that the impact of frost was variable across both crops and varieties (discussed in Table 2). For example, in field peas at Rupanyup, frosts during spring, which contributed to bacterial blight, and then in early November, are likely to have more significantly impacted on the earlier 'standard' sowing date in comparison to delayed sowing (Table 1). No major frosts had an impact on the crops at Ouyen and Curyo, but heat and drying conditions during spring are likely to have significantly impacted the delayed sowing plots, generally resulting in substantially lower yields. For chickpeas there was only a 9% reduction in yield from delayed sowing at Ouyen, but 28% and 17% reductions were observed at Curyo and Rupanyup, respectively (Table 1). The relatively low reduction observed at Ouyen is likely related to the poor ability of chickpeas to set pods at low temperatures (below 15°C mean daily average).

The treatments sown earliest were flowering during colder temperatures, therefore pod set was poor. As temperatures increased, soil moisture also became limiting, therefore both the standard and delayed sowing date treatments set pods during the same period. Further work is ongoing within PBA looking for traits enabling chickpeas to set pods at cooler temperatures. In 2017, many of these lines flowered much earlier than current varieties and breeding lines in the trials, but did not appear to set pods any earlier (data not shown).

Table 1. Mean grain yield (t/ha) of pulse crops (across all varieties) sown at standard sowing dates in comparison with delayed sowing at VIC SPA trials sites in 2017. Ouyen – central Mallee, Curyo – southern Mallee, Rupanyup – Wimmera, Streatham – south west.

Site (Rainfall Zone)	Sowing Date	Lentils	Chickpeas	Field Peas	Faba Beans
Ouyen (LRZ)	Standard (10 May)	1.04	1.14	1.99	
	Delayed (31 May)	0.66	1.04	1.45	
	% Yield Loss	*37*	*9*	*27*	
Curyo (LRZ)	Standard (9 May)	2.33	2.30	3.10	
	Delayed (7 June)	1.90	1.65	1.98	
	% Yield Loss	*18*	*28*	*36*	
Rupanyup (MRZ)	Standard (10 May)	3.35	2.80	3.10	4.26
	Delayed (16 June)	2.73	2.32	3.05	3.88
	% Yield Loss	*19*	*17*	*2*	*9*
Streatham (HRZ)	Standard (3 May)				4.24
	Delayed (2 June)				3.22
	% Yield Loss				*24*

Table 2. Grain yield (t/ha) of lentil varieties and breeding lines sown at standard sowing dates in comparison with delayed sowing at VIC SPA trial sites in 2017. (Varieties and breeding lines ranked based on mean average yield across all sites. Shades relate to relative yield within a sowing date at one site).

Variety	Ouyen		Curyo		Rupanyup	
	May 10	May 31	May 09	June 07	May 18	June 16
CIPAL1522	1.17	0.68	2.63	2.16	3.59	3.07
CIPAL1504	1.39	0.78	2.80	1.74	3.38	2.90
PBA Jumbo2$^{\phi}$	1.20	0.68	2.55	1.75	3.52	3.12
CIPAL1301	1.04	0.55	2.51	1.95	3.65	3.08
CIPAL1721	0.93	0.92	2.49	1.91	3.55	2.97
CIPAL1701	1.15	0.56	2.58	1.99	3.36	3.04
L1	1.30	0.62	1.97	1.86	3.92	2.98
PBA Ace$^{\phi}$	1.00	0.80	2.53	2.28	3.14	2.68
PBA Bolt$^{\phi}$	0.92	0.67	2.33	2.15	3.41	2.90
CIPAL1521	1.02	0.63	2.56	1.96	3.44	2.54
CIPAL1601	1.10	0.50	2.18	2.08	3.37	2.62
PBA Jumbo$^{\phi}$	1.06	0.82	2.33	2.12	3.05	2.47
CIPAL1602	0.87	0.64	2.12	1.73	3.52	2.69
CIPAL1621	1.00	0.56	1.98	1.86	3.59	2.57
PBA Greenfield$^{\phi}$	0.91	0.65	2.26	1.77	3.06	2.79
CIPAL1422	1.00	0.78	2.27	1.84	3.14	2.40
PBA Hurricane XT$^{\phi}$	0.87	0.65	2.09	1.75	3.60	2.44
PBA Giant$^{\phi}$	1.04	0.54	2.09	2.02	3.00	2.42
CIPAL1523	0.95	0.51	2.08	1.47	3.20	2.21
PBA Flash$^{\phi}$	0.87	0.66	2.20	1.58	2.41	2.67
Average	*1.04*	*0.66*	*2.33*	*1.90*	*3.35*	*2.73*
LSD (P<0.05)						
TOS x Variety	0.27		NS		NS	
TOS	0.26		0.34		0.53	
Variety	0.19		0.37		0.35	

Variety	Cross Site Average		
	Standard	Delayed	Mean
CIPAL1522	2.46	1.97	2.22
CIPAL1504	2.52	1.81	2.17
PBA Jumbo2$^{\phi}$	2.42	1.85	2.14
CIPAL1301	2.40	1.86	2.13
CIPAL1721	2.32	1.93	2.13
CIPAL1701	2.36	1.86	2.11
L1	2.40	1.82	2.11
PBA Ace$^{\phi}$	2.22	1.92	2.07
PBA Bolt$^{\phi}$	2.22	1.91	2.06
CIPAL1521	2.34	1.71	2.03
CIPAL1601	2.22	1.73	1.98
PBA Jumbo$^{\phi}$	2.15	1.80	1.98
CIPAL1602	2.17	1.69	1.93
CIPAL1621	2.19	1.66	1.93
PBA Greenfield$^{\phi}$	2.08	1.74	1.91
CIPAL1422	2.14	1.67	1.91
PBA Hurricane XT$^{\phi}$	2.19	1.61	1.90
PBA Giant$^{\phi}$	2.04	1.66	1.85
CIPAL1523	2.08	1.40	1.74
PBA Flash$^{\phi}$	1.83	1.64	1.73
Average	*2.24*	*1.76*	*2.00*

Note: Cross site data still to be analysed at time of writing.

In 2018, growers are encouraged to continue sowing pulses in the optimal sowing window. Avoid delayed sowing unless there is a strategic management advantage related to disease or weed control or if they are being sown in a frost prone region. In the long term, from a VIC perspective, early sowing has generally proved profitable, as heat events and rapidly drying soil during late spring in the flowering and podding phase occur almost every year and cause significant yield losses to delayed sowing. Further discussion and SA results will be provided at the updates.

There was also a significant variation in the response of varieties to sowing dates across the various trial sites. Results in Table 2 highlight trends for lentils in 2017, although similar observations were seen in other crops investigated (data not shown). Grain yields for lentils were generally less than in 2016, but still profitable based on gross margin, ranging between 0.50t/ha to 1.39t/ha at Ouyen, 1.47t/ha and 2.80t/ha at Curyo and 2.21t/ha and 3.92t/ha at Rupanyup. Overall, PBA Jumbo2$^{\phi}$ was the highest yielding commercial variety, equivalent to the highest yielding lines, continuing to highlight its yield stability across a range of regions and seasons. PBA Flash$^{\phi}$ was the lowest yielding commercial variety, while PBA Hurricane XT$^{\phi}$ performed relatively poorly, reflective of industry observations in 2017. It was noted in industry that throughout many regions, PBA Hurricane XT$^{\phi}$ appeared to show more visual symptoms from Group C herbicides in early growth and then from frost damage during vegetative growth (pale and burnt upper leaves). Both of these factors could have contributed to the relative lower yields observed in industry during 2017, however it is important to note that long term trial yields have always indicated approximately 10% lower yield of PBA Hurricane XT$^{\phi}$ relative to the latest conventional varieties, such as PBA Jumbo2$^{\phi}$.

Average yield losses from delayed sowing were 37% at Ouyen and 18% at Curyo and Rupanyup, however within each site, losses varied significantly across variety (1% to 55% at Ouyen, 3% to 38% at Curyo and -11% to 32% at Rupanyup — Table 2). There did not appear to be a clear link with phenology (flowering and maturity). For example, both CIPAL1504 (mid to late) and CIPAL1523 (early) showed yield losses of 28% and 33%, respectively, averaged across sites. While some varieties/breeding lines showed relatively consistent yield losses across sites, for example, PBA Ace$^{\phi}$ and CIPAL1422, others, such as CIPAL1601 and CIPAL1621 varied greatly. The potential reasons for these responses and implications for breeding and agronomy are currently being investigated.

Disease management in field peas

Multi-year evaluation of the efficacy and yield benefit of new foliar fungicides for control of AB in field peas

Recently, new fungicide actives have emerged in the market, offering superior disease control in field crops. However, they have not been tested for AB control in field peas. As part of continuing research, experimental field studies have been undertaken to evaluate the efficacy of new actives in disease control and yield benefits in low (Minnipa, upper Eyre Peninsula) and medium (Hart, Mid-North) rainfall zones in SA. The trials undertaken by SARDI are part of the SPA project funded by the Grains Research and Development Corporation (GRDC) (DAV00150). The performance of two new actives constituting a) bixafen (75g/L) in combination with prothioconazole (150g/L) retailed as Aviator Xpro®, and b) azoxystrobin (200g/L) in combination with cyproconazole (80g/L) trading as Amistar Xtra® were compared to, mancozeb (2kg/ha), seed treatment P Pickle T®, fortnightly chlorothalonil treatment (complete disease control) and an untreated (Nil) treatment. Experimental field trials were conducted from 2015 to 2017.

In 2015, trials compared the new actives against the industry standard practice of a seed dressing plus two mancozeb sprays at nine weeks after sowing (WAS) and early flowering. In 2016, trials included an earlier spray at the four node to six node growth stage, when disease was first sighted. In 2017, two times of sowing were included to produce high and low disease risk with fungicide treatments as per 2016 at Hart only.

In all years, disease severity was assessed at vegetative and flowering growth stages. Grain yield was recorded at maturity. Notably, only selected treatments have been presented in this report.

Results

Effect of fungicide treatments on disease severity

Disease onset occurred earlier in the low rainfall zone compared to the medium rainfall zone, indicating the drivers of AB onset were different across the two environments (Table 3). Subsequently, results showed AB response to fungicide treatment changes depending on environmental conditions.

Mancozeb applications reduced AB severity compared to the Nil treatment at Hart in 2015 and 2016, while there was no reduction in 2017. In contrast, AB severity was not reduced at Minnipa, where severity was initially higher. This may be due to the establishment of the disease prior to the first foliar applications nine WAS weeks after sowing.

Amistar Xtra® reduced disease infection levels at Hart in 2015, but not in 2016 nor in either year at Minnipa. In 2017, disease severity in Amistar Xtra® was similar to mancozeb and the two Aviator Xpro® treatments, but lower than the Nil treatment.

Aviator Xpro® sprayed at six WAS to eight WAS, plus early flowering, reduced disease severity over the Nil treatment at Hart and Minnipa in 2015. The strategy of including an early spray of Aviator Xpro® at 4 WAS, followed by a second application at 9 WAS and mancozeb at early flowering resulted in lower disease severity at both Hart and Minnipa, compared to treatments other than fortnightly sprays of chlorothalonil in 2016. There was no fungicide interaction with sowing date in 2017, with the fungicide effect similar across sowing dates. The application of two Aviator Xpro® treatments showed similar higher disease control to the Amistar Xtra® treatment, compared to the mancozeb and Nil treatments.

Effect of fungicide treatments on grain yield

The mean site grain yield was 1.6t/ha in 2015 for both Hart and Minnipa, with higher yields at Hart (1.74t/ha) than at Minnipa (1.30t/ha) in 2016 (Table 4). In 2017, the first time of sowing (27 April) yielded 3.1t/ha with the second time of sowing (31 May) 2.3t/ha (Table 5). Fungicide strategies in field peas are generally economic for yields above 1.5t/ha.

Grain yields showed a similar fungicide treatment response across the two sites in 2015. In 2016, a significant fungicide treatment by site interaction was found for grain yield. Across all trials the highest yields were associated with Aviator Xpro®, Amistar Xtra® and fortnightly sprays of chlorothalonil, while mancozeb sprays did not significantly increase yield over Nil treatments in any of the trials (Table 4).

In 2017, the three spray application strategy of Aviator Xpro® at early disease sighting plus early flowering and a late spray of mancozeb at mid-flowering produced yields similar to fortnightly chlorothalonil (Table 4). In contrast, this response was not found in 2016, where fortnightly chlorothalonil had higher yields than the three

Table 3. AB disease severity (% plot severity) assessed at between 9 node and 13 node growth stage in field peas (PBA Coogee$^{(b)}$) under different fungicide treatments at Hart (Mid-North, SA) and Minnipa (upper Eyre Peninsula, SA) 2015 to 2017.

Year	Fungicide Treatment	Application Timing	Disease severity (%)	
			Hart	Minnipa
2015	Nil		24	37
	P Pickle T®	Seed treatment	28	27
	Mancozeb	8 WAS + Early flowering	12	30
	Amistar Xtra®	8 WAS + Early flowering	6	30
	Aviator Xpro®	8 WAS + Early flowering	4	23
	Chlorothalonil	Fortnightly	9	18
		Lsd (*P*<0.05) Fungicide x site	**8**	
2016	Nil		32	51
	P Pickle T®	Seed treatment	36	46
	Mancozeb	6 WAS + Early flowering	24	47
	Amistar Xtra®	6 WAS + Early flowering	33	49
	Aviator Xpro®	6 WAS + Early flowering	24	46
	Aviator Xpro® + mancozeb	4 WAS, 9 WAS + mancozeb at early flowering	17	42
	Chlorothalonil	Fortnightly	14	25
		Lsd (*P*<0.05) Fungicide x site	**7.8**	
2017	Nil		55	
	Mancozeb	Early disease + Early flowering	48	
	Amistar Xtra®	Early disease + Early flowering	42	
	Aviator Xpro®	Early disease + Early flowering	39	
	Aviator Xpro® + mancozeb	Early disease + Early flowering + mancozeb mid-flowering	37	
	Chlorothalonil	Fortnightly	2	
		Lsd (*P*<0.05) Fungicide	**8.1**	

NOTE: WAS = weeks after sowing. NB: Fungicide application rates have been withheld. Notably, in 2017, a trial was not conducted at Minnipa due to the late break of the season.

spray strategy. This may be due to the number of chlorothalonil sprays being applied in seasons with more favourable and wetter finishing conditions. Although 2017 was generally drier, a substantial amount of rain fell in late winter to early spring. The late spray of mancozeb in the Aviator Xpro® treatment was beneficial in controlling the spread of AB, resulting in yield increases in early sown crops, similar to the fortnightly chlorothalonil treatment.

Grain yields increased by up to 20% from the use of new actives over the current industry standard in the early sown plots at Hart in 2017. In the later sowing, there was no yield response to fungicides. This result shows that significant yield penalties can occur if field pea crops are sown later or in high disease risk situations, such as early sowing, where fungicides are not applied.

In 2017, severe frost events occurred, coinciding with the critical development period of pod filling in early sown crops at the Hart site. The frost damage impacted the grain quality of early sown crops, whereby more seeds had a shrunken and discoloured appearance on the seed coat (Figure 1). This suggests that site selection is important when early sowing crops in order to avoid a frost event during critical growth and development periods. Growers may need to adjust the sowing window of early sown crops depending on the history of frost events in the district.

In conclusion, early disease control with new fungicide actives is important for reducing initial AB infection levels. In addition, a late fungicide spray is important to control AB in spring when rainfall is conducive to disease spread and pod and seed infection. In situations with yield potentials above 1.5t/ha, the new fungicides showed improved disease control and a yield benefit of 15% to 20% over the current industry standard. Early sowing into a high disease risk window with these improved new fungicide actives was demonstrated to have improved yield benefits over later sowing in the 2017 season. The results, however, need to be interpreted with caution as disease pressure was low and progression was reduced by below average rainfall in 2017. The susceptibility of early sown field peas to frost events will also require consideration. Further research is being undertaken to understand the drivers of AB in the different environments.

Grain quality and harvest timing

Generally, little is understood about the impact of adverse weather events on mature pulse crops, yet major quality and industry issues have arisen when they have occurred in the past. Genetic and agronomic differences have been reported as being important in reducing quality losses. SPA has undertaken opportunistic research in 2016 and 2017 through trials assessing delayed harvest and weather events on a range of genotypes. Selected results from the 2016 season are presented here,

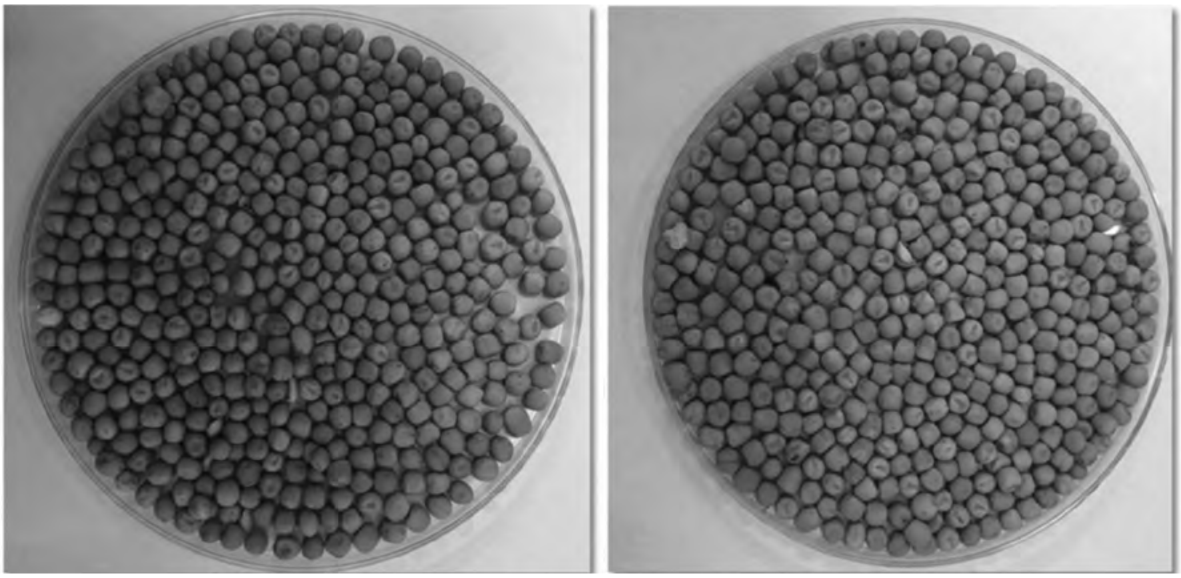
Table 4. Mean grain yields (t/ha) of field peas (PBA Coogee^{A}) sown with different fungicide treatments at Hart (Mid-North, SA) and Minnipa (Eyre Peninsula, SA) in 2015 and 2016.

Year	Fungicide Treatment and Rate (gai/ha)	Application Timing	Grain Yield (t/ha)	
			Hart and Minnipa	
2015	Nil		1.55	
	P Pickle T®	Seed treatment	1.47	
	Mancozeb	8 WAS and Early flowering	1.47	
	Amistar Xtra®	8 WAS and Early flowering	1.77	
	Aviator Xpro®	8 WAS and Early flowering	1.79	
	Chlorothalonil	Fortnightly	1.73	
			Lsd (P<0.05) Fungicide = 0.16	
			Hart	Minnipa
2016	Nil		1.49	0.95
	P Pickle T®	Seed treatment	1.33	1.05
	Mancozeb	6 WAS + Early flowering	1.54	1.19
	Amistar Xtra®	6 WAS + Early flowering	1.84	1.32
	Aviator Xpro®	6 WAS + Early flowering	1.93	1.4
	Aviator Xpro® + mancozeb	4 WAS, 9 WAS + Early flowering	1.65	1.58
	Chlorothalonil	Fortnightly	2.67	1.67
			Lsd (P<0.05) $_{\text{Fungicide X Site}}$ = 0.34	

Table 5. Mean grain yields (t/ha) of field peas (PBA Oura$^{(b)}$) at different sowing dates under varying AB disease risk levels and different fungicide treatments at Hart (Mid-North, SA) in 2017.

Fungicide Treatment	Grain yield (t/ha)		Grain weights (g/100 seed)	
	27-April	31-May	27-April	31-May
Chlorothalonil	3.53^{a}	2.29^{a}	22.99^{a}	22.11^{a}
Aviator Xpro® and mancozeb	3.42^{a}	2.19^{a}	22.15^{b}	22.51^{a}
Aviator Xpro®	3.22^{b}	2.33^{a}	22.00^{b}	22.46^{a}
Amistar Xtra®	3.04^{b}	2.37^{a}	21.21^{c}	22.57^{a}
Mancozeb	2.76^{c}	2.31^{a}	20.87^{cd}	22.57^{a}
Nil	2.66^{c}	2.28^{a}	20.65^{d}	22.35^{a}
Lsd (P<0.05) Fungicide x Sowing time	**0.19**	**0.19**	**0.47**	**0.47**

NB: Seed dressing of P Pickle T® was used at sowing in all treatments except the Nil treatment.



TOS 1 (April, 27) –Seed coat damage (shrunken) and discolouration

TOS 2 (May, 31) – Seed coat damage (shrunken) and discolouration

Figure 1. Frost damage expressed as shrunken and discoloured seed coat in field peas (PBA Oura$^{(b)}$) sown at different sowing dates under varying AB disease risk levels and different fungicide treatments at Hart (Mid-North, SA) in 2017.

showing delayed harvest significantly impacted on grain quality. Assessments are currently also occurring from the 2017 season, including the impact of frost, with some data likely to be available for the update presentations.

In 2016, trials in SA investigated the impact of harvest timing (delayed harvest and climatic events) on seed quality (grain weight, seed coat colour, seed coat wrinkling and screenings) of different pulse crops. Harvest time 1 was considered as the control and was harvested post physiological maturity, approximately 10 days after crop desiccation. The crops were then exposed to significant weather (rainfall) events prior to conducting subsequent latter harvests. Grain quality was assessed for common defects including poor seed coat colour (discolouration), wrinkles, screenings (splits and cracks), and grain weight. The results related to lentils are highlighted here, with full details of all crops and treatments available in the 2016 Southern Pulse Agronomy Annual Result Summary.

For lentils, there was a significant interaction between variety and harvest timing observed for screenings, seed coat colour and wrinkles indicating that lentil varieties were affected differently in these grain quality attributes depending on harvest timing. All varieties had screenings of less than 1 % at the initial harvest timing of 10 days after reaching physiological maturity, with screenings gradually increasing as harvesting was delayed. Harvesting one month and almost two months after physiological maturity led to a rapid increase in screenings in the early maturing lentil variety, PBA Blitz$^{(b)}$ and two green lentils, PBA Giant$^{(b)}$ and PBA

Greenfield$^{(b)}$ compared to other varieties (Table 6). This indicated that the three varieties were more sensitive to damage in this defect by delaying harvest. Varietal differences in seed weight were characteristic of the inherent differences between varieties in this grain quality attribute. Seed weight of some varieties such as PBA Blitz$^{(b)}$, PBA Giant$^{(b)}$ and PBA Greenfield$^{(b)}$ tended to decrease more compared to other varieties as harvest was delayed (data not shown). All varieties maintained seed coat colour within the maximum allowable limit of less than 1% for grade 1 lentils at a timely harvest of 10 days post physiological maturity (Table 7).

Data from one season showed that only three varieties, Nugget$^{(b)}$, PBA Flash$^{(b)}$ and PBA Hurricane XT$^{(b)}$ maintained seed coat colour of less than 1%, for grade 1 lentils, when harvested a month post physiological maturity. All other varieties had started to discolour at this timing, deliverable only as grade 2 except for PBA Giant$^{(b)}$ whose colour was more than 3.0% above the allowable maximum limit for this grade. Late harvesting at almost two months post physiological maturity caused significant discoloration of seed coat colour in all varieties (>10%), which was beyond delivery of grade 1 and 2 lentils. The length in period of exposure to

Table 6. Screenings (% by weight) in 12 lentil varieties, averaged across three different harvest timings at Turretfield, SA, 2016.

Variety	Harvest time 1		Harvest time 2		Harvest time 3	
	SQRT	Raw data	SQRT	Raw data	SQRT	Raw data
CIPAL1301	0.70	0.49	1.88	3.54	2.84	8.04
CIPAL1422	0.79	0.62	1.92	3.70	2.80	7.85
Nipper$^{(b)}$	0.84	0.71	1.37	1.87	1.75	3.07
Nugget$^{(b)}$	0.75	0.56	1.93	3.71	2.91	8.49
PBA Ace$^{(b)}$	0.69	0.48	2.17	4.70	3.00	9.00
PBA Blitz$^{(b)}$	1.21	1.46	3.23	10.43	4.35	18.88
PBA Bolt$^{(b)}$	0.82	0.67	1.98	3.91	2.97	8.84
PBA Flash$^{(b)}$	0.88	0.77	1.75	3.07	2.88	8.27
PBA Giant$^{(b)}$	0.97	0.94	3.63	13.18	4.87	23.72
PBA Greenfield$^{(b)}$	0.61	0.37	2.50	6.25	3.67	13.49
PBA Hurricane XT$^{(b)}$	0.71	0.51	1.51	2.29	2.33	5.42
PBA Jumbo 2$^{(b)}$	0.94	0.87	1.76	3.11	2.64	6.97
LSD	**0.52**		**0.52**		**0.52**	

Table 7. Poor seed colour (% by weight) in 12 lentil varieties, averaged across three different harvest timings at Turretfield, SA, 2016.

Variety	Poor seed coat colour (% by weight)					
	Harvest time 1		Harvest time 2		Harvest time 3	
	SQRT	Raw data	SQRT	Raw data	SQRT	Raw data
CIPAL1301	1.2	0.2	2.7	1.4	9.7	18.8
CIPAL1422	0.7	0.0	2.9	1.6	13.0	34.0
Nipper$^{(b)}$	0.6	0	3.2	2.0	5.9	7.0
Nugget$^{(b)}$	0.5	0	1.5	0.4	10.0	20.0
PBA Ace$^{(b)}$	0.4	0	2.5	1.2	7.9	12.6
PBA Blitz$^{(b)}$	1.4	0.4	2.8	1.6	15.7	49.0
PBA Bolt$^{(b)}$	0.5	0	2.9	1.8	11.9	28.2
PBA Flash$^{(b)}$	0.3	0	2.0	0.8	10.5	22.0
PBA Giant$^{(b)}$	2.0	0.8	4.8	4.6	12.5	31.2
PBA Greenfield$^{(b)}$	1.6	0.4	3.9	3.0	13.8	38.0
PBA Hurricane XT$^{(b)}$	0.8	0.2	1.9	0.8	9.5	18.2
PBA Jumbo 2$^{(b)}$	1.2	0.2	2.5	1.2	9.8	19.2
LSD	**1.62**		**1.62**		**1.62**	

Table 8. Seed coat wrinkling (% by weight) in 12 lentil varieties, averaged across three different harvest timings at Turretfield, SA, 2016.

Variety	wrinkling (% by weight)					
	Harvest time 1		Harvest time 2		Harvest time 3	
	SQRT	Raw data	SQRT	Raw data	SQRT	Raw data
CIPAL1301	1.7	0.6	8.4	14.2	9.7	18.8
CIPAL1422	1.6	0.6	8.4	14.2	10.4	21.6
Nipperᶲ	1.4	0.4	6.5	8.4	5.3	5.8
Nuggetᶲ	3.5	2.4	10.7	23	9.9	19.8
PBA Aceᶲ	1.6	0.6	7.0	9.8	9.2	17
PBA Blitzᶲ	3.8	3.0	12.2	29.6	11.4	26
PBA Boltᶲ	1.3	0.4	7.9	12.4	10.9	23.8
PBA Flashᶲ	2.1	0.8	9.9	19.8	7.0	9.8
PBA Giantᶲ	4.2	3.4	12.3	30.4	9.3	17.2
PBA Greenfieldᶲ	2.4	1.2	14.1	39.6	12.1	29.7
PBA Hurricane XTᶲ	1.3	0.4	6.4	8.2	10.9	23.6
PBA Jumbo 2ᶲ	2.6	1.4	6.4	8.2	7.5	11.4
LSD	**2.52**		**2.52**		**2.52**	

environmental effects was a major factor influencing the loss of seed coat colour across all varieties. Varieties such as Nuggetᶲ, PBA Blitzᶲ, PBA Giantᶲ, PBA Greenfieldᶲ and PBA Jumbo 2ᶲ had wrinkled seed coat levels more than 1% by the first harvest time of 10 days post physiological maturity. At this harvest timing, the site had already received 17mm of rainfall post physiological maturity, indicating that these varieties were more sensitive to wrinkle damage from rainfall. Subsequent delays in harvesting caused significant seed coat wrinkling across all varieties indicating that rainfall was a significant factor in causing this defect (Table 8).

In conclusion, timely harvest within the optimum window of 10 days post physiological maturity was important for retaining grain quality attributes such as seed coat colour, seed coat wrinkling and screenings within the allowable maximum limit for total defective material and delivery of premium quality (grade 1) crops. A delay in harvest post this window, coupled with exposure to environmental elements, including significant rainfall events and long periods of exposure to sunlight, had a significant and negative effect on grain quality which led to subsequent downgrading across all crops. In lentils, the amount of seed with poor seed coat colour and screenings increased as the period between post physiological maturity and harvesting was increased. Some varieties, PBA Blitzᶲ, and green lentil types PBA Giant^{A} and PBA Greenfieldᶲ, were found to have an increased level of screenings and discoloration as harvest timing was delayed. There was a rapid increase in seed coat wrinkling across all lentil varieties as the amount of rainfall increased post the optimum harvest window. This indicated that exposure to significant amounts of rainfall was an important environmental driver of this quality parameter. Good rainfall conditions during the growing season and springtime led to increased crop growth and lengthened the grain filling period by approximately one month across all crops. Rainfall continued well after crops had reached physiological maturity. Managing harvest under such conditions was important in the delivery of quality. Our results show that a delay in harvesting increased quality defects above the allowable maximum limit and some varieties were more sensitive to others in respective crops. However, it is worth noting that the data provided constitutes data from one season and therefore should be interpreted with care. The current research is ongoing and further results will be provided in the coming season.

Pulse pathology 2017

AB in faba beans

Forty isolates of *A. fabae* collected in 2016 from faba bean field trials and commercial paddocks in SA and VIC were tested on a differential host set that included Australian commercial varieties. Faba bean varieties have not changed reactions to AB since 2015 (Table 9) and screening of the isolates identified three reaction groups. Farahᶲ is moderately susceptible to AB in the Lower to Upper North of SA, PBA Ranaᶲ and PBA Zahraᶲ

Table 9. Reactions of a number of faba bean varieties to Aschochyta blight.

Test reaction	Icarus (susceptible check)	Farah$^{\phi}$	Nura AR$^{\phi}$	Rana$^{\phi}$	Samira$^{\phi}$	Zahra$^{\phi}$
R	0	1	40	0	20	1
MR	0	1	0	11	12	8
MRMS	0	7	0	13	7	23
MS	0	23	0	15	1	8
S	40	8	0	1	0	0

are partially compromised, while PBA Samira$^{\phi}$ and Nura$^{\phi}$ remain resistant. These new pathotypes are also becoming established in the Yorke Peninsula, South East and Wimmera growing regions. A three spray fungicide strategy is now required to control AB in Farah$^{\phi}$, while podding sprays should be planned for PBA Rana$^{\phi}$ and PBA Zahra$^{\phi}$ to prevent pod and seed infection.

There were several reports of AB in PBA Samira$^{\phi}$, however, it is important to remember that even resistant rated pulses may get some lesions. Testing conducted at SARDI has found that PBA Samira$^{\phi}$ remains resistant to AB and the few reports of infection most likely reflect genetic drift from outcrossing, which has partially compromised resistance in some grower retained seed.

AB in lentils

Thirty eight isolates of *A. lentis* collected in 2016 from lentil field trials and commercial paddocks in SA and VIC were tested on a differential host set that included PBA Hurricane XT$^{\phi}$ and Nipper$^{\phi}$ (Table 10). Lentil varieties have not changed reactions to AB since 2015. However, very few isolates were able to infect Nipper$^{\phi}$, in contrast to previous seasons when the frequency of Nipper$^{\phi}$ virulent isolates was high. This drop is presumably in response to the low cropping frequency of Nipper$^{\phi}$ so there is no selection pressure for this type of isolate. Lesions have been observed on PBA Hurricane XT$^{\phi}$ crops, but in controlled environment tests, no isolates were highly virulent on PBA Hurricane XT$^{\phi}$. Resistant parents ILL7537 and Indianhead were resistant to most isolates, although a small number of isolates could infect Indianhead, a common source of resistance in the Australian lentil breeding program.

AB collections

Growers and agronomists are asked to monitor their pulse crops for development of AB. Sara Blake, Research Officer at SARDI, is seeking assistance in collecting diseased samples from commercial crops as part of GRDC-funded research (CUR00023) monitoring AB pathogen populations and any changes in variety resistance. If ascochyta lesions are seen, please contact SARDI in SA — Sara via email (sara.blake@sa.gov.au) or phone on 08 8303 9383 for a collection envelope and return post envelope.

Agriculture Victoria — Cropsafe, Private Bag 260, Horsham, Vic 3401, 08 5362 2111.

Bacterial blight in field peas

Bacterial blight in field peas was detected across the Mallee and Wimmera regions following hail storms, frost or radiating from wheel tracks. Unfortunately, there is nothing that can be done to protect an infected crop or help it recover. The main recommendation is to stay out of the crop to prevent the disease being spread further on tyres or on boots. Infected crops should be the last field pea crops to be harvested. This is to prevent the trash from infecting field pea grain of non-infected crops. No grain should be kept from infected crops as there is a high chance of seed infection. If a crop has only a small area infected, then it is possible to harvest a clean area for seed.

When planning to sow field pea crops, growers need to consider that if a paddock is frost prone, it is best to sow field peas into a fallow rather than retaining the stubble. This is because the stubble increases the risk of frost, which in turn increases

Table 10. Reactions of a number of lentil varieties to Aschochyta blight.

Test reaction	Cumra$^{\phi}$ (susceptible check)	Nipper$^{\phi}$	PBA Hurricane XT$^{\phi}$	ILL7537 (resistant line)	Indianhead (resistant line)
R	1	18	25	38	29
MR	7	20	13	0	5
MRMS	16	0	0	0	2
MS	9	0	0	0	2
S	5	0	0	0	0

the risk of bacterial blight. The preferred field pea varieties to grow in frost prone areas are PBA Oura$^{\Phi}$ or PBA Percy$^{\Phi}$, which are less susceptible to bacterial blight than other varieties.

Further information on bacterial blight is available at http://www.dpi.nsw.gov.au/content/agriculture/broadacre/pests-diseases/winter-crops-lupins-chickpeas-other-pulses/bacterial-blight-peas

Soil-borne diseases

First time, provisional ratings for the root lesion nematode, *Pratylenchus neglectus*, have been released for chickpeas and faba beans. These ratings add to the current ratings provided, allowing growers to manage root lesion nematodes.

Root rot in irrigated chickpeas

A number of irrigated chickpea crops in the south east of SA have been severely infected with a root rot, resulting in significant yield loss. These crops were sown in late winter or early spring and grown under center pivots. Samples submitted to SARDI Crop Pathology are currently being investigated for the causal pathogen, and preliminary results suggest a *Phytophthora* species, *Pythium* species or possibly a combination of these two fungal pathogens. Phytophthora root rot is a common problem in chickpea crops in northern New South Wales (NSW) and southern Queensland (QLD), especially where soils are waterlogged. Management strategies include using a metalaxyl seed dressing, such as ridomil[Φ], at sowing but the effect of this fungicide wears off after six to eight weeks and infection can still occur. There is no resistance to phytophthora root rot in southern chickpea varieties. Growers and agronomists are asked to monitor chickpea crops for development of root rot and submit samples to Jenny Davidson or Tara Garrard at SARDI (Locked Bag 100, Glen Osmond, Urrbrae 5064) to assist with identification of this problem.

[Φ] *Ridomil is not registered for use in chickpeas. Rampart or Mantle (containing metalaxyl) are registered for Phytophthora in chickpeas. Commercial users must adhere to label requirements.*

Acknowledgments

This research is a collaborative project between the GRDC, DEDJTR and SARDI. The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. Thanks to the technical staff for maintaining trials and collecting and entering data.

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Notes

High rainfall wheat and barley review

Jon Midwood and Claudia Gebert.

Southern Farming Systems.

Keywords

- wheat, barley, varieties, agronomy, management, yield, high rainfall zone (HRZ).

Take home messages

- The final yields and gross margins in 2017 of wheat and barley were strongly influenced by key weather events.
- Delayed sowing of wheat by nearly three weeks at one site significantly improved establishment and average yields by 1.5t/ha by avoiding a 56mm rainfall event a day after sowing.
- Minimum temperatures at Westmere on four consecutive days of 0°C or less, during flowering and grain fill at the beginning of November, affected the yield and quality of both barley and wheat.
- In 2017, the additional cost of the fully managed strategy in the early sown wheat trials did not provide an improvement in financial return on average.
- Wheat varieties, LRPB Trojan$^{\phi}$, LRPB Beaufort$^{\phi}$ and Longsword$^{\phi}$ all gave significantly ($p<0.05$) greater yields at both trial sites under the fully managed strategy.
- RGT Planet$^{\phi}$ was the highest yielding barley variety overall ($p<0.05$) at the Inverleigh site and in the early sown trial at Westmere.
- Fully managed input treatments yielded significantly ($p<0.05$) higher than standard input treatments in all Southern Farming Systems (SFS) barley variety trials in 2017.

Background

Grain producers have become more proficient atWith limited wheat and barley varieties suited to the high rainfall zone (HRZ), it is important that there are agronomy packages available that suit each variety to maximise production and profitability. In the 2017 season, SFS created a new system of running variety trials, and now creates tailored agronomic packages for varieties with different levels of input management across existing and upcoming wheat and barley varieties, that are grown in the HRZ, including Tasmania. These trials, along with other GRDC projects such as DAN0017 Barley Agronomy, are helping to build a strong database of knowledge for targeted variety management, which will give advisers and growers confidence to try new varieties as they come to the table.

To determine input levels for the agronomy packages, pre-set yield targets were created for standard and fully managed input treatments:

- barley trials were aiming for 9t/ha yields in fully managed input treatments, and 6t/ha for standard input treatments; and
- in the wheat trials, 10t/ha was the target for fully managed treatments, and 7t/ha was the target for standard input treatments.

Once yields were determined, inputs such as fertiliser, fungicide and plant growth regulators (PGRs) were altered accordingly. Treatments that received higher inputs were pushing for maximum yield potential, while standard management input decisions were based on the likelihood of receiving an economic return.

Table 1. SFS wheat variety TOS dates.

Location	Inverleigh		Westmere	
Time of Sowing	TOS1	TOS2	TOS1	TOS2
Date	23/04/2017	12/05/2017	2/05/2017	16/05/2017

This paper utilises the data from these management trials in 2017 with some references to SFS and GRDC NVT trial results from the Western districts in 2016.

Wheat trials

Trial setup

In the 2017 season, SFS ran a number of wheat variety management trials consisting of both existing and upcoming varieties that are suited to the HRZ. The trials were repeated at two times of sowing (TOS) at SFS sites across the Western district. Trials varied in design, depending on entries, either split plot factorial which included two different levels of management or randomised complete block with a single management level.

Table 2. Complete list of wheat varieties tested.

Variety	Supplying company
ADV 11.9419	DOW
LRPB Beaufort$^{\phi}$	Grainsearch
Beckom$^{\phi}$	AGT
Coolah$^{\phi}$	AGT
Cutlass$^{\phi}$	AGT
DS Pascal$^{\phi}$	DOW
EDGE06-18b-10	Edstar
Jet	Edstar
LRPB Kittyhawk$^{\phi}$	AGF
Manning$^{\phi}$	Grainsearch
Longsword$^{\phi}$	AGT
SQP Revenue$^{\phi}$	Grainsearch
RGT Accroc$^{\phi}$	Seed Force
SF Adagio	AGF
Sunlamb$^{\phi}$	AGT
LRPB Trojan$^{\phi}$	AGF
Zircon	Edstar

Nitrogen management

The previous crop at both the Westmere and Inverleigh sites was faba beans which were brown manured at late flowering. Available nitrogen (N) at sowing in the top 60cm at Inverleigh was 188kg N per hectare, and 80kg N per hectare at the Westmere site. Nitrogen (N) applications were applied at GS31 with a further application post GS32 for fully managed input treatments.

Varietal performance

SQP Revenue$^{\phi}$ followed on its strong performance at the Westmere site in 2016 by being the top yielding variety in the early sown Westmere trial in 2017 under both management strategies, with an overall yield of 8.35t/ha. It was, however, not significantly ($p<0.05$) higher yielding at this site in 2017, under the standard management, or 2016 than RGT Accroc$^{\phi}$ or ADV 11.9419 under the full management and 2016. Only four varieties in the fully managed strategy gave a significant ($p<0.05$) yield improvement over the standard approach — LRPB Trojan$^{\phi}$, LRPB Beaufort$^{\phi}$, Longsword$^{\phi}$ and LRPB Kittyhawk$^{\phi}$.

Results for the early sown trial at Inverleigh were affected by significant soil wash from a 56mm rain event one day after sowing, but RGT Accroc$^{\phi}$ still yielded 9.55t/ha under the fully managed strategy and only 0.25t/ha less under the standard management. DS Pascal$^{\phi}$ yielded considerably better at the Inverleigh site, which may suggest it was adversely affected by the frost at Westmere. Only four varieties in the fully managed strategy gave a significant ($p<0.05$) yield improvement over the standard approach — LRPB Trojan$^{\phi}$, Beaufort$^{\phi}$, Longsword$^{\phi}$ and Zircon. Interestingly, the three varieties LRPB Trojan$^{\phi}$, Beaufort$^{\phi}$ and Longsword$^{\phi}$ were the only varieties in the fully managed strategy that gave a significant ($p<0.05$) yield improvement over the standard approach at both sites suggesting something in the additional inputs was producing additional yield.

Table 3. Wheat variety yield results TOS 1 Inverleigh and Westmere, including 2016 results from Westmere.

Variety	Westmere 2017 Fully managed	Westmere 2017 Standard	Westmere 2016 (t/ha)
SQP Revenue$^{(b)}$	8.35 a	8.35 a	9.4 a
Zircon	8.35 a	8.05 ab	6.9 de
ADV 11.9419	8.03 ab	7.73 b-e	8.7 ab
LRPB Trojan$^{(b)}$	7.95 abc	7.23 fgh	Not entered
Sunlamb$^{(b)}$	7.95 abc	7.95 abc	Not entered
Beaufort$^{(b)}$	7.83 bcd	7.15 gh	8.4 abc
Manning$^{(b)}$	7.83 bcd	7.93 abc	Not entered
RGT Accroc$^{(b)}$	7.70 b-f	8.10 ab	9.2 a
Longsword$^{(b)}$ (RAC2341)	7.63 b-g	6.88 hi	Not entered
Jet	7.50 c-g	7.38 d-g	9.1 a
SF Adagio	7.28 e-h	7.30 e-h	Not entered
LRPB Kittyhawk$^{(b)}$	6.45 ij	5.95 kl	7.15 cde
EDGE06-18b-10	6.23 jk	6.18 jk	7.4 be
DS Pascal$^{(b)}$	5.53 l	5.58 l	Not entered
LSD	0.49	0.49	1.4
p-value	0.04	0.04	0.0002

**Treatments with same letter do not significantly differ when p=0.05*

Table 4. Wheat variety yield results TOS 1 Inverleigh and Westmere, including 2016 results from Westmere.

Variety	Inverleigh 2017 Fully managed	Inverleigh 2017 Standard	Inverleigh 2016(t/ha)
SRGT Accroc$^{(b)}$	9.55 a	9.30 ab	10.37 a
ADV 11.9419	8.85 bc	8.40 cd	Not entered
DS Pascal$^{(b)}$	7.90 def	8.18 de	Not entered
Beaufort$^{(b)}$	7.88 d-g	7.13 h-m	Not entered
Manning$^{(b)}$	7.68 e-h	7.48 f-i	9.73 abc
LRPB Kittyhawk$^{(b)}$	7.63 e-i	7.23 g-k	Not entered
Zircon (EDGE06-039-13	7.53 e-i	6.46 mno	Not entered
SF Adagio	7.40 f-j	7.63 e-i	9.27 b-e
Jet (EDGE06-025-03)	7.20 h-k	7.18 h-l	Not entered
Revenue$^{(b)}$	6.98 i-n	6.60 k-n	9.03 c-f
LRPB Trojan$^{(b)}$	6.76 j-n	5.25 q	9.10 cde
Longsword$^{(b)}$ (RAC2341)	6.53 l-o	5.70 pq	Not entered
Sunlamb$^{(b)}$	6.38 no	5.93 op	7.47 h
LSD	0.67	0.670.72	
p-value	0.02	0.02	0.0001

**Treatments with same letter do not significantly differ when p=0.05*

Table 5. Wheat variety yield results TOS 2 Inverleigh and Westmere 2017.

Variety	Westmere 2017 (t/ha)	Westmere 2016 (t/ha)	Inverleigh 2017 (t/ha)
Cutlass$^{\phi}$	7.9 a	Not entered	8.6 bc
Jet	7.3 ab	Not entered	9.4 a
Zircon	7.3 ab	Not entered	8.4 c
Longsword$^{\phi}$	6.8 bc	Not entered	8.4 c
LRPB Beaufort$^{\phi}$	6.8 bc	9.2 b	9.3 ab
LRPB Trojan$^{\phi}$	6.5 bc	8.6 bcd	9.2 ab
Coolah$^{\phi}$	6.5 bc	Not entered	8.9 abc
Beckom$^{\phi}$	6.3 cd	7.6 fg	8.6 bc
DS Pascal$^{\phi}$	5.7 d	8.4 cde	9.5 a
HIL 049	Not entered	Not entered	8.4 c
EDGE06-18b-10	5.6 d	7.3 g	Not entered
LSD	0.8	0.7 0.725	
p-value	0.0001	0.0001	0.014

**Treatments with same letter do not significantly differ when p=0.05*

TOS effect

Earlier sowing time showed improvements in some varieties at the Westmere site due to flowering and grain fill being less impacted by frost events. At the Inverleigh site, large rain events prior to sowing meant that the earlier sown varieties experienced severe soil wash, resulting in a stronger yield performance in the later sown trial.

Fully managed and standard input results

Yield and protein

Where the two management strategies were used, fully managed input treatments yielded significantly (p<0.05) higher than standard input treatments in all trials in 2017. On average, proteins were higher in fully managed input treatments across all varieties, however as there was some spread of yield between fully managed and standard treatments, it seems that extra N that was applied to fully managed input treatments post GS32 has increased protein.

The input cost/ha for standard input treatments was $559, while input cost/ha for fully managed input treatments was $700. These prices include an identical herbicide regime, but different fertiliser, fungicide and PGR rates. A contract price for machinery was included per application.

Given these values and prices for feed and milling wheat per tonne from 2017, the extra yield per hectare required to cover the added cost of fully managed input treatments can be calculated. These costs have been outlined in Table 8.

Table 6. Yield performance of fully managed and standard management trials when all varieties are combined.

Management strategy	TOS 1 Westmere	TOS 1 Inverleigh
Fully managed	7.47 a	7.56 a
Standard	7.27 b	7.11 b
LSD	0.13	0.19
***p*-value**	0.0034	0.0001

**Treatments followed by same letter do not significantly differ when p=0.05*
Economic breakdown of fully managed and standard inputs

Table 7. Economic breakdown ($/ha) of fully managed and standard inputs Inverleigh wheat trials.

Grade	Trial	M'ment Strategy	Seed	Chem	Fert	Mach	Total cost	Income	Gross Margin $/ha
H2	TOS 1 WHT INV	Full	70	212	221	197	700	1892	1192
	TOS 1 WHT INV	Standard	70	183	137	169	559	1768	1209
	TOS 2 WHT INV	Standard	70	183	137	169	559	2216	1657
APW1	TOS 1 WHT INV	Full	70	212	221	197	700	1805	1105
	TOS 1 WHT INV	Standard	70	183	137	169	559	1686	1127
	TOS 2 WHT INV	Standard	70	183	137	169	559	2114	1555
FED1	TOS 1 WHT INV	Full	70	212	221	197	700	1607	907
	TOS 1 WHT INV	Standard	70	183	137	169	559	1502	943
	TOS 2 WHT INV	Standard	70	183	137	169	559	1882	1323

Table 8. Yield required to cover cost of fully managed inputs per hectare.

Cost difference between fully managed and standard inputs	**$141**	
Wheat price	$249 (H2)	$211.5 (Feed)
Additional yield required to cover cost of full inputs	$141/249 = **0.5t/ha**	$141/$211.5 = **0.6t/ha**

Table 9. SFS barley variety trial sowing dates.

Location	Inverleigh		Westmere	
Time of sowing	TOS1	TOS2	TOS1	TOS2
Date	7/05/2017	17/05/2017	2/05/2017	16/05/2017

When variety and input effects are combined, results show that economic benefits between fully managed and standard inputs are variety specific, however on average, the best returns were gained from the standard level of inputs.

Barley trials

Trial setup

In the 2017 season, SFS ran four barley variety trials consisting of nine existing and upcoming varieties that are suited to the HRZ. The trials were repeated at two TOS at the Westmere and Inverleigh trial sites, in the Western districts. Trials were a split plot design, and each variety was tested with two different levels of management as outlined earlier.

Table 10. Varieties tested in fully managed and low management variety trials.

Alestar$^{\phi}$	Edstar
Topstart$^{\phi}$	Edstar
Oxford	Edstar
Bottler	Grainsearch
Westminster$^{\phi}$	Grainsearch
IGB1305	Intergrain
Rosalind$^{\phi}$	Intergrain
Kiwi	Malteurop
RGT Planet$^{\phi}$	Seed Force

Nitrogen management

The previous crop at Westmere was faba beans that was brown manured, while at Inverleigh the previous crop was oaten hay. Available N in the top 60cm at Inverleigh was 121kg N per hectare and coincidentally, the same at the Westmere site. Nitrogen applications were split into two different timings — mid tiller and GS31. Fully managed input treatments received 20% of their total N requirement at mid tiller, and the remaining 80% at GS31. Treatments under the standard input program received 30% of their N requirement at mid tiller, and the remaining 70% at GS31.

Varietal performance

High yields were achieved, despite the Westmere trials being impacted by frost events in early November. Some varieties at Inverleigh achieved malting quality, but would currently be binned as F1 due to these varieties still awaiting malt-accredited status, apart from Westminster$^{\phi}$ which achieved a malt grade in the early TOS.

RGT Planet$^{\phi}$ was a standout variety in 2017, yielding the highest at Inverleigh across both TOS, and in the early TOS at Westmere. Rosalind$^{\phi}$ was also consistent and yielded the greatest in the second TOS at Westmere. The early maturing characteristic of Rosalind$^{\phi}$ allowed it to complete most of its grain fill before November frost events, meaning it had a heavier test weight at this TOS compared to all other varieties.

These results are consistent with NVT results in 2016, with RGT Planet$^{\phi}$ and Rosalind$^{\phi}$ holding the highest NVT site mean % at Inverleigh and RGT Planet$^{\phi}$ at Streatham. Results from Streatham in 2017 have not been included as they will be part of the frosted report.

TOS effect

At Westmere, the average yield of all varieties sown at the earlier sowing time was 0.4t/ha greater than when sown two weeks later, when management levels were combined. The results from Westmere follow on from data gained in the 2016 SFS variety trials at that site, where the earlier TOS averaged 1t/ha more yield on average. This result is also supported by a further TOS barley trial that was run at the Westmere site as a part of the GRDC Barley Agronomy Project (DAN000173), which achieved a significant result of 1.1t/ha more from early May sowing compared to mid-May in 2017.

Table 11. Variety yield results Inverleigh and Westmere (combining both management strategies) including 2016 results from Westmere.

Variety	Inverleigh		Westmere			
	2017 TOS1 (t/ha)	2017 TOS2 (t/ha)	2017 TOS1 (t/ha)	2016 TOS1 (t/ha)	2017 TOS2 (t/ha)	2016 TOS2 (t/ha)
RGT Planet(l)	10.0 a	9.9 a	8.6 a	Not entered	7.7 ab	9.0 a
Rosalind(l)	8.9 b	8.9 c	8.3 ab	8.3 ab	8.3 a	6.4 ef
Bottler	8.7 bc	9.1 bc	8.1 abc	Not entered	7.4 b	8.1 b
Oxford	8.5 bc	8.5 d	7.6 bcd	9.0 a	7.1 bc	8.0 b
Alestar(l)	8.7 bc	8.2 e	7.6 cd	7.8 bc	7.0 bc	6.7 de
Topstart(l)	8.9 b	9.4 b	7.2 de	Not entered	7.1 bc	Not entered
Kiwi	8.3 cd	8.5 de	7.1 de	Not entered	6.4 c	Not entered
IGB1305	8.3 cd	8.5 de	6.6 ef	7.4 cd	7.4 b	6.6 de
Westminster(l)	7.8 d	8.4 de	6.4 f	8.2 abc	5.5 d	7.0 cde
LSD	0.56	0.35	0.67	0.80	0.79	0.92
p-value	0.0001	0.0001	0.0001	0.0017	0.0001	0.0001

**Treatments with same letter do not significantly differ when p=0.05*

Fully managed and standard input results

Yield and protein

Fully managed input treatments yielded significantly ($p<0.05$) higher than standard input treatments in all barley trials in 2017.

Fully managed inputs were shown to significantly increase test weights in later sown trials and significantly increased protein across all trials (refer Table 8). Although proteins did increase with higher inputs, they did not indicate that excess N was utilised for grain protein rather than yield. With new feed barley varieties possessing strong yield potentials, there is merit in pushing N applications to achieve greater yields, rather than limiting N to contain protein within malting specifications. For further discussion on this topic, please refer to the SFS report 'Barley-Malt or Feed' available in the resources section.

The input cost for standard input treatments was $405/ha, while input cost for fully managed input treatments was $510/ha. These prices include an identical herbicide regime, but different fertiliser, fungicide and PGR rates. A contract price for machinery was included per application.

Table 12. Yield, test weight and protein performance of fully managed and standard management levels Inverleigh.

Management Strategy	TOS 1			TOS 2		
	Yield (t/Ha)	Test weight (kg/hL)	Protein (%)	Yield t/Ha	Test weight (kg/hL)	Protein (%)
Fully managed	8.9a	63a	11.1a	9.1a	63a	10.4a
Low	8.5b	63a	10.4b	8.5b	62b	9.7b
LSD	0.2	0.52	0.36	0.17	0.6	0.5
CV %	4.6 %	1.7 %	6.9 %	1.6 %	2.7 %	9.3 %
p-value	0.0002	0.4	0.0001	0.0001	0.0087	0.0018

**Treatments followed by same letter do not significantly differ when p=0.05*

Economic breakdown of fully managed and standard inputs

Table 13. Economic breakdown of fully managed and standard input treatments Inverleigh ($/ha)

Grade	Trial	Treatment	Seed	Chem	Fert	Mach cost	Total cost	Income	Gross Margin
Malt	TOS 1 INV	Full	85	164	174	187	610	$2,380	$1,770
F1	TOS 1 INV	Full	85	164	174	187	610	$1,988	$1,379
	TOS 1 INV	Standard	85	89	137	177	488	$1,857	$1,370
	TOS 2 INV	Full	85	164	174	187	610	$1,988	$1,379
	TOS 2 INV	Standard	85	89	137	177	488	$1,857	$1,370

Table 14. Yield required to cover cost of high inputs per hectare.

Cost difference between standard and fully managed inputs	**$122**	
Barley price at two quality levels	$219 (Feed)	$262 (Malt)
Yield required to cover cost of high inputs (t/ha)	$122/$219 = **0.6 t/ha**	$122/$262 = **0.5t/ha**

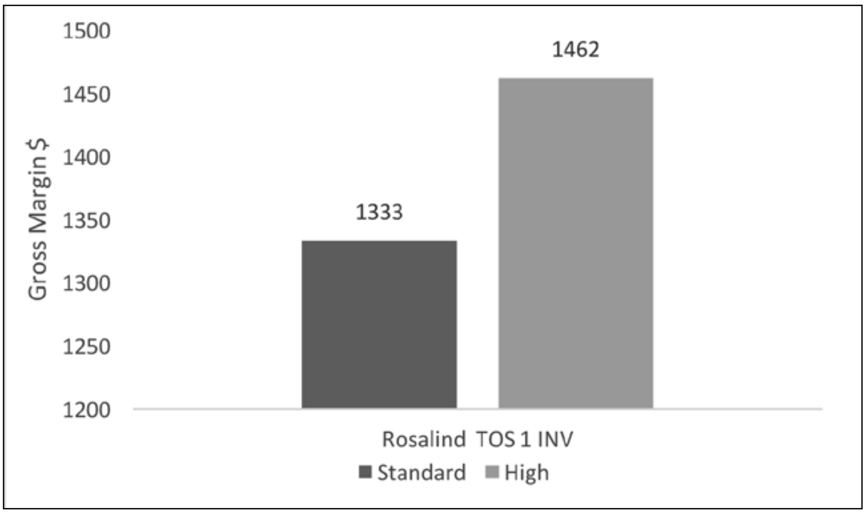

Figure 1. Rosalind⁽ᴾ⁾ margin in early sown trial Inverleigh.

Given these values, and prices for feed and malt barley per tonne from 2017, the extra yield per hectare required to cover the added cost of fully managed input treatments can be calculated — Table 10 below illustrates this.

When variety and input effects are combined, results show that economic benefits between fully managed and standard inputs are variety specific.

The varieties that achieved the strongest economic benefits between fully managed and standard input treatments were Rosalind⁽ᴾ⁾, Bottler, Westminster⁽ᴾ⁾ and Alestar⁽ᴾ⁾ across the Inverleigh site. An example of this is given in Figure 1, where Rosalind⁽ᴾ⁾ achieved an average yield of 1.2t/ha more with fully managed inputs in the earlier sown trial, resulting in an increase of $129 per hectare.

Useful resources

http://www.sfs.org.au/trial-result-pdfs/Trial_Results_2013/2013_BarleyMaltOrFeed_VIC.pdf

Acknowledgements

SFS would like to acknowledge the GRDC for its investment into the Barley Agronomy Project (DAN00173) trials referenced in this report, and the contributing breeders for co-funding the SFS trials. We would also like to thank our host growers — the Hamilton family of Inverleigh, the McCrow family of Westmere, and the Herrmann family of Tarrington.

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Notes

Cereal disease update - 2018

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GRDC project codes: DAV00129, DAV00144, DAV00136, DAS00137, DAN00175, DAV00136, DAV00128

Keywords

- yellow leaf spot, rust, septoria tritici blotch (STB), stubble borne disease, root lesion nematodes, crown rot, cereal cyst nematode, spot form net blotch (SFNB), net form net blotch (NFNB).

Take home messages

- Cereal diseases will need to be actively managed in 2018 to prevent yield losses.
- Growers need to consider variety disease ratings and avoid sowing susceptible varieties into infected stubble (consult a current Disease Guide).
- Manage the green bridge to minimise rust carryover on cereal volunteers.
- Foliar diseases caused up to 25% yield loss during 2016 and 2017, so put in place a fungicide plan if necessary.
- Root diseases caused yield losses of up to 20% during 2017, so have a PREDICTA® B test done prior to planting to identify paddocks at risk.

Background

During 2017, cereal diseases were generally well managed and at low levels despite high inoculum levels following the wet 2016 season and suitable climatic conditions for disease development. Agriculture Victoria field trials showed losses of approximately 20% due to both foliar and root diseases where appropriate management was not used. The results from these field experiments and grower experience showed that losses from diseases were minimised cost effectively where proactive disease management strategies were implemented.

Cereal disease management in 2018

Cereal diseases will require proactive management prior to and during the 2018 season. The good growing conditions during 2017 have resulted in high levels of inoculum of stubble and soil borne diseases. Also, the green bridge (volunteer cereals growing over summer/autumn) will support carryover of rust (and viral diseases) to provide early infection of crops.

Growers should develop a disease management plan that considers variety rating (consult a current Disease Guide) and inoculum loads within a paddock (consider stubble and soil borne diseases and cropping history) and the district (consider the green bridge). A fungicide strategy should then be developed for each crop based on the identified risks. Diseases can be cost effectively controlled when a proactive management approach is used.

Wheat foliar diseases

During 2017, septoria tritici blotch (STB) was widespread in the Western District and in Wimmera wheat crops. In many cases, fungicide applications were necessary. Yellow leaf spot was less severe than in 2016, but within Agriculture Victoria field trials, losses of 17% were measured in susceptible varieties. Stripe and leaf rust appeared relatively late in the 2017 season and their impacts would have been minimal.

Yellow leaf spot

Yellow leaf spot, a stubble borne foliar disease of wheat, is favoured by growing susceptible wheat varieties, stubble retention practices and wet seasonal conditions. Even though this is a common disease in Victorian (VIC) wheat crops, its impact on grain yield and quality has been unclear. Therefore, Agriculture Victoria has been running field experiments to measure yield loss, develop control options and evaluate the PREDICTA® B test as a tool for identifying paddocks at risk of yellow spot.

Yield loss experiments during 2016 and 2017 showed losses of up to 23% due to yellow spot (Table 1). Yield losses were greater in 2016 (more rain days and more total rain) than in 2017 (drier spring) in both the Wimmera and Mallee. Yield losses were lower when resistant varieties were grown in preference to susceptible varieties. Therefore, to minimise yield loss due to yellow spot, avoid sowing susceptible varieties into paddocks where infected stubble is present.

Fungicide experiments in the Wimmera during 2016 and 2017 showed that improvements in yield can be achieved with foliar fungicides when susceptible varieties are grown in the presence of yellow leaf spot (Table 2). Two applications of fungicide (growth stages 31 and 39) gave significant

Table 1. Yield losses due to yellow leaf spot in wheat varieties with contrasting resistance/susceptibility in the VIC Mallee and Wimmera during 2016 and 2017.

	Mallee				Wimmera			
Year	2016		2017		2016		2017	
Total rain (Jun-Sept)	222mm		89mm		251mm		147mm	
Rain days (Jun-Sept)	62		39		93		79	
	Yield loss		Yield loss		Yield loss		Yield loss	
Variety	t/ha	%	t/ha	%	t/ha	%	t/ha	%
Corack$^{\phi}$ (MR)	n.s [A]	-	0.2		0.4	6	n.s	-
Emu Rock$^{\phi}$/Magenta$^{\phi}$ (MRMS)[B]	n.s	-	n.s	-	0.3	4	n.s	-
Kord CL Plus$^{\phi}$ (MSS)	0.7	19	n.s	-	0.9	14	n.s	-
Shield$^{\phi}$ (MSS)	0.6	15	n.s	-	1.2	17	0.6	9
Scout$^{\phi}$ (SVS)	0.8	18	n.s	-	1.7	23	1.1	17
Phantom$^{\phi}$ (SVS)	0.8	19	n.s	-	1.3	21	0.9	16
P value	<.001		<.001		<.001		<.001	
LSD (0.05)	0.31		0.14		0.23		0.30	
CV%	5.0		3.1		3.3		5.7	

[A] n.s = yield loss is not significant.

[B] Emu Rock$^{\phi}$ (2016) and Magenta$^{\phi}$ (2017).

Table 2. Yellow leaf spot severity, grain yield and economic return of fungicide treatments for yellow leaf spot control in a susceptible wheat variety (Phantom$^{\phi}$) at Horsham, 2016 and 2017.

	Wimmera [A]					
Year	2016			2017		
Total rain (Jun-Sept)	251 mm			147mm		
Rain days (Jun-Sept)	93			79		
Treatment	Leaf area affected (%)[B]	Yield (t/ha)	Net Return ($/ha) [C]	Leaf area affected (%)[A]	Yield (t/ha)	Margin Return ($/ha) [C]
No Fungicide	70 ^{d}	4.4 ^{a}	-	32 ^{c}	4.8^{a}	-
Prosaro® @25	67 ^{d}	4.7 ^{bc}	$35	29 ^{bc}	5.0^{ab}	$12 n.s
Prosaro® @31	62 ^{d}	4.9 ^{c}	$81	28 a^{bc}	5.3^{b}	$81
Prosaro® @39	39 ^{b}	5.3 ^{d}	$173	21 ^{ab}	5.1^{ab}	$35 n.s
Prosaro® @31&39	33 ^{b}	5.5 ^{e}	$185	25 ^{abc}	5.4^{b}	$70
No Disease	14 ^{a}	5.9 ^{f}	-	18 ^{a}	6.2^{c}	-
P value	<.001	<.001		0.002	<.001	
LSD (0.05)	8.2	0.25		6.3	0.41	
CV%	13.9	4.3		20.9	6.6	

[A] Data that do not share the same letters within the same column are significantly different from each other.

[B] Percentage leaf area affected assessments conducted on 22/09/2016 and 16/10/2017.

[C] Treatment Net Return: additional grain income less treatment cost. Prosaro® was $34/ha per 300ml application, wheat prices based on H2 $230/t as of 30 December, 2017.

improvements in grain yield, but did not provide complete control with yield significantly lower than the disease free control. Since fungicides rarely provide complete yellow spot control, growers should first consider paddock and variety selection.

Agriculture Victoria, in collaboration with the South Australian Research and Development Institute (SARDI), has been conducting field studies to evaluate the PREDICTA B test as a pre-planting tool to assist with yellow leaf spot management. A field experiment conducted during 2017 showed good relationships between pre-planting yellow spot levels, disease development and grain yield in a following susceptible wheat (Figure 1). Our findings indicate that the PREDICTA B yellow spot test can assist with paddock selection to avoid planting susceptible wheat varieties into at high risk paddocks. This work is continuing during 2018 to help identify thresholds.

Septoria tritici blotch

STB is currently the most important disease of VIC wheat crops. It has been common in the high rainfall zone for several years and was widespread in the Wimmera during 2017. It is important that growers develop a plan to manage STB during 2018.

An integrated approach that incorporates crop rotation (avoiding paddocks with infected wheat stubble), variety selection (avoid susceptible varieties) and fungicides can provide effective suppression of STB. Identification of strains with partial resistance to common fungicides highlights the need to adopt an integrated control approach that is not solely reliant on fungicides for control.

Rust in wheat

The importance of rust to wheat crops during 2018 will be determined by the degree of carryover of inoculum on volunteers growing over summer and autumn acting as a green bridge from the 2017 season. Rust is most severe in seasons following wet summers that result in large areas of uncontrolled volunteers (green bridge).

Rust carryover can be reduced by removing volunteer cereals in paddocks by the end of February. This will provide a break from one season to the next, and therefore break the life cycle of rusts. Removing volunteers also provides benefits for water storage, and general weed and management of other pests and diseases such as aphids and viruses.

Avoiding susceptible varieties is the best method to control rust. Review the susceptibility of varieties to the three rusts, using a current Cereal Disease Guide and develop plans for rust management during 2018.

Barley foliar disease management

Barley foliar diseases had the potential to become severe and cause grain yield and quality losses during 2017. Early sowing, high stubble loads and volunteers all contributed to this risk, where rainfall was average or above. Proactive fungicide application strategies, where used, provided good foliar disease control and minimised losses. Dry conditions significantly reduced disease development in some regions.

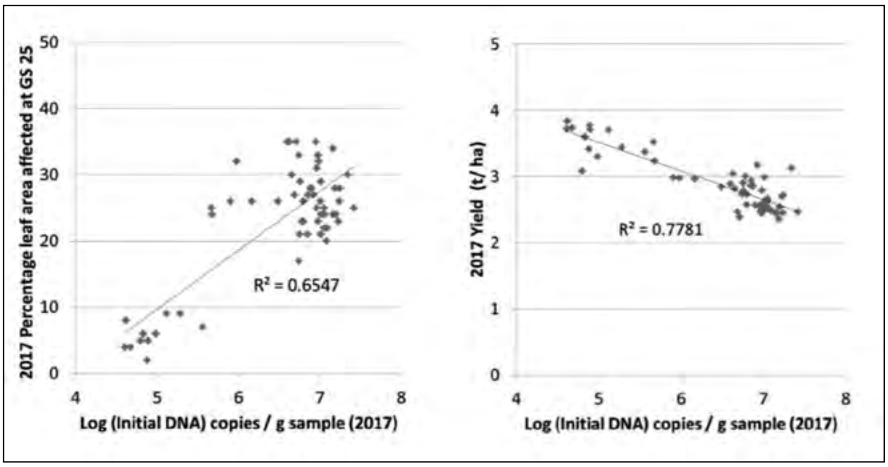

Figure 1. Relationships between pre-planting yellow leaf spot level, as detected using PREDICTA B, and disease severity (left) and grain yield (right) of a susceptible wheat (Phantom$^{(\phi)}$) grown at Dooen, 2017.

Spot form of net blotch (SFNB) and scald were common, while the net form of net blotch (NFNB) was found in susceptible varieties such as RGT Planet$^{(b)}$, Fairview$^{(b)}$ and Oxford. Each of these diseases has the potential to cause 15% to 30% grain yield loss, as well as reductions in grain plumpness, affecting retention, screenings and weight during conducive seasons (McLean et al. 2016, 2017a, 2017b).

Agriculture Victoria conducted experiments during 2017 to further understanding of effective management of important foliar diseases of barley using fungicides and host plant resistance.

Spot form of net blotch

Fungicide timing in the Mallee

A field experiment at Curyo evaluated the benefits of the seed treatment Systiva® and different timings of foliar applied Prosaro® for control of SFNB in a susceptible barley variety (Rosalind$^{(b)}$). Seven treatments were tested and compared to a minimum disease (Systiva + Prosaro @ Z31 and Z39) and Nil treatment (no fungicide) (Table 3).

Moderate SFNB developed at Curyo reducing grain yield by 0.6t/ha (10%) (Figure 2). Fungicides provided significant grain yield improvements when applied proactively. The Systiva alone or Systiva and Prosaro tank mixes at Z39 treatments provided the greatest yield benefits of 0.4t/ha (6%) compared to the Nil treatment. Foliar fungicide application of Prosaro at Z25, Z31 or Z31 and Z39 were effective in reducing SFNB during the important grain development stages and provided 0.3t/ha (5%) yield improvement. Prosaro at Z39 was less effective due to dry conditions after flag leaf emergence. Prosaro application at Z15 did not provide significant yield improvement compared to the Nil treatment, as SFNB was able to re-establish during the winter and spring months. There were no treatment effects on grain quality. Average retention, screenings and grain weight were 87%, 2% and 67kg/hL, respectively.

Table 3. Treatment applied to barley var. Rosalind$^{(b)}$ infected with SFNB at Curyo, 2017.

Treatment	Method/timing	Rate
1. Minimum disease	Seed applied and at Z31 and Z39	150ml/100kg + 150ml/ha
2. Systiva®	Seed applied	150ml100 kg
3. Systiva® and Prosaro® @ Z39	Seed applied and at Z39	150 ml/100kg + 150ml/ha
4. Prosaro® @ Z31	Z31	150ml/ha
5. Prosaro® @ Z39	Z39	150ml/ha
6. Prosaro® @ Z31 and 39	Z31 and Z39	150ml/ha
7. Prosaro® @ Z15	Z15	150ml/ha
8. Prosaro® @ Z25	Z25	150ml/ha
9. Nil	No fungicide	-

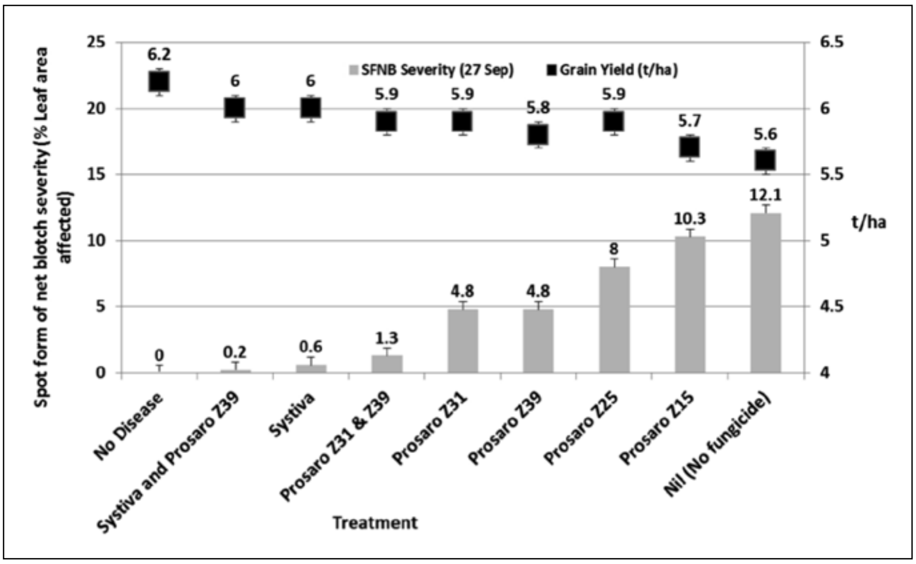

Figure 2. Spot form of net blotch severity at ripening (Z85) and grain yield of Rosalind$^{(b)}$ barley in response to fungicide treatments at Curyo, 2017.

Fungicide chemistry

An experiment was conducted near Horsham to evaluate 10 different fungicide treatments for the control of SFNB on a susceptible barley variety (Dash$^{\Phi}$). Systiva was applied to seed, Uniform® to fertiliser and all other treatments as foliar sprays at early stem elongation (Z31) and were compared to a Nil (no fungicide) treatment (Table 4).

All fungicide treatments provided reductions in SFNB severity and improved grain yield compared to the Nil treatment (Figure 3). Seed applied Systiva provided the greatest grain yield improvements. Amistar Xtra, Taser Xpert and Radial were least effective.

Net form of net blotch

Host plant resistance and yield loss

An experiment was conducted near Horsham to determine the grain yield and quality loss of barley in four varieties with different resistance or susceptibility to NFNB. Two treatments were applied: 1) Low disease treatment to determine grain yield and quality potential, and 2) High disease treatment (no fungicide) to determine loss.

Severe NFNB developed in the susceptible variety RGT Planet$^{\Phi}$ and breeding line VB9613, resulting in grain yield losses of approximately 2t/ha (Figure 4) and quality losses relating to grain plumpness (retention, screenings) and weight (Figure 5). NFNB severity, grain yield and quality losses were much less for Fathom$^{\Phi}$ and Commander$^{\Phi}$, demonstrating the benefits of avoiding susceptible varieties. Timing and the number of fungicide applications are important when managing NFNB with previous research showing that an application at flag emergence provides the greatest benefit. In seasons conducive to NFNB development, two or three fungicides applications may be required.

Table 4. Fungicide treatments applied to barley cultivar Dash near Horsham, 2017.

Treatment/Product	Chemistry	Rate
1. Systiva®	fluxapyroxad	150 ml/100kg
2. Prosaro®	prothioconazole, tebuconazole	300 ml/ha
3. Bumper®	propiconazole	500 ml/ha
4. Amistar Xtra®	azoxystrobin, cyproconazole	800 ml/ha
5. Opera®	pyraclostrobin, epoxyconazole	1000 ml/ha
6. Radial®	azoxystrobin	840 ml/ha
7. Uniform®	azoxystrobin, metalaxyl-M	400 ml/ha
8. Taser Xpert® + Banjo® adjuvant	azoxystrobin + epoxiconazole	500 ml/ha
9. Nil (no fungicide)	-	-

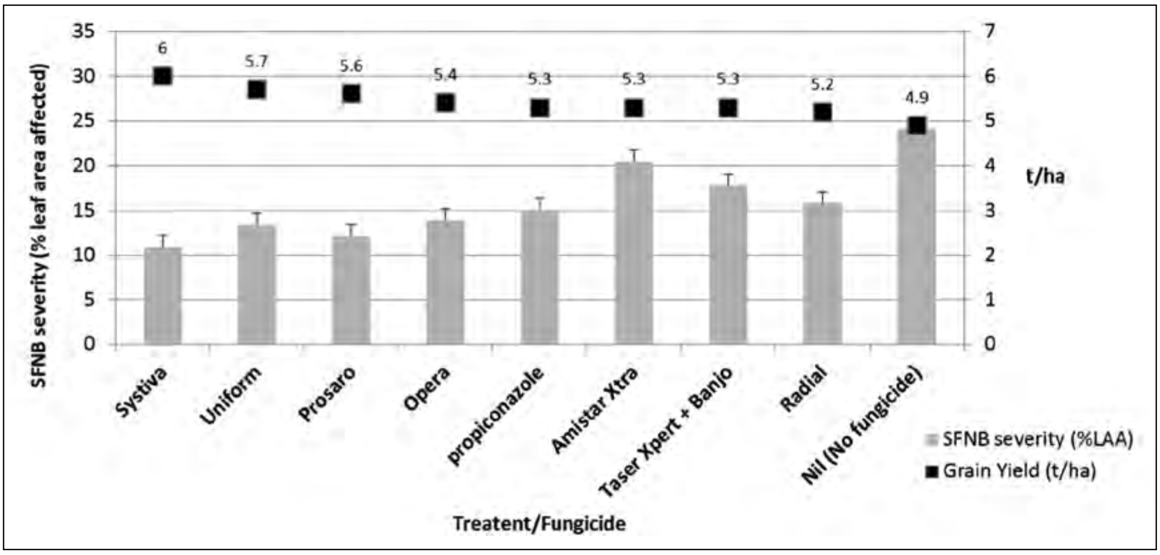

Figure 3. SFNB severity and grain yield of susceptible barley variety Dash$^{\Phi}$ in response to different fungicide treatments at Horsham, 2017.

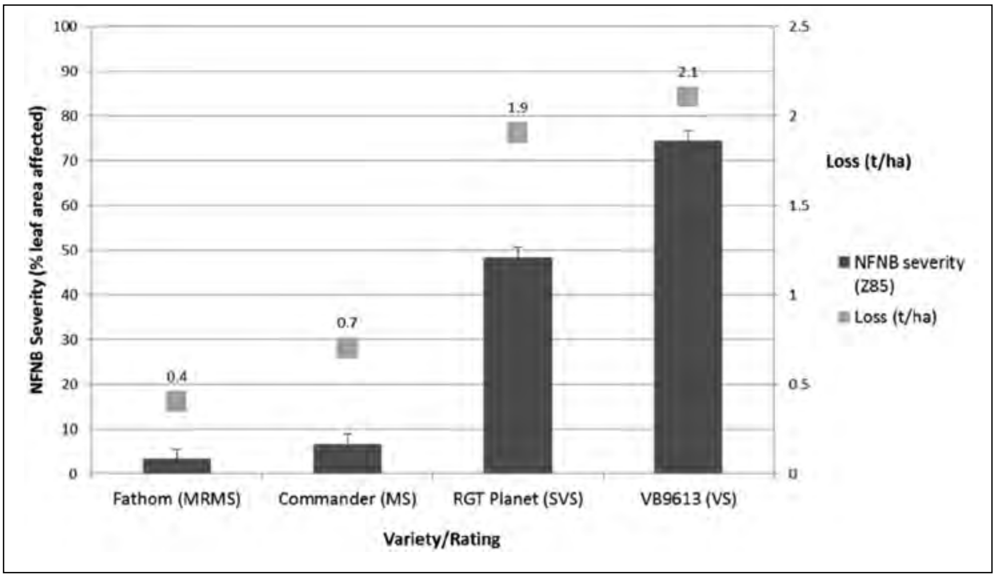

Figure 4. NFNB severity and grain yield loss in four barley varieties near Horsham, 2017.

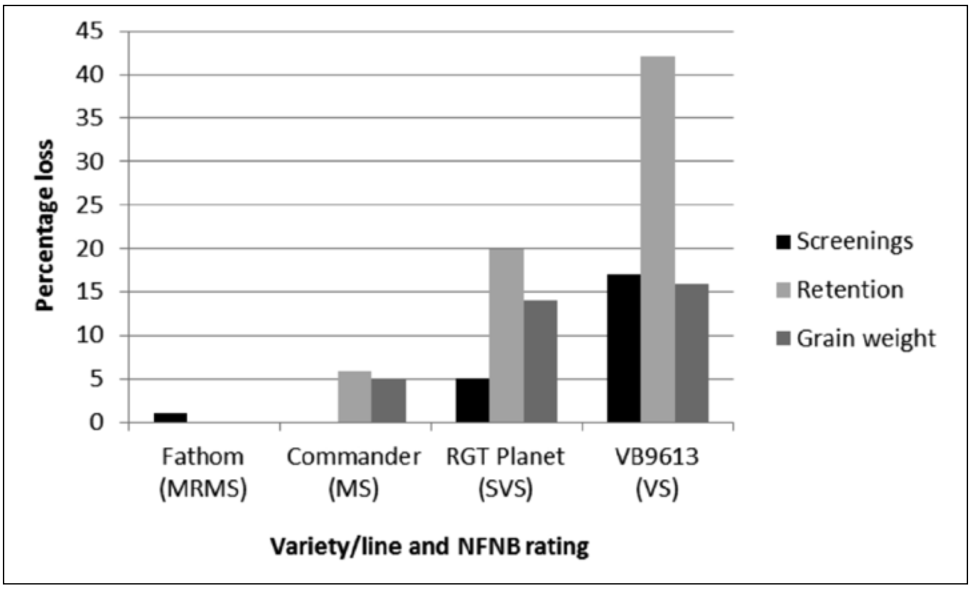

Figure 5. Grain quality losses of four barley varieties due to NFNB near Horsham, 2017.

Resistance management in cereal fungicides

During the past 20 years, there has been widespread adoption of fungicides for control of foliar diseases in VIC cereal crops. As a consequence, reports of resistance or reduced sensitivity to fungicides in diseases are occurring (such as STB and powdery mildew in wheat). To slow the development of resistance to fungicides in the pathogen populations, there are strategies that should be adopted. These strategies include:

1. Using an integrated disease management approach that incorporates multiple strategies including paddock (avoid infected paddocks) and variety selection (avoid susceptible varieties) and timely use of effective fungicides (use before the disease levels become high).
2. Not applying the same active more than once in a season (preferably alternating between fungicide resistance groups) and if possible, applying products that contain more than one active ingredient.
3. Following label guidelines and ensuring maximum residue limits (MRLs) are adhered to.

Soil borne diseases

Yield losses associated with root diseases often go unrecognised as symptoms are below ground. A PREDICTA B test provides an effective way to detect paddocks at risk. As shown in Figure 6, the grain yield of durum wheat decreased as pre-sowing crown rot levels (as detected using PREDICTA B) increased. For most soil borne diseases,

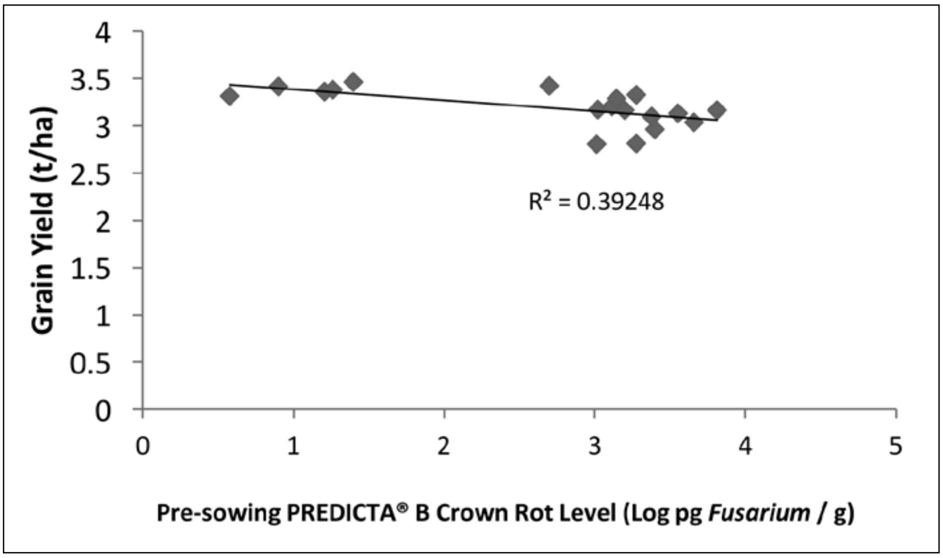

Figure 6. Grain yield of durum wheat (DBA Aurora$^{\Phi}$) decreases with increasing PREDICTA B crown rot level tested prior to sowing in a season not conducive to crown rot at Dooen, 2017.

rotation to resistant crops or varieties is generally recommended to reduce disease levels and yield losses where medium to high pre-sowing disease levels are detected.

Cereal cyst nematodes (CCN)

Large and widespread yield losses caused by CCN during the 1970s and 1980s have been effectively controlled through the use of resistant cereal varieties. However, recently, CCN is being detected in approximately 5% to 10% of paddocks and may be due to a recent increase in the use of cereals without CCN resistance and/or poor grass control in break crops. In most of these paddocks, CCN densities are low, but do pose a potential risk where susceptible varieties continue to be grown.

A field trial by Agriculture Victoria during 2017 showed yield losses of approximately 20% (Table 5) due to CCN demonstrating the extent of losses possible should CCN not be effectively controlled. Growers are advised to monitor paddocks where CCN susceptible cereals are being grown using a PREDICTA B test and plan rotations to keep CCN densities at low levels.

Root lesion nematodes

The root lesion nematodes, *Pratylenchus neglectus* and *P. thornei* are widespread in VIC cropping paddocks. Fortunately, in most paddocks these nematodes are present at low densities, however, where higher levels are present, yield losses, even though sporadic, can occur. A field trial by SARDI during 2017 demonstrated yield losses of up to 25% due to *P. neglectus* (Table 6).

To keep nematode densities below yield limiting thresholds, it is important to grow varieties with a moderately resistant-moderately susceptible (MRMS) or better rating. If susceptible varieties are grown, it is important they are rotated with resistant crops/varieties and nematode densities monitored using a pre-sowing PREDICTA B test. If medium to high nematode densities are present, consider growing resistant crops or varieties.

Bunts and smuts

Seed treatments provide cheap and effective control of bunt and smut diseases. Seed should be treated every year as bunt and smut can increase rapidly, resulting in unsaleable grain. Good coverage of seed is essential and clean seed should be sourced if a seed lot is infected. Fertiliser treatments do not control bunt and smuts, so seed treatments are still required.

Loose smut of barley

Loose smut has been observed in barley crops, particularly the varieties Hindmarsh$^{\Phi}$, La Trobe$^{\Phi}$ and Spartacus CL$^{\Phi}$, due to their greater susceptibility than other varieties. Often, infection has occurred despite registered seed treatments being applied to seed and good coverage achieved.

Loose smut infection occurs when spores released at flowering infect florets and the developing grain in the head. Once a crop is infected with loose smut, there is nothing that growers can do to stop infections and further spread. This means that growers should ensure that good coverage of an effective seed treatment is used for barley.

Table 5. Grain yield and loss in 20 cereal varieties grown in the presence of low and high densities of CCN at Rupanyup, 2017.

Variety	CCN Density		Yield (t/ha)		Yield Loss (%)
	Low	High	Low	High	
RGT Planet⍉	0	47	2.74	2.77	0
Compass⍉	1	41	3.03	3.01	1
Cutlass⍉	1	37	2.54	2.51	
Axe⍉	1	42	2.46	2.41	2
La Trobe⍉	1	42	2.46	2.32	5
DBA-Aurora⍉	1	33	2.64	2.49	6
Hatchet CL Plus⍉	1	29	2.42	2.28	6
Mace⍉	1	38	2.37	2.20	7*
Spartacus CL⍉	1	48	2.38	2.20	7*
Rosalind⍉	2	37	3.01	2.74	9*
Alestar⍉	1	56	2.94	2.65	10*
Kord CL Plus⍉	1	29	2.10	1.89	10*
Scope CL Plus⍉	1	43	2.71	2.44	10*
Scepter⍉	1	33	2.30	2.06	10*
Scout⍉	1	38	2.50	2.19	13*
Hindmarsh⍉	1	31	2.50	2.18	13*
Kiora⍉	1	26	2.55	2.13	16*
DS Darwin	1	23	2.34	1.93	17*
Impala⍉	1	74	2.31	1.85	20*
LRPB Arrow⍉	1	38	2.36	1.82	23*

**Indicates a significant grain yield loss (P<0.05)*

Table 6. Yield loss due to the root lesion nematode *P. neglectus* at Pinery, SA, 2017. Nematode densities were 1 *P. neglectus* and 12 *P. neglectus*/g soil, for the low and high plots, respectively.

Variety	Grain Yield (t/ha)		Yield Loss (%)
	Low	High	
Spartacus CL⍉	5.07	5.21	0
Hindmarsh⍉	5.31	5.40	0
Wallup⍉	4.74	4.78	0
Chief CL Plus⍉	4.96	4.98	0
DBA Aurora⍉	5.05	5.05	0
RGT Planet⍉	5.58	5.52	1
Alestar⍉	5.20	5.06	3
DS Darwin⍉	4.83	4.63	4
Astute⍉	4.22	4.03	5
Rosalind⍉	5.58	5.31	5
LRPB Arrow⍉	4.31	4.09	5
Harper⍉	4.56	4.32	5
Corack⍉	5.26	4.97	6
Cosmick⍉	5.22	4.86	7
Skipper⍉	5.10	4.72	8
Scepter⍉	5.17	4.77	8
Mace⍉	4.74	4.26	10*
Bison⍉	4.66	4.14	11*
Beckom⍉	5.47	4.81	12*
Scout⍉	5.31	4.61	13*
Emu Rock⍉	5.61	4.81	14*
Hatchet CL Plus⍉	4.80	3.97	17*
Cutlass⍉	5.83	4.57	22*
Trojan⍉	5.98	4.51	25*

**Indicates a significant grain yield loss (P<0.05)*

Work by Hugh Wallwork (SARDI) found that products containing just triadimenol provide only approximately. 50% control of loose smut in Hindmarsh⁽ᴰ. Products containing flutriafol and tebuconazole or a low rate of Rancona® Dimension (80mL/100 kg seed) allow some infection to persist in crops. If using Vibrance® or Rancona Dimension, then higher rates set for rhizoctonia control should be used. The most effective control was provided by products containing carboxin and the succinate dehydrogenase inhibitor (SDHI) fungicide EverGol® Prime, although even these products may not be 100% effective in all situations. For more detailed information, consult the SARDI Cereal Seed Treatment Guide.

Conclusion

In the absence of proactive disease control, yield losses due to diseases can be greater than 20%. It is therefore important that plans are developed to effectively manage wheat diseases this season.

Useful resources

Current Victorian Cereal Disease Guide: http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-disease-guide

Identification and Management of Field Crop Diseases in Victoria: http://www.croppro.com.au/crop_disease_manual.php

extensionAUS: updates on seasonal issues: https://extensionhub.com.au/web/field-crop-diseases

Root lesion nematode: https://grdc.com.au/Resources/Factsheets/2015/03/Root-Lesion-Nematodes

Bunts and smuts: http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/bunts-and-smuts-of-cereals

Yellow leaf spot: http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/yellow-leaf-spot-of-wheat

Septoria: http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/septoria-tritici-blotch-of-wheat

Cereal Seed Treatments 2018 http://pir.sa.gov.au/__data/assets/pdf_file/0005/237920/_final_web_CerealSeed_Treatments_2017-18_booklet.pdf

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Acknowledgements

This research is a collaborative project between the GRDC and Agriculture Victoria. 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. Thanks to Agriculture Victoria's Cereal Pathology Team: Graham Exell, Jordan McDonald, Tom Pritchett, Jon Baker, Laura Roden, Luise Sigel and Samantha Exell. Thanks also to the Birchip Cropping Group for field trials within the Victorian Mallee.

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Notes

Best options for optimal performance from rhizobial inoculants

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GRDC project codes: UA00138, DAS00128

Keywords

- dry sowing, granules, nitrogen fixation, nodulation, peat, rhizobia.

Take home messages

- Peat slurry inoculants applied to seed perform consistently well; other formulations can also provide good nodulation, but outcomes are dependent on the carrier and sowing conditions.
- There is little data on the survival of rhizobia in different formulations when dry sown. Some of the first data for rhizobial survival under dry sowing conditions in southern Australia is presented.
- Agrochemicals and fertilisers at sowing can affect rhizobial survival — avoid contact between these and rhizobia.
- New acid tolerant rhizobia have improved faba bean and lentil nodulation and may increase the area where these pulses can be grown.

Background

Nitrogen (N) is the major nutrient required for grain production in Australia. Pulse crops provide an inexpensive and sustainable source of fixed N that underpins high value pulse production and provides residual N for the following cereal and canola crops. N fixation is dependent on the availability and number of suitable root nodule bacteria (rhizobia) (Drew et al. 2012, Denton et al. 2013). Pulses are estimated to fix 40kg N/ha to 136kg N/ha on average (Unkovich et al. 2010), worth about $220 million each year to Australian farming systems. However, not all pulses in Australian farming systems are well nodulated and fix optimal N. One reason for this is poor rhizobial adaptation in some soils. To increase the productivity of pulses and to expand pulses beyond their current range, particularly into acid soils, rhizobia that are better adapted to these soils are required. The development of rhizobia that improve nodulation in these soils will assist the expansion of pulses into new areas.

Current farming production systems often involve sowing crops early in the season. As a consequence, pulses such as faba bean, lupin and even chickpea in some areas are being dry sown before breaking rains. Rhizobia are sensitive to desiccation and the consequences of dry sowing to rhizobia survival for different inoculant formulations are poorly understood, as there have been limited studies in Australia to understand the extent to which dry sowing affects the nodulation, N fixation and grain yield in pulses.

Although peat slurry inoculation is very effective, different inoculant types and methods of application are also available. Granular products differ greatly in their rhizobial number, granule size, initial moisture content and efficacy when sown into moist soil (Denton et al. 2009). Understanding how dry sowing impacts on performance of these different formulations and application methods is a question often asked by growers. In addition, where dual stresses occur, such as dry sowing combined with acid soils or dry sowing combined with toxic chemicals, the consequences for rhizobial survival are likely to be increased.

Nodulation can also be detrimentally affected by the agrochemicals, fertilisers, or additives that come into contact with rhizobia at sowing. Since rhizobia are living organisms, they are very susceptible to toxic chemicals, extremes of pH, desiccation, heat and high salt concentrations. The inadvertent or deliberate mixing of different compounds with rhizobia often causes rapid cell death, leading to sometimes catastrophic nodulation failure. Where this occurs there is little recourse for growers other than to re-inoculate. Better advice is required to support recommendations about the effect of additives on rhizobial survival, and therefore, to avoid failures.

Results and discussion

Do inoculant types and application methods differ in their effectiveness?

Over the last two decades, the use of granular and liquid inoculants in Australia has increased markedly (Denton et al. 2009, 2017). Although peat slurry inoculants have been used effectively over the last hundred years in Australia, and are supplied at high quality by inoculant companies, the methods of application to seed can be inconvenient, especially to large volumes of pulse seed when there are time pressures around sowing. Granular and liquid inoculant application systems also provide an opportunity to separate rhizobia from toxic chemicals, such as pickles applied to the seed coat. Peat slurry inoculants typically contain a greater number of rhizobia, than bentonite clay granules (Denton et al. 2009), and this is reflected in the relative levels of nodulation by the different formulations across multiple trial sites (Figure 1).

A comparison of peat applied to seed as a slurry, with peat-based granules and peat suspension in water injected into furrows was tested in four field experiments (Denton et al. 2017). In this study, inoculation improved nodulation (data not shown), grain yield and N fixation of faba bean (Table 1). At Mininera there were no differences in grain yields of faba bean with different inoculation methods, while at Culcairn, peat slurry applied to seed, again provided the best outcome and inoculant injected as a liquid into the furrow was lower by 1t/ha (Table 1). Similarly, there were no differences in N fixation among the different inoculation methods at Mininera, while peat slurry inoculation was superior in N fixation at Culcairn (Table 1).

Does inoculation work when pulses are dry sown?

Growers often sow faba bean, lupin, lentil and even chickpea into dry soil. However, assessment of different inoculant types under dry sowing conditions are limited in providing much general information to growers. Sowing inoculated seed into dry soil is not recommended where a legume crop is sown for the first time, as there may not be a suitable background level of rhizobia (Drew

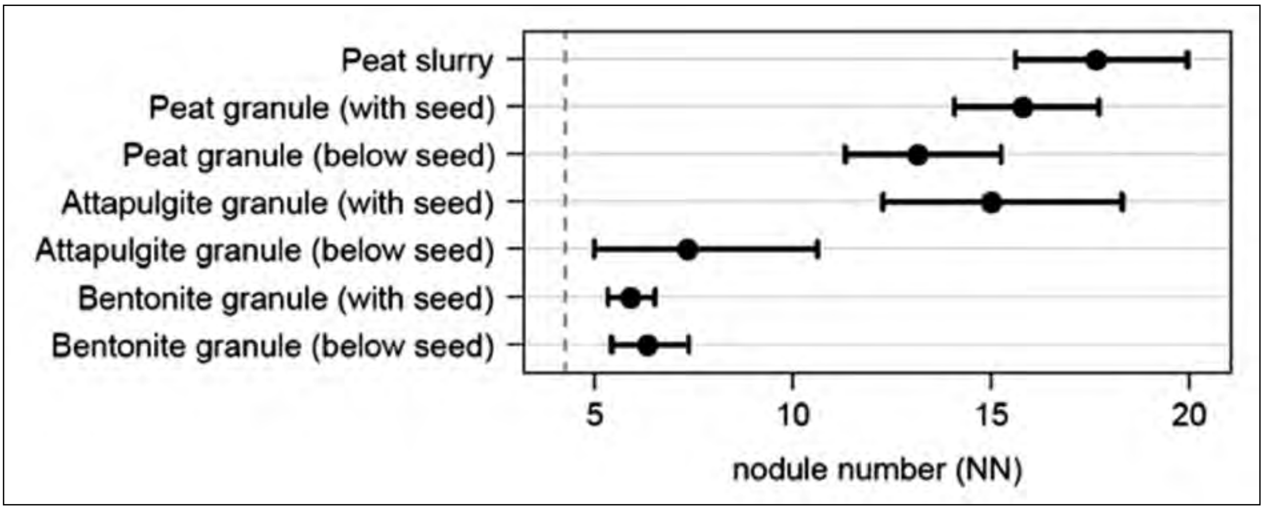

Figure 1. Mean nodule numbers for rhizobia inoculation using either peat slurry inoculants or with different granular inoculant treatments applied with or below the seed. Data are means of 37 replicated field experiments conducted in SA, Victoria and southern NSW. Background nodulation for un-inoculated plants was 4.3 nodules per plant (geometric mean for the 37 experiments), shown as a dashed line. Error bars are 1% least significant difference intervals; if these overlap for a pair of treatments they are not significantly different at the 1% level. Data from Denton et al. (2009).

Table 1. Faba bean grain yield and N fixation when inoculated with peat slurry applied to seed, peat granules or peat as a liquid suspension injected into furrows. Means in a column not followed by the same letter are significantly different at the give P values.

Treatment	Mininera, Vic		Culcairn, sNSW	
	Grain yield (t/ha)	N fixation (kg N/ha)	Grain yield (t/ha)	N fixation (kg N/ha)
Uninoculated	0.94 b	17 b	1.75 c	36 c
Peat slurry	1.42 a	63 a	3.69 a	316 a
Peat granules	1.13 ab	44 a	3.50 a	130 b
Peat as liquid	1.37 a	66 a	2.70 b	121 b
	P <0.01	*P<0.001*	*P<0.001*	*P<0.001*

et al. 2014). On the other hand, where a legume has been used frequently and the soil is not particularly hostile to rhizobia, the risk of nodulation failure resulting from dry sowing is much reduced. Rhizobial formulations applied in furrow, such as granules or peat suspended in liquid, can be placed at a greater depth in the soil where theoretically they will have a better chance of survival, as soil moisture and temperature fluctuations will be less extreme at these depths. Currently only two granular formulations (supplied by Alosca and Novozymes) are recommended for use when dry sowing. Field trials were conducted at two sites in 2017 assessing a range of formulations at different rates and in combination (including peat on seed); these treatments push the boundaries of current recommendations, with the aim of providing better guidelines for growers around dry sowing. In a recent field experiment at Wanilla, all inoculants improved the nodulation of faba bean relative to no inoculation (Figure 2). Novozymes granules provided the best nodulation at two sampling times and for both sowing times, and surpassed the nodulation provided by peat slurry inoculation on seed at that site (Peat) (Figure 2).

In a similar study using different inoculants on lupin at Farrell Flat, mid North of SA, there were fewer differences between formulations, and granules provided similar nodulation to peat slurry. However peat slurry in combination with freeze-dried inoculant enhanced nodulation of the crop sown late into moist soil at measured at the second sampling time (Figure 3).

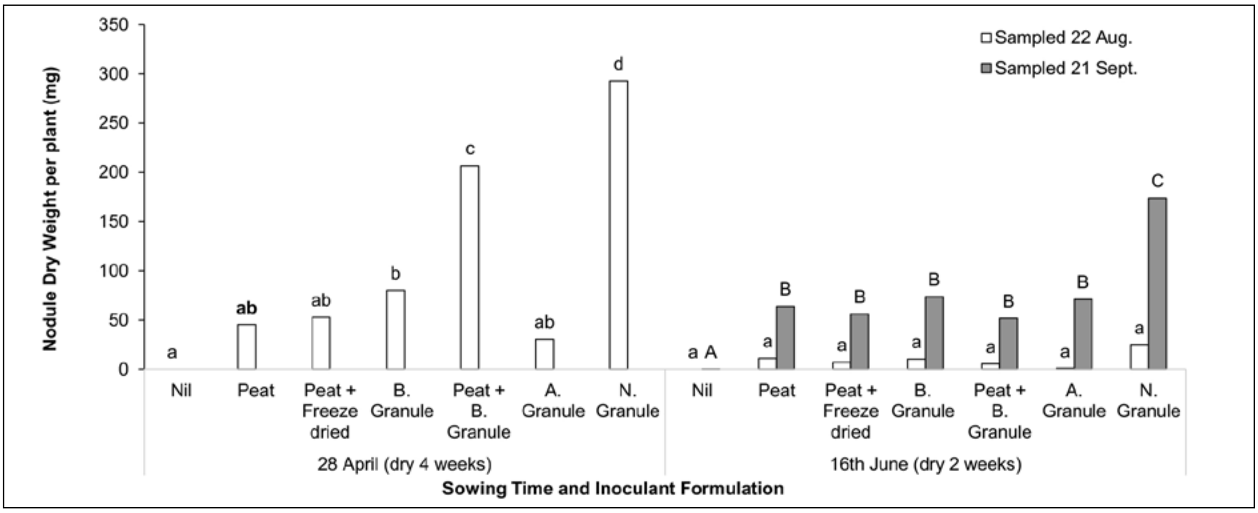

Figure 2. Nodulation of faba bean when sown dry (28 April — approximately four weeks between sowing and sufficient rainfall for germination, and 16 June — approximately two weeks between sowing and sufficient rainfall for germination) and when different inoculant applications were applied at Wanilla, SA. Nodule weight per plant was measured on the 22 of August and 21 of September. Letters that differ within a sampling time indicate significance at P<0.05. All inoculants are group F; peat slurry on seed (Peat) and BASF granules (B. Granule) were supplied by BASF and applied separately or in combination, Freeze dried inoculant (Freeze dried) was supplied by New Edge Microbials (applied with the Peat treatment), Alosca granules (A. Granule) were sourced from Landmark and Novozymes (N. Granule) were supplied by Novozymes.

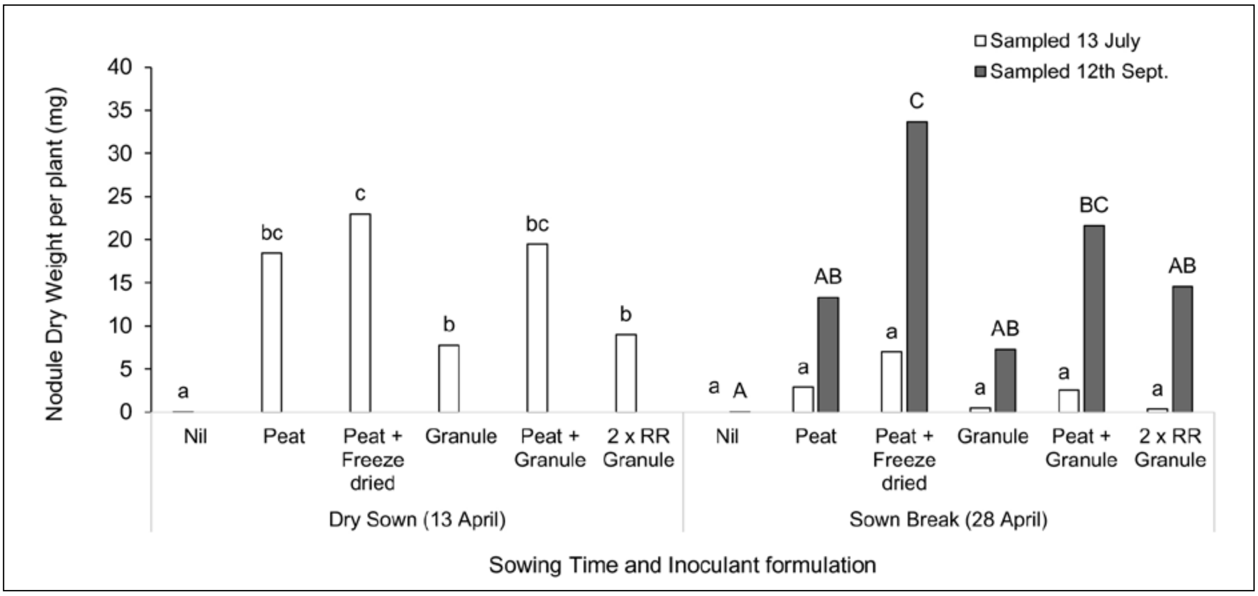

Figure 3. Nodulation of lupin sown into dry soil (13 April — seven days between sowing and sufficient rainfall for germination) or moist soil (28 April) when different inoculant applications were applied at Farrell Flat, mid North of SA. Nodule weight per plant was measured on the 13 July and 12 of September. Letters that differ within a sampling time indicate significance at $P<0.05$. All inoculant was group G Lupin. Peat slurry on seed (Peat) and BASF granules (B. Granule) were supplied by BASF and New Edge Microbials supplied freeze dried inoculant (Freeze dried). Granules were supplied at the standard rate and two times the recommended rate (2 x RR Granule).

Despite a very dry finish at Wanilla which limited faba bean grain yields, all inoculants improved yields for the early sown treatments (Table 2). Novozyme granules increased yield at both sowing times, relative to peat slurry inoculation (Table 2). Notably the combination of peat slurry on seed and granules (BASF) also resulted in improved nodulation and yields when sown early. Late sown treatments produced less than half the yield of early sown treatments due to decreased growing degree days.

Inoculation with any formulation improved grain yield of lupin at either sowing time at Farrell Flat, SA (Table 3). In the dry sown treatments, peat slurry inoculation on seed provided the best inoculation response. However, crop yields were generally lower when sown after the break, most likely due to reduced degree days experienced by the crop. There were no differences among the different inoculant formulations for these treatments that were sown into moist soil (Table 3).

Table 2. Grain yields (t/ha) of Samira$^{\text{(D}}$ faba bean at Wanilla, SA in response to different inoculation treatments when sown into dry soil. Note that there was approximately four weeks between sowing and sufficient rainfall for germination after sowing 1 and approximately two weeks between sowing and sufficient rainfall for germination after sowing 2.

Inoculation treatment	Sowing Time	
	28 April (dry four weeks)	16 June (dry two weeks)
Uninoculated	0.13 ef	0.07 g
BASF peat	0.30 d	0.10 fg
BASF peat and New Edge freeze dried	0.30 d	0.11 fg
BASF granules	0.39 c	0.11 fg
BASF peat + granules	0.49 b	0.14 ef
Alosca granules	0.33 cd	0.11 fg
Novozyme granules (tag team)	0.57 a	0.19 c
l.s.d.	0.06	

Table 3. Grain yields (t/ha) of narrow-leaf lupin at Farrell Flat, SA in response to different inoculation treatments sown either prior to the break or following breaking rains.

Inoculation treatment	Sowing Time	
	Dry sown (13 April)	Sown after break (28 April)
Uninoculated	1.64 c	1.86 c
BASF peat	2.90 a	2.46 b
BASF peat and New Edge freeze dried	2.67 ab	2.33 b
BASF peat granules	2.48 b	2.35 b
BASF peat + granules	2.50 ab	2.40 b
BASF granules x 2	2.46 b	2.35 b
l.s.d.	0.34	

Which additives reduce the efficacy of rhizobia?

Although Australian peat inoculants are considered to be the highest quality in the world (Hartley et al. 2005), nodulation potential can be quickly reduced through mixing with additives such as herbicides, fungicides, insecticides and/or fertilisers. The effects of these practices become obvious when a legume is sown on an inoculation responsive site. While it is recommended that mixing rhizobia with other amendments is best avoided, it is currently commonplace. The compatibility of rhizobial inoculants with some commonly used products is being tested in the laboratory to determine the effects of these additives on rhizobial survival. Some preliminary data indicated that zinc sulphate seed treatments are highly toxic to rhizobia (Ballard et al. 2016).

Recent laboratory tests also indicated that the presence of Gaucho® insecticide (imidacloprid) did not significantly reduce nodulation in field pea, relative to the water control (Figure 4). However, the application of either Thiram® (dimethyl dithiocarbamate) or P-Pickel T® (thiram and thiabendazole) both significantly reduced rhizobial numbers and nodulation. In chickpea, rhizobia numbers on seed and the resulting nodulation were

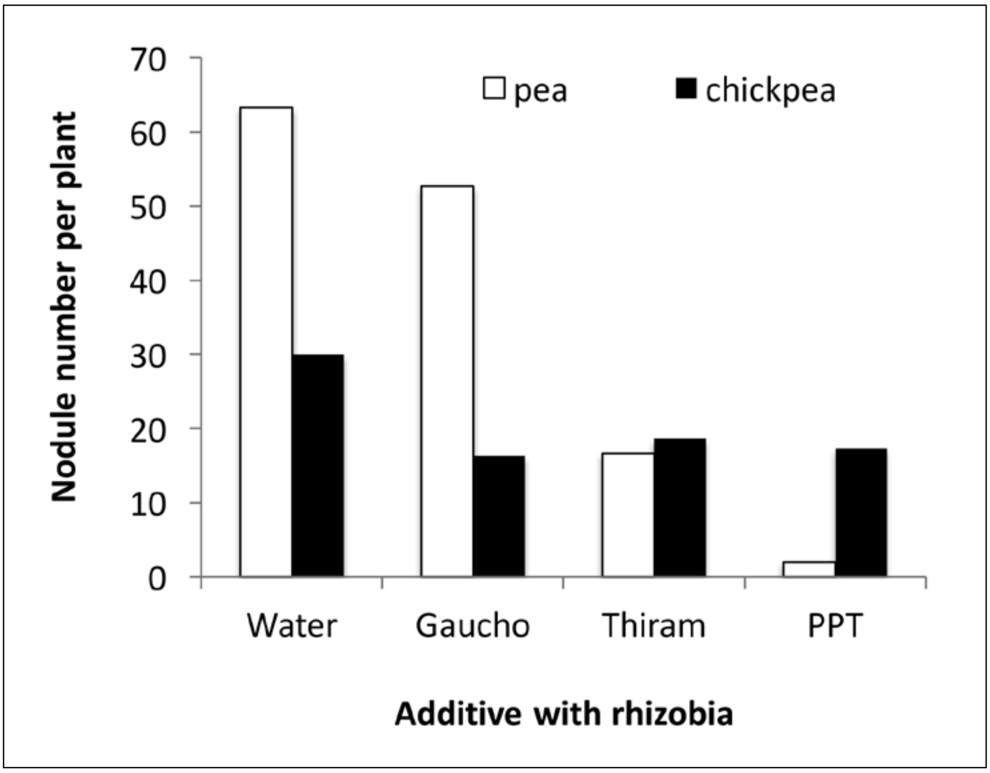

Figure 4. Number of nodules formed following the exposure of rhizobia on seed to different additives for 24 hours under laboratory conditions. Significant differences were observed among treatments for pea – l.s.d. 5% of 23; chickpea: l.s.d. 5% of 15.

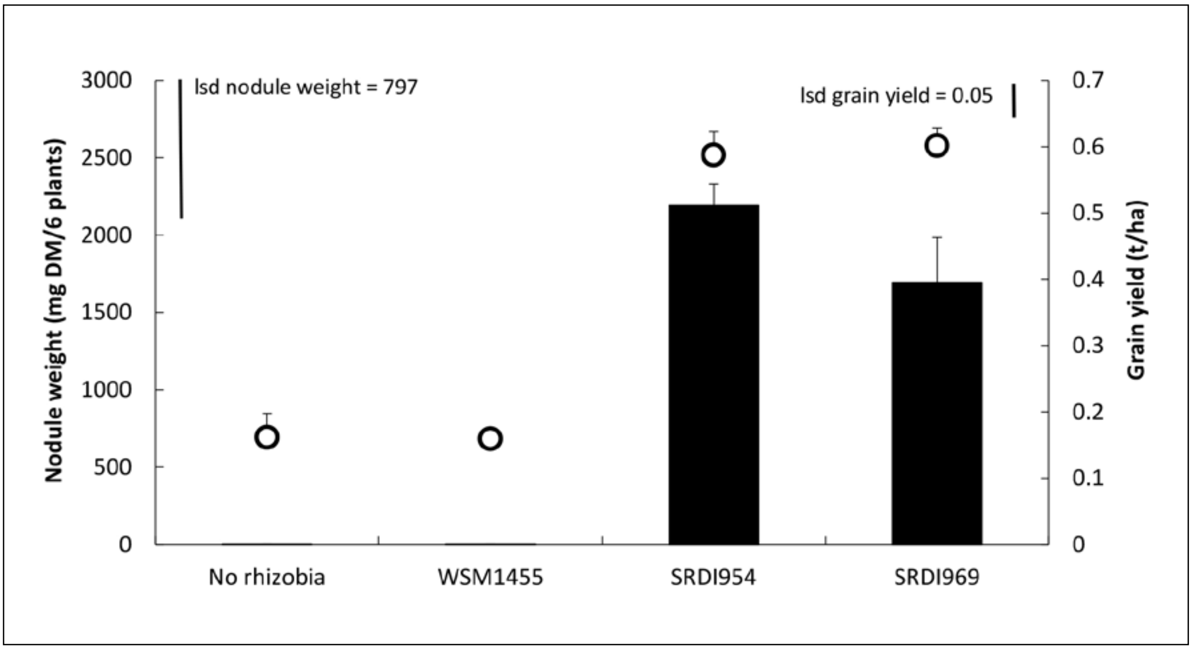

Figure 5. Effect of rhizobia strain on nodule weight (left axis, columns) and grain yield (right axis, circles) of SamiraA faba bean at Wanilla, Eyre Peninsula SA in 2017. Site pH(Ca) = 4.3, sown into dry soil at standard rates of inoculation on 28 April. Standard error of means shown as bars above columns and circles.

both reduced by the addition of Gaucho insecticide, Thiram or P-Pickel T (Figure 4), indicating that chickpea rhizobia may be more sensitive than pea rhizobia to Gaucho.

Can new rhizobial strains improve nodulation in faba bean and lentil?

Rhizobia are typically much more sensitive to acid soils than the host legume plant. Improved acid tolerance in rhizobia that nodulate faba and lentil (along with pea and vetch) are likely to increase the area where these legumes can be grown. Promising strains of acid tolerant rhizobia for faba bean have been tested in 2017. The acid tolerant strains are showing encouraging results and the use of two strains, SRDI954 and SRDI969 have resulted in increased nodulation over the current commercial strain, WSM1455 (Figure 5). Strain SRDI954 has increased nodulation at five of the eight sites where it has so far been tested. Plans are also afoot to test the ability of these strains in improving the lentil symbiosis. It is envisaged that these new strains may enable expansion of pulses onto more acidic soils than has previously been possible.

Conclusion

Peat slurry inoculant applications often provide the best nodulation when sown into moist soil, due to their high titres of rhizobia and the protective properties of peat, as well as proximity of the inoculant to the seed relative to other formulations and application methods. Granular inoculants and peat inoculants delivered using liquid injection have produced similar, sometimes even better results to peat applied to seed in some trials, but on the whole are less consistent in their performance. Since these alternative inoculation methods allow the inoculant to be separated from harmful seed-applied chemicals, it would be useful to better understand the conditions where they are effective.

Recognising that the dry sowing of pulses is a common practice despite its potential detriment on the symbiosis where there are no background rhizobia, efforts are underway to better understand the effects of dry sowing on rhizobial survival, so that improved recommendations can be provided to growers. Initial results indicate that some peat granules and traditional peat slurry inoculants applied to seed in high numbers produced satisfactory nodulation and grain yield in dry sowing conditions for faba bean and lupin. Further work is required to understand more broadly and conclusively how rhizobia survive and nodulate under dry sowing conditions. In the short term, results indicate that to optimise nodulation when dry sowing, rhizobia can be applied in high numbers at sowing by increasing the rate of inoculant applied (e.g. 2 x recommended rate of peat or granules, or applying both peat + granules together).

In practice, inoculation is often used in conjunction with other additives. Growers should be very wary when using additives such as fertilisers, seed-applied fungicides and organic products with rhizobia. The use of these products may lead to reduced rhizobial survival, nodulation, N fixation and grain yield.

New rhizobia for faba bean and lentil appear to provide greater acid tolerance than the current commercial strain of rhizobia. Commercialisation of these strains will lead to an improvement in soil adaptation of these crops.

Useful resources

Inoculating Legumes: A Practical Guide http://www.grdc.com.au/Resources/Bookshop/2015/07/Inoculating-Legumes

www.ua.edu.au/legume-inoculation

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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. The support of SAGIT (project S217) is acknowledged for the work presented on dry sowing.

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Weather and seasonal forecasting — science or fiction in 2017?

Dale Grey.

Agriculture Victoria, Bendigo.

Keywords

- climate, El Niño, weather model, Sub Tropical Ridge (STR), Southern Annular Mode (SAM), rainfall variability.

Take home messages

- Half of the weather models surveyed had drier predictions for autumn throughout Victoria (VIC).
- During 2017, models performed satisfactorily at predicting the weather, despite the early El Niño prediction being wrong.
- Modern computer climate models look at much more than just El Niño and La Niña when making their predictions.

Background

2014 started with early El Niño predictions which failed to materialise but due to the presence of too much high air pressure systems in spring, the VIC finish was challenging. During 2015, an El Niño and a positive Indian Ocean Dipole (IOD) were predicted early, which did eventuate in both instances. The effects of these weather patterns in VIC were strong, but less so in South Australia (SA), while New South Wales (NSW) experienced a reasonable season due to some favourable air pressure and Southern Annual Mode (SAM) patterns. 2016 had early predictions of a La Niña and a negative IOD — the predicted La Niña did not occur, but the negative IOD led to a wet season that was well predicted by many models. 2017 once again started with El Niño predictions which also failed to eventuate, but the season, while reasonable in VIC due to a good April start, was average to below average in much of SA and southern NSW— why was this so?

Results and discussion

The 2017 growing season throughout VIC was close to the average, varying between decile 3 and decile 8, but the majority was decile 4 to decile 5. The exception was Gippsland which was a dry decile 1 season. From January to March, it was stormy and wetter in the Mallee as a result of troughs and cyclonic breakdowns coming in from the north-west. The 2016 and 2017 summer experienced much lower pressure over VIC, indicating favourable conditions for rainfall transport to the south from the tropics. Most areas received between 50mm to 100mm for summer. This topped up the deep soil moisture left over from the wet spring in 2016.

Rainfall in March was essentially average. More than half the models surveyed in March predicted that an El Niño was possible for the coming season. Similarly, there was good consensus for a positive IOD for winter. These predictions were being discussed despite this being a time where the skill of models at making such predictions is the poorest. Figures 1 and 2 show the summary of rainfall and temperature predictions made for April to June and for July to September. Consensus was split between average and drier rainfall and average and warmer temperatures for both three month prediction periods.

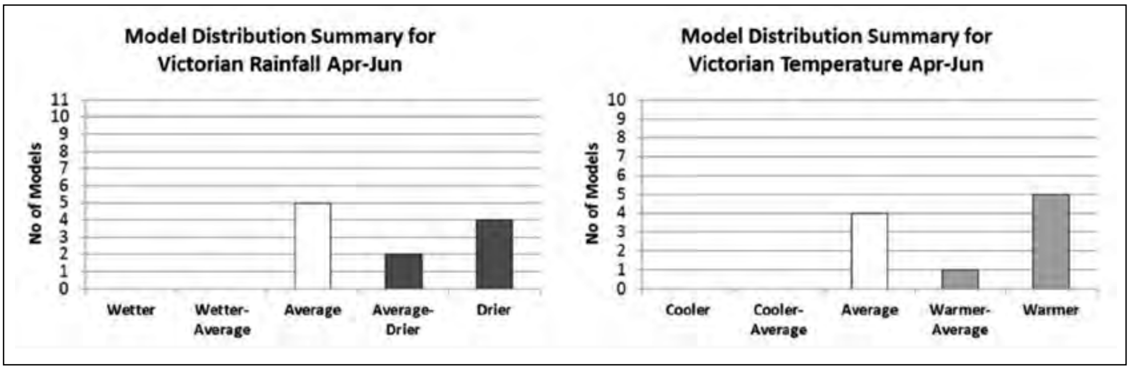

Figure 1. April to June rainfall and temperature predictions for southern VIC from 11 models run in March.

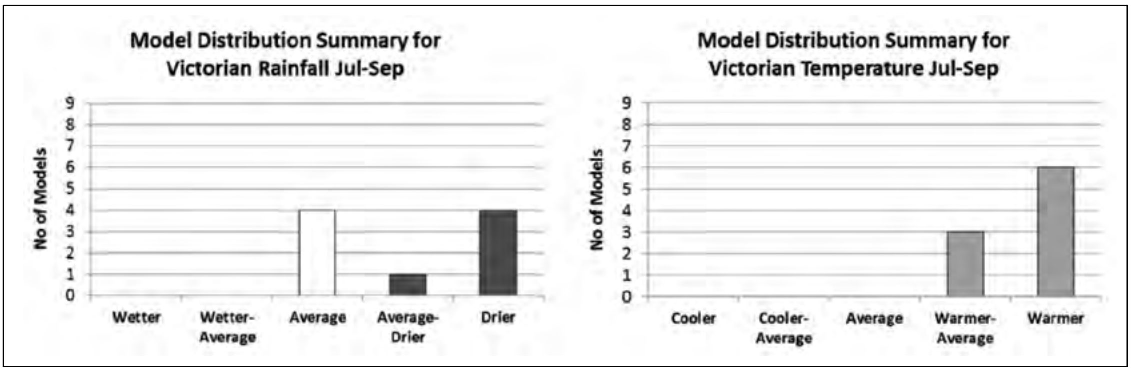

Figure 2. July to September rainfall and temperature predictions for southern VIC from 11 models run in March.

The unexpected point about this year's El Niño prediction was that it was not easy for those who examine climate models (climate scientists or otherwise) to see the underlying fundamentals of where these forecasts were coming from. In previous years, a signal of some note usually pre-exists in the eastern Pacific equatorial sub-sea. Figure 3 shows that sub-sea temperature anomalies were in fact cooler at this time and any signals the models were receiving was from the slightly warmer western Pacific, which was predicted to make its way under and over to the South American coast. The reversed trade winds east of Papua New Guinea which are needed for this to happen never occurred. Once May was reached, almost all of the models were still convinced of a positive IOD but this also did not eventuate. So for whatever reason, models were 'crying wolf' early last year.

April saw great opening rains with 50mm to 100mm falling over most of the state with the Eastern Mallee and North East receiving the biggest share. Soils were now wet to depth and there was a need to prioritise wet paddocks for sowing. This was an unexpected weather event that VIC benefited from the most, while SA's Eyre Peninsula (EP) and NSW's cropping areas missed out.

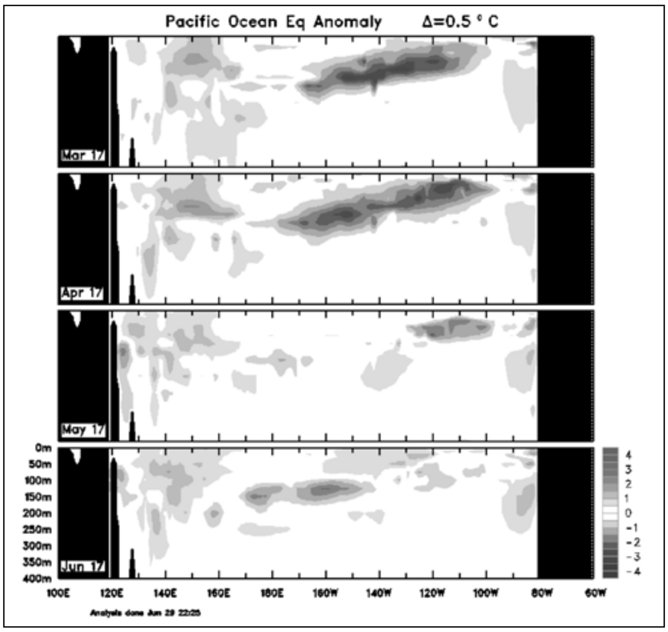

Figure 3. Sub-sea temperature anomaly cross section of the Equatorial Pacific Ocean March to June 2017.

May rainfall was average over much of the state, but the Wimmera was wetter, making its grey clays quite untrafficable. June was very dry, which allowed crops to finally be sown. The start to the season

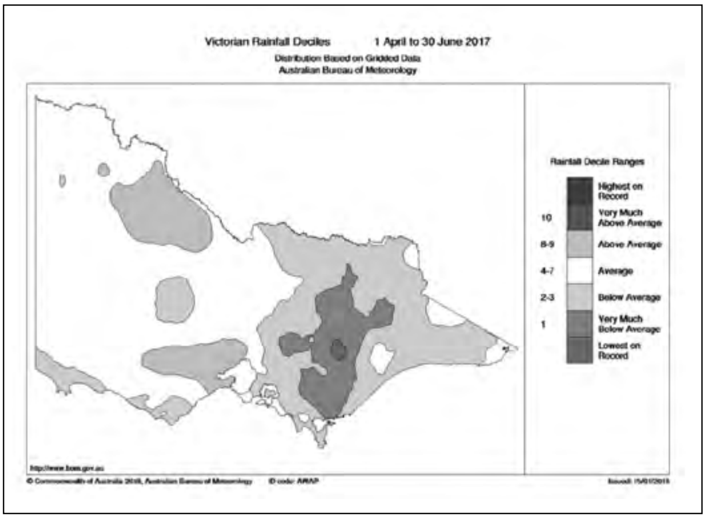

Figure 4. Decile ranking of April to June rainfall, VIC 2017.

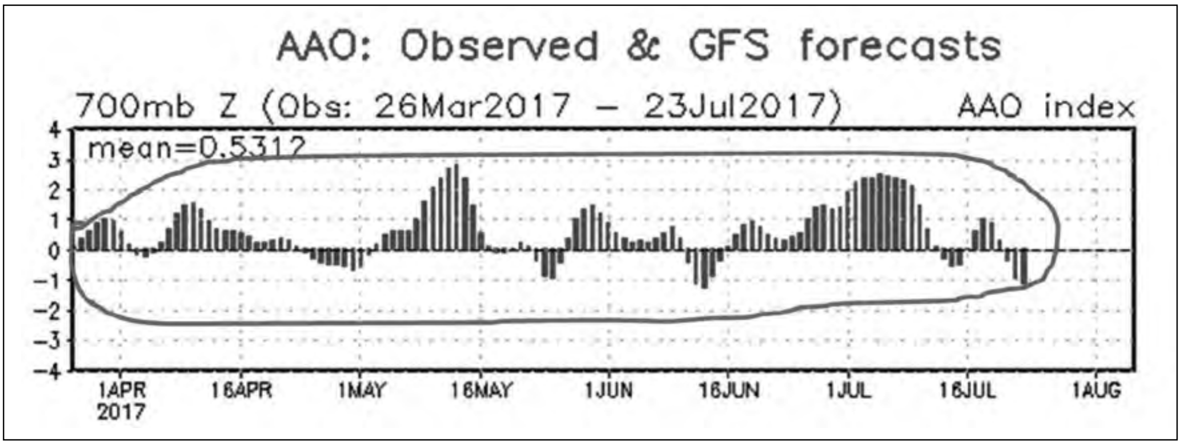

Figure 5. SAM measurements across April to July 2017.

was drier in the east and average to wetter in the west (Figure 4). A history of model watching over 10 years suggests that when half the models indicate something different than average, it usually occurs. In this case, the situation in the western half of VIC was different to the rest of SA and NSW. So what was the climate playing at here?

Broad scale changes to pressure and the position of rainfall triggers resulted in a dry SE Australia. The SAM was positive through most of April to July (Figure 5).

A positive SAM meant that winds were spinning faster around Antarctica and pulling the frontal and low pressure rainfall triggers to the south. The lower rainfall was therefore due to a lack of rainfall triggers, not a lack of moisture source. June in particular was dominated by a massively high pressure pattern that set up over the SA and VIC border. This effectively blocked rainfall triggers from coming anywhere near SE Australia. In effect, two factors were both at play, preventing June rainfall. The difference was, the April rainfall which was a chance lining up of a rainfall trigger with a moisture source, was very specific to Western VIC.

July was average to drier over most of the state with the exception of the West Wimmera.

During July, the position of the Sub Tropical Ridge (STR) of high pressure started moving further north of its normal position over Adelaide. In fact, through August the ridge moved as far north as Coober Pedy. This has the benefit of pressure being lower than 'normal' and consequently, there was no impediment to fronts coming through. However, due to the fronts being pulled south by the SAM, the wetter effect was stronger in SA in July. August was the wettest month during the growing season and most of VIC's crops received 50mm to 100mm.

At the end of July, weather models have their best chance of being accurate for August to October. Once again during 2017, the models were split

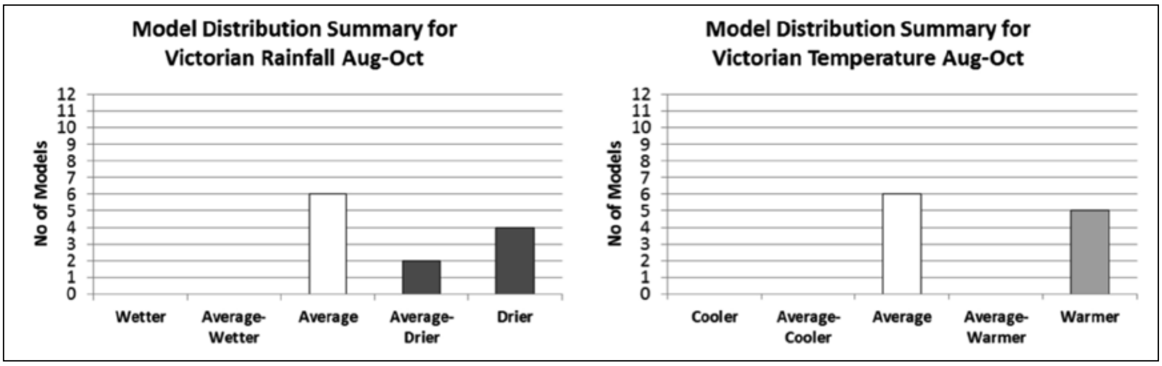

Figure 6. August to October rainfall and temperature predictions for VIC from 11 models run in July.

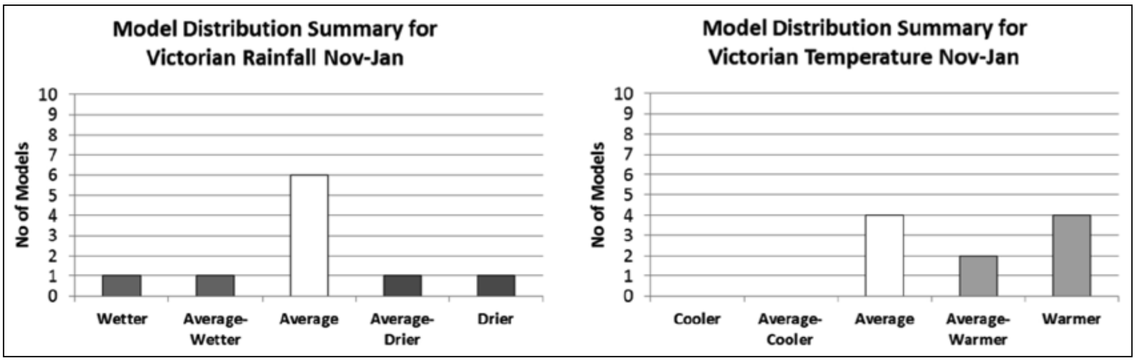

Figure 7. November to January rainfall and temperature predictions for VIC from 11 models run in July.

between an average to drier spring and average to warmer temperatures. Predictions for summer started to be haphazard, with models indicating that temperatures were likely to be average to warmer (Figures 6 and 7).

'September maketh the crop', however it was largely disappointing, particularly north of the Great Dividing Range, which only received approximately 5mm to25mm of rainfall. The southern areas once again received more rainfall than the rest of the state. In addition, the SAM in September went strongly positive dragging fronts and lows south, which was clearly obvious in the north. Soil water use was very high through September, with most crops surviving on moisture from the previous year.

Rainfall in October was average or below average for the state, with most areas receiving 10mm to 25mm. August to October was close to average in most cropping districts and slightly drier in the centre of the state (Figure 8).

During October to November, there were some severe frosts, particularly in early November, which is quite late for frost occurrence on average. In addition, the topsoils were very dry. Rain fell in November and December (with a decile 8 to 9 of 25mm to 50mm). This was too late for most crops and significantly affected the grain quality of the later harvested cereals. What happened here?

The STR did not settle at its 'normal' southern Melbourne position and continued moving down to Tasmania. This, combined with lower pressure at Darwin and the onset of a weak La Niña, allowed for easy moisture troughing down from the tropics. The lower position of the highs also allowed colder air to come from Antarctica as the start of the highs drifted over VIC with SW winds.

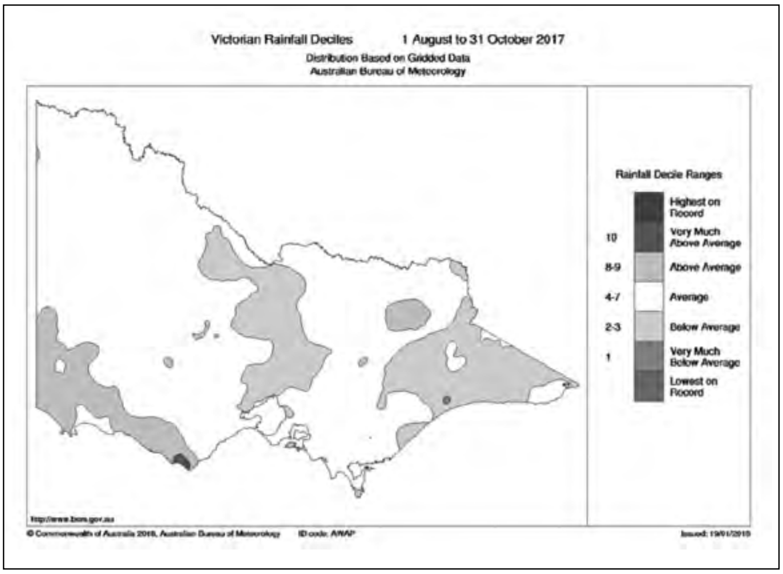

Figure 8. Decile rainfall distribution for August to October 2017 across VIC (Source: Bureau of Meteorology).

Conclusion

2017 was a confusing and frustrating year for many climate related reasons. While the early predictions of El Niño failed to come to fruition, half the models were consistently suggesting a drier trend to the season, which did eventuate. This shows that modern computer models can assess other factors, such as the SAM and STR, and not just the EL Niño – Southern Oscillation (ENSO) when making predictions.

A history of model watching over 10 years suggests that when half the models indicate something different than average for spring, it usually occurs. If not for the stored soil moisture and the good April rain, VIC would have experienced a similar weather scenario to SA or SNSW.

Useful resources

Subscribe to The Break newsletters, email; the.break@ecodev.vic.gov.au

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Fungicide resistance — recent discoveries pave way to better understanding the resistance mechanisms

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$^{\Phi}$Extra technical comment by Protech Consulting Pty Ltd

GRDC project code: CUR00023

Keywords

- fungicide resistance, fungal disease, mutations, DMI, SDHI, resistance mechanism, monitoring, net form of net blotch, spot form of net blotch, barley powdery mildew, wheat powdery mildew.

Take home messages

- Un-strategic use of fungicides and poor disease management practices have an impact on the entire Australian grains industry.
- Un-strategic use of fungicides with the same mode of action will speed up the development of resistance.
- The development of fungicide resistance can be limited by using the lowest doses that gives good control of fungal disease, appropriate mode of action (MOA) rotations, clean seeds and resistant varieties.
- Fast (and cost effective) monitoring of fungal pathogen populations is central for the sustainable management of diseases with fungicides.

Note: Reference to a fungicide in this paper does not constitute a recommendation for control of a specific disease.

Background

Fungicides have been in the forefront of control of fungal pathogens of humans, animals and plants for nearly 40 years. The direct consequence of the undeniable success of fungicides in controlling diseases has been the rise of fungicide resistance due to continuous exposure of fungal populations to these compounds. Fungicide resistance is now common around the world and has become a serious problem in agricultural systems.

The widespread adoption of the use of multiple fungicide treatments to control disease in Australian agriculture did not begin in earnest until about 15 years ago. Many first generation fungicide patents had expired so the products were cost effective enough to become economically rational options for disease control.

One consequence was that a small number of actives from a single mode of action (MOA) group – the DeMethylation Inhibitors (DMIs) or Group 3 fungicides — dominated the market.

It is widely accepted that the risk of fungicide resistance is greatest in pathogens with short latent periods, with high levels of virulence against prevalent varieties and when fungicides with a single MOA are used. These conditions are often met in Australian crops where most diseases have short or very short latent periods, the levels of virulence against some commonly used varieties are high, and fungicides from the same MOA are regularly applied during the growing season. Under this scenario, it is not surprising to find several diseases with high levels of resistance to fungicides, especially from the groups 3 (DMI) and 11 (Quinone outside inhibitors (QoI)). So far, six cases of fungicide resistance and four cases of reduced sensitivity (resistance does not reach the level of field failure) have been identified in Australia in the past five years (Table 1).

Table 1. Fungicide resistance cases identified in Australia during the period 2012-2017.

Disease	Fungicide Group
Barley powdery mildew[a]	Group 3 (DMI)
Wheat powdery mildew[a]	Groups 3* and 11 (QoI)
Barley net form of net blotch[a]	Group 3*
Barley spot form of net blotch[b]	Group 3
Canola blackleg[a]	Groups 2 (MAP-Kinase) and 3*
Wheat septoria leaf blotch[a]	Group 3*
Chocolate spot[a]	Group 1 (MBC)
Ascochyta blight[a]	Group 1

[a] Identified between 2012-2016; [b] Identified in 2017;
**Reduced sensitivity that does not reach the level of field failure*

The 2009 to 2012 epidemic of highly virulent and tebuconazole-resistant barley powdery mildew (Bgh) in WA was estimated to have caused at least an average of $100 million loss p.a. The lesson learnt from that episode was the need to be prepared in order to avoid and/or mitigate similar situations in the future. Here we present the most recent discoveries of fungicide resistance and use the data obtained from the analysis of different resistance mechanisms to address the development of new and more effective anti-resistance management strategies.

Method

Fungal samples and in vitro fungicide resistance analysis

One hundred and twelve samples of spot form of net blotch (SFNB) were collected by a combination of especially designed bait trials and a network of collaborators from farms and trials during the 2016 and 2017 growing seasons. Bait trials sown with the SFNB susceptible varieties Stirling and RGT PlanetⒹ were designed to work as a fungicide resistance early warning system. Plots of 2m x 4m were sprayed with either 1× or 2× the maximum registered dose of fungicides from the Groups 3 (DMI), 11 (QoI) and 7 (Succinate dehydrogenase inhibitor (SDHI)), at growth stages GS31 and GS39. Treatments were replicated three times. Leaf samples from bait trials were collected seven days following to the second spray application.

Samples were processed in the laboratory and 20 SFNB pure fungal isolates established following the isolation procedure described by Mair et al. (2016). A set of fungicide discriminatory concentrations was established based on previous analysis of their sensitivity baselines to different fungicides (tebuconazole = 10µg/mL; epoxiconazole = 5µg/mL; boscalid[Φ] = 10µg/mL; azoxystrobin = 5µg/mL). Isolates able to grow above those concentrations were considered to be resistant in vitro. Growth of the isolates at these discriminatory doses does not necessarily imply a field failure. Further studies are needed.

[Φ] This active is not registered for the control of SFNB

Molecular analysis of known fungicide resistance

Isolates able to grow above discriminatory concentrations were subjected to digital polymerase chain reaction (dPCR) analysis for the detection of the previously discovered fungicide resistance mutation F489L. This mutation, which affects the Group 3 fungicides target site only, was reported in 2013 to 2016 in net form of net blotch (NFNB) in some areas of WA. In addition to the isolate analysis, samples from field surveys are currently being investigated for the presence of resistance using this same methodology.

Characterisation of fungicide resistance in SFNB

SFNB isolates that grew above Group 3 discriminatory doses were subjected to further molecular characterisation. The Group 3 fungicide target site was sequenced in order to determine if mutations of any kind were associated with the resistance levels detected.

In addition, the expression level of the target gene of the resistant isolates was compared with that of the wild types. Sensitive isolate U7 and resistant 16FRG073 were cultured in Fries2 liquid media amended with tebuconazole at a concentration that inhibits the growth of each isolate by 50% , also known as effective concentration 50 (EC50; Mair et al. 2016).

A dPCR detection methodology was developed for the detection of mutations in SFNB resistant to some Group 3 fungicides.

Results and discussion

Discovery of resistance to Group 3 fungicides (DMI) in SFNB

The analysis of the samples collected during the 2016 and 2017 (analysis of sample still in progress at time of writing) growing seasons has revealed the existence of some Group 3 SFNB resistant populations in the southern region of WA.

Table 2. Effective concentration 50 (EC50) and resistance factors of Group 3 resistant isolate 16FRG073 (Esperance), sensitive isolate U7 and the mean of 20 sensitive SFNB isolates collected between 1996-2013. Cultures were grown at different concentration ranges of the fungicides tebuconazole, epoxiconazole and prothioconazole.

Isolates	Tebuconazole	Epoxiconazole	Prothioconazole
Mean (1996-2013)	0.31	0.17	0.07
U7 (wild type)	0.24	0.32	0.09
16FRG073	2.57	1.29	0.34
Resistance Factor	8.3	7.7	5.1

Case 1: Esperance, WA

The analysis of a sample collected near Esperance in late 2016 using a discriminatory concentration test showed high levels of resistance to the Group 3 fungicide tebuconazole. Further *in vitro* characterisation of isolates from this sample revealed the existence of an isolate named 16FRG073 that showed high levels of resistance to tebuconazole and epoxiconazole, (resistance factors RF = 8.3 and 7.7, respectively) and lower to prothioconazole (RF = 5.1) (Table 2).

The analysis of the fungicide target site did not identify any mutations that could be associated with resistance. However, when the genetic region that regulates the production of the target was investigated, an insertion was observed in the resistant isolate compared to the wild type. Similar insertions have been previously correlated with increased levels of the target in other plant fungal pathogens (Ishii and Hollomon, 2015; Figure 1).

The expression of the Group 3 target in the solvent control cultures was more than 2500 higher in 16FRG073 than in U7 (p=.001, Mann-Whitney U=72). Production of the Group 3 target in the cultures under tebuconazole EC50 treatment was 22-fold higher in 16FRG073 than in U7 (p < .001, U=576). These results reveal two important elements of this resistance — i) the resistant isolate has a higher production of the fungicide target (i.e. more target available for the fungicide molecules) even in the absence of the fungicide, and ii) the presence of the fungicide increases further the production of the target.

The implications of this type of resistance for the management of SFNB are important since a higher production of the fungicide target has the potential to affect all actives within the Group 3 chemistry, which will be perceived as a progressive decline of the fungicide activity. This means that the overuse of Group 3 fungicides for the control of SFNB will contribute to the increase of resistance through time and will jeopardise the current effectiveness of existing Group 3 compounds, such as prothioconazole, which has good activity against current resistant populations.

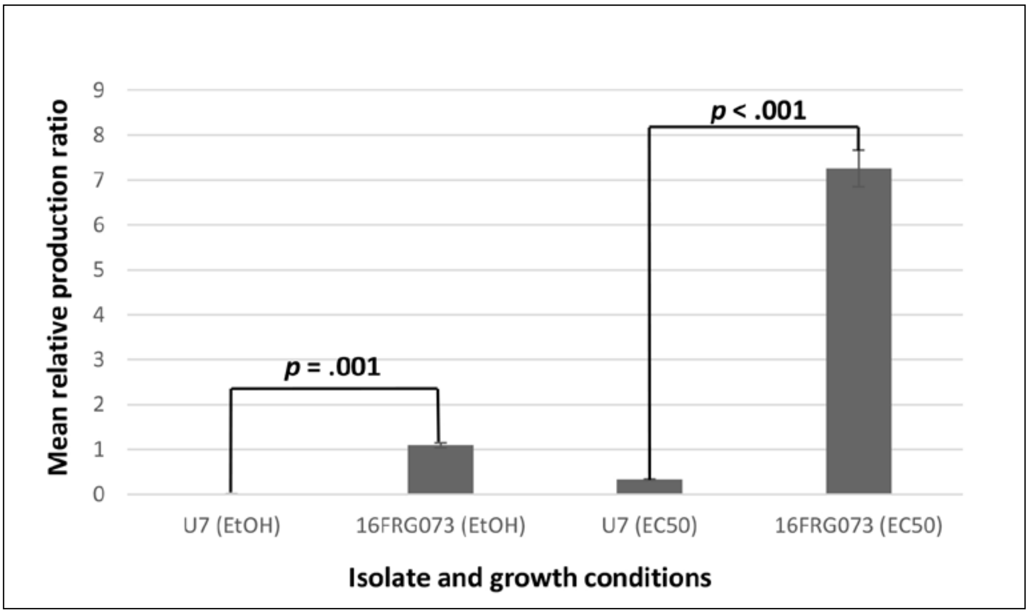

Figure 1. Mean relative production ratio of a number of different isolates.

Case 2: South Stirling, WA

In late 2017, researchers from the Department of Primary Industries and Regional Development (DPIRD) collected SFNB samples from a crop in South Stirling with significant levels of disease after five consecutive fungicide applications (tebuconazole as seed dressing at 400mL/100kg seed, propiconazole at 325mL/ha at Z25, cyproconazole + azoxystrobin at 400mL/ha at Z31, epoxiconazole at 250mL/ha at Z39 and propiconazole at 500mL/ha at Z52). The in vitro analysis of the samples using a discriminatory concentration test showed the same pattern found in the case of the samples collected from Esperance (Table 3).

The analysis of the genetic region that regulates the expression of the Group 3 fungicide target indicated that there was an insertion very similar to that found in the isolates collected from Esperance. Although the analysis is not complete yet, it is expected that the level of target expression in the South Stirling samples containing this gene alteration will be similar to that of the resistant samples collected from Albany.

The analysis of the fungicide target revealed a mutation, F489L, which was previously reported to occur in NFNB isolates resistant to Group 3 fungicides (Mair et al. 2016). It is still unclear as to whether this mutation has originated independently in both species due to fungicide selection pressure or it has been transferred from NFNB to SFNB during a hybridisation event (McLean et al. 2014).

What have we learnt from the analysis of SFNB resistance?

The characterisation of SFNB resistance to Group 3 fungicides has improved our understanding on how fungicide resistance develops develops with selection pressure from fungicide use. While in net form net blotch (NFNB) there seems to exist only one mechanism of resistance to Group 3 fungicides that has spread across the WA wheatbelt, in the case of SFNB the resistance found is due to two different mechanisms — an insertion in the genetic region that controls expression of the target, and the combination of a similar insertion and a mutation in the target of the fungicide. The presence of the two different insertions in SFNB increases the expression of the fungicide target with the result that more molecules of fungicides are required to inhibit fungal growth. The second mechanism found the mutation F489L contributes to modifying the binding affinity of the fungicide target, hence making the interaction between the target and the fungicides less effective. The combination of these two mechanisms provides SFNB with a clear advantage when the majority of fungicides used for its control are from the Group 3 chemistry.

However, there is also some good news. Thanks to the understanding that we now have on the mechanisms underlying this resistance, new tools can be developed for the fast, accurate and affordable detection of resistance in field samples. Based on the knowledge already available on mutation F489L (Mair et al. 2016) and the findings reported here, a digital PCR test has been developed that accurately detects and quantifies resistance in SFNB (Figure 2). This test uses highly specific molecular probes that detect the presence of the genetic changes associated with resistance directly in the plant material. This means that now there is no need to purify samples in the laboratory to obtain pure fungal cultures, which substantially reduces turnaround time and cost of analysis.
In addition to this, the presence of the resistant pathogen can be accurately quantified as shown in Table 4. The advantage of this technique is that it provides growers with the possibility of adjusting their spraying regimes shortly after a disease sample has been submitted for analysis.

Table 3. Fungicide sensitivity profile of Group 3 resistant isolates 16FRG073 (Esperance) and 17FRG089 (South Stirling), and sensitive isolate U7 when grown on agar plates amended with specific fungicide discriminatory concentrations.

Isolate	No Fungicide (Control)			Tebuconazole (10µg/mL)			Epoxiconazole (5µg/mL)			Boscalid (10µg/mL)			Azoxystrobin (5µg/mL)		
16FRG073	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
17FRG089	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
U7	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-

+ = Growth on agar plate; - = No growth. Scored at 48 hrs pi (boscalid and azoxystrobin); 96 hrs pi (tebuconazole and epoxiconazole).

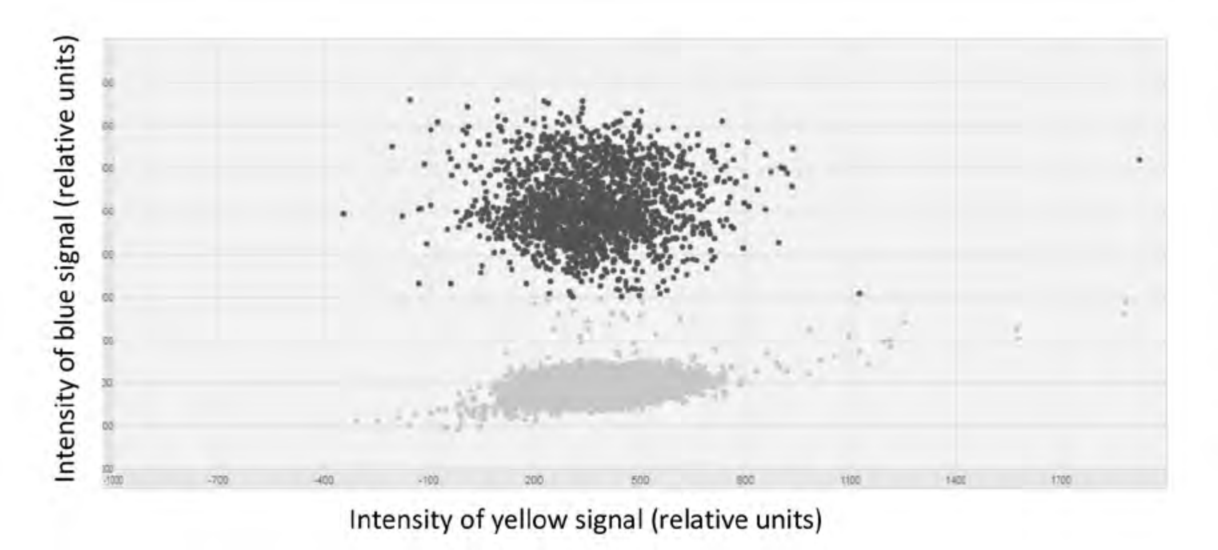

Figure 2. Scatter plots of a field sample depicting the detection of one of the two insertions in the genetic region that controls the Group 3 fungicide target production. Individual isolates with the insertion (resistant) are represented by blue signals (top cluster of dots), while sensitive isolates without the insertion are represented by yellow signals (bottom cluster of dots).

Table 4. ADigital PCR analysis of SFNB samples collected in the Esperance region (WA) indicating percentage of resistant isolates in each of the samples analysed. Lower detection threshold was established at 0.1%.

Sample	Wild type control	B003	B013	B002	B010	B012	B008	EDRS	Mutant control
% Resistant	<0.1%	<0.1%	<0.1%	<0.1%	0.349%	0.591%	1.973%	23.728%	99.991%

Conclusion

Many growers will experience a disappointing result with a commercial fungicide application at some stage. This could be due to application technique; the conditions were not ideal for spraying, or the product, while following the product label, was not appropriate for the situation (diseases present, level of infection and/or crop grow stage). Or it could be due to the build-up of resistance in the fungal pathogen population. The key issue is how growers respond to such a situation of failed disease control. Spraying again with a different fungicide may control the disease or it may make the resistance problem worse, especially if the second fungicide application is the same MOA. Sometimes simply changing the fungicide product does not help the situation because actives used in different products are often the same. For this reason it is very important to clearly identify the active being used and the MOA it belongs to (commonly Groups 3, 7 and 11). Understanding how fungicide resistance occurs will enable us to minimise the impact and delay the worst effects.

Since resistance to some Group 3 fungicides was found in NFNB in 2013, there has been a debate about the development of resistance in SFNB. It has now been confirmed that resistance to Group 3 fungicides has developed in the south of WA and that there are two different mechanisms responsible for this. Growers need to be cautious about SFNB control and implement adequate integrated disease management strategies to minimise the ongoing selection of SFNB resistant populations. Being a stubble borne disease, rotating crops is paramount for reducing disease carryover, the same as using disease resistant varieties.

These measures however, will not be very effective unless care is given to the choice of fungicide. Any spray program heavily dependent upon Group 3 fungicides will increase the selection of the resistant populations. The introduction of mixtures containing fungicides from different chemical groups (Groups 3, 7 and 11), in combination with the removal of tebuconazole and epoxiconazole from the control programs in those areas where resistance is found, will provide the best opportunity to limit the spread of the resistance in SFNB and its emergence in other barley growing regions of Australia.

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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.

The authors would also like to acknowledge the contribution of Department of Primary Industries and Regional Development (DPIRD, WA), The Foundation for Arable Research in Australia (FAR) and the grains industry.

Special thanks is extended to growers and grower groups submitting samples to the Fungicide Resistance Group (FRG) and contributing to our research.

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Notes

The effect of stubble on nitrogen tie-up and supply

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GRDC project codes: CSP186, CSP174, MSF0003, BWD00024

Keywords

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

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 1% to 6% of the N requirement of crops is derived from wheat stubble.
- Nitrogen tie-up by cereal residue is not just a problem following incorporation — it occurs in surface-retained and standing-stubble systems.
- Nitrogen tie-up in cropping soils is only a temporary constraint as the immobilised N will be released through microbial turnover, generally later in the crop season in spring.
- Management of tie-up is reasonably straightforward — supply more N (5kg N for each t/ha of cereal residue) and supply it early to avoid impacts of N tie-up on crop yield and protein.
- Deep-banding N can improve the N uptake, yield and protein of crops, especially in stubble-retained systems.

Background

In many Australian agricultural soils, carbon (C) availability is the most limiting constraint of microbial functions. Hence management of biologically available C is the key to improving biological functions including those involved in N mineralisation. Crop residues are one of the major sources of C for soil biota, therefore stubble retention can provide benefits through changes in soil physical, chemical and biological properties which influence C turnover, nutrient generation and subsequent availability of nutrients to crops. Although stubble retention benefits are expected to be realised in all soil types, the magnitude and nature of change in biological functions can vary depending on type and timing of stubble management and is influenced by soil type and environmental factors, such as rainfall.

Most dryland growers in Australia retain all, or most of their crop residues to protect the soil, retain soil moisture and maintain soil fertility in the long-term. However, a pro-active and flexible approach to stubble management that recognises and avoids situations in which stubble can reduce productivity or profitability makes sense, and has been promoted as part of the GRDC Stubble Initiative (Swan et al. 2017a). One such situation is where large amounts of retained stubble, especially high C:N ratio cereal stubble, 'ties-up' soil N leading to N deficiency in the growing crop that may reduce yield. The timing, extent and consequences of N tie-up are all driven by variable weather events (rainfall and temperature), as well as soil and stubble type, so quite different outcomes may occur from season to season and in different paddocks (Gupta, 2016). In this paper, we firstly review in simple terms the process of N tie-up (immobilisation) to understand the factors driving it. We then provide the results from a series of recent experiments in southern NSW and SA (both long-term and short-term) that serve to illustrate the process, and the ways in which

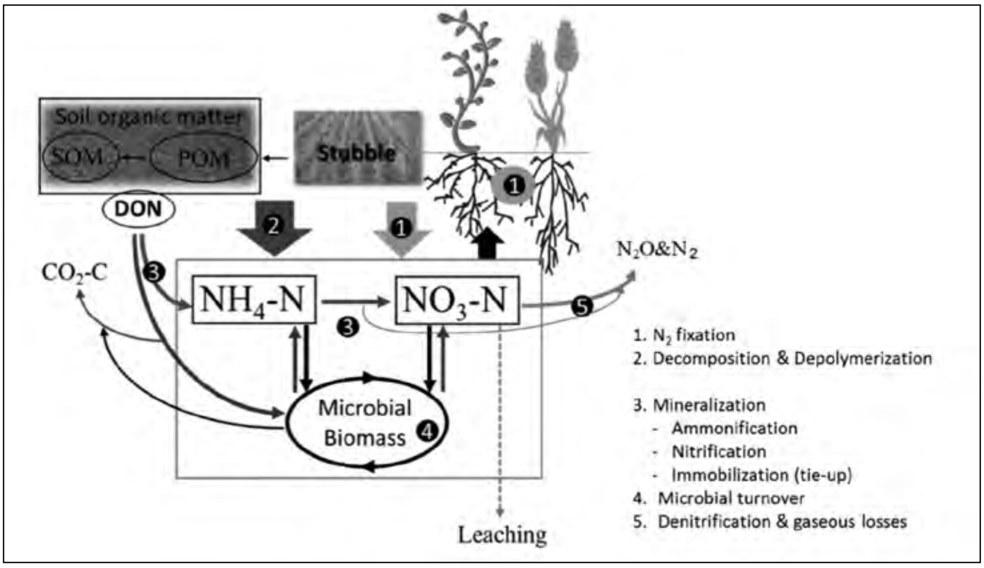

Figure 1. Biological processes involved in N cycling that influence plant available N levels in soil. SOM – soil organic matter, DON – dissolved organic nitrogen, POM – particulate organic matter (Gupta, 2016).

the negative consequences can be avoided while maintaining the benefits of stubble.

N cycling processes and controlling factors

Nitrogen mineralised from soil organic matter (SOM) and crop residues makes a substantial contribution (approximately 50%) to crop N uptake (Angus and Grace, 2017, Gupta, 2016). The rate and timing of N mineralisation regulate plant available mineral N levels in soils and the release of mineral N in soil is regulated by the processes associated with microbial turnover (Figure 1). Microbial activities are also responsible for the conversion of fertiliser N into plant available forms.

The process of N tie-up and release (N-immobilisation and supply)

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

Microbial biomass in soil

Soil microbial biomass (MB) is a store-house for nutrients. Changes in the amount of MB due to management and seasonal variation can exert a significant impact on microbial immobilisation and net N mineralisation. In Australian agricultural soils, MB-C accounts for 1.5% to 3.0% of soil organic C and MB-N 2% to 5% of total N. The amount of MB varies with soil type and agro-ecological region (Table 1) and is influenced by crop rotation, tillage and stubble management practices that influence microbial populations and the quantity and quality of residues. The MB-C:N ratio generally varies between 6.5 and 9.0 and a wide MB-C:N ratio is shown to be associated with cereal crop residues and rhizosphere soils. Due to the short turnover time of MB in Australian soils, it may only act as a short-term reservoir for nutrients and as a biocatalyst for SOM cycling and N release, in particular in-crop

N mineralisation. As microbial turnover and the associated N mineralisation-immobilisation balance is influenced by seasonal conditions, estimation of N supply potential at the beginning of a crop season should include the amount of N in MB and the N that can be mineralised from SOM and crop residues (Gupta 2016, McBeath et al. 2015a). In addition, management practices that increase the size of the MB pool and modulate its turnover could assist with the synchronisation of N mineralisation to crop demand. For example, higher N mineralisation after a legume crop is related to higher MB, whereas greater microbial turnover after canola also contributes to higher N mineralisation (Gupta, 2016).

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 5 April with 8t/ha of undecomposed standing wheat stubble from the previous crop after a dry summer. A 30mm storm wets the surface soil providing a sowing opportunity. Fearing the seeding equipment cannot handle the residue, but not wanting to lose the nutrients in the stubble by burning, the residue is mulched and incorporated into the soil. A canola crop is sown in mid-April with a small amount of N (to avoid seed burn) and further N application is delayed until buds are visible due to the dry subsoil.

So in this case, the cereal stubble (high C and low N — usually approximately 90:1) is well mixed through a warm, moist soil, giving the microbes maximum access to a big amount of C (energy),but not enough N (microbe bodies need a ratio of about 7:1). The microbes will need all of the available N in the stubble and the mineral N in the soil, and may even break down some existing organic N (humus) to obtain more N if they need it (so C is lost from the soil). The microbes will grow rapidly, so when the crop is sown, there will be little available mineral N - it is all 'tied-up' by the microbes as they grow their population on the new energy supply. Some of the microbes are dying as well, but for a time more are growing than dying, so there is 'net immobilisation'. As the soil cools down after sowing, the 'turnover' slows, and so is the time taken for more N to be released (mineralised) than consumed (immobilised) and net-mineralisation is delayed. Meanwhile, the relatively N-hungry canola crop is likely to become deficient in N as the rate of mineralisation in 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 these simple principles, it is 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 a lower C:N ratio and tie up less N.

Table 1. Amount of microbial biomass C and N supply and immobilisation potentials in the surface 0cm to 10cm of agricultural soils from the different cropping regions of Australia (Gupta 2016).

Location	Soil type	MB-C	N immobilisation potential[&]	N supply potential[$]
		kg C/ha	kg N/ha	
Rutherglen, VIC	Red brown earth	350 - 700	25 - 50	30 - 100
Horsham, VIC	Sandy loam	140 - 230	12 - 24	10 - 16
Horsham, VIC	Clay	546 - 819	39 - 59	52 - 72
Waikerie/Karoonda, SA	Sand and sandy loam	150 - 300	15 - 25	10 - 35
Streaky Bay, SA	Calcarosol - sandy loam	210 - 400	15 - 30	20 - 50
Minnipa, SA	Calcarosol - loam	560 - 710	40 - 51	42 - 56
Appila, SA	Loam	450 - 585	32 - 42	35 - 45
Leeton/Warialda, NSW	Clay	350 - 1000	25 - 60	25 - 75
Condobolin, NSW	Sandy loam	240 - 585	17 - 42	20 - 45
Kerrabee, NSW	Loam	420 - 525	30 - 40	35 - 50
Temora, NSW	Red earth	525 - 735	35 - 55	50 - 100
Millewa, NSW	Sandy loam	150 - 310	11 - 22	14 - 31
Wongan Hills, WA	Loamy sand	250 - 350	18 - 25	25 - 40

[&] *N immobilisation potential is estimated assuming an average 50% increase of MB during a growing season.*

[$] *N supply potential is calculated from N in MB plus N mineralisation measured in a laboratory aerobic-incubation assay.*

(3) The stubble could be incorporated earlier (more time to move from immobilisation to mineralisation before the crop is sown).

(4) Nitrogen could be added during incorporation (to satisfy the microbes and speed up the 'turnover').

(5) More N could be added with the following 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 (CSP187, CSP00174, MSF 00003, BWD00024), we have been investigating the dynamics of N in stubble-retained systems. Here we provide examples from recent GRDC-funded experiments in southern NSW, VIC and SA, and discuss the evidence for the impact of immobilisation and provide some practical tips to avoid the risks of N tie-up.

Cereal stubble is not a major source of N for crops – tracing N from previous cereal crop stubble

Studies at three sites in southern Australia (Temora, Horsham and Karoonda) have tracked the fate of N in wheat 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 Horsham (Figure 2), of the 32kg/ha of N contained in 4t/ha of wheat residue retained in 2014, only 0.85kg/ha N (2.5%) was taken up by the first crop (representing 3% of crop requirement) and 3.5kg/ha N (11%) was taken up by the second wheat crop (2.5% of crop requirement).

The majority of the N after two years remained in the SOM pool (13kg N/ha or 40%) and some remained as undecomposed stubble (20% or 6kg

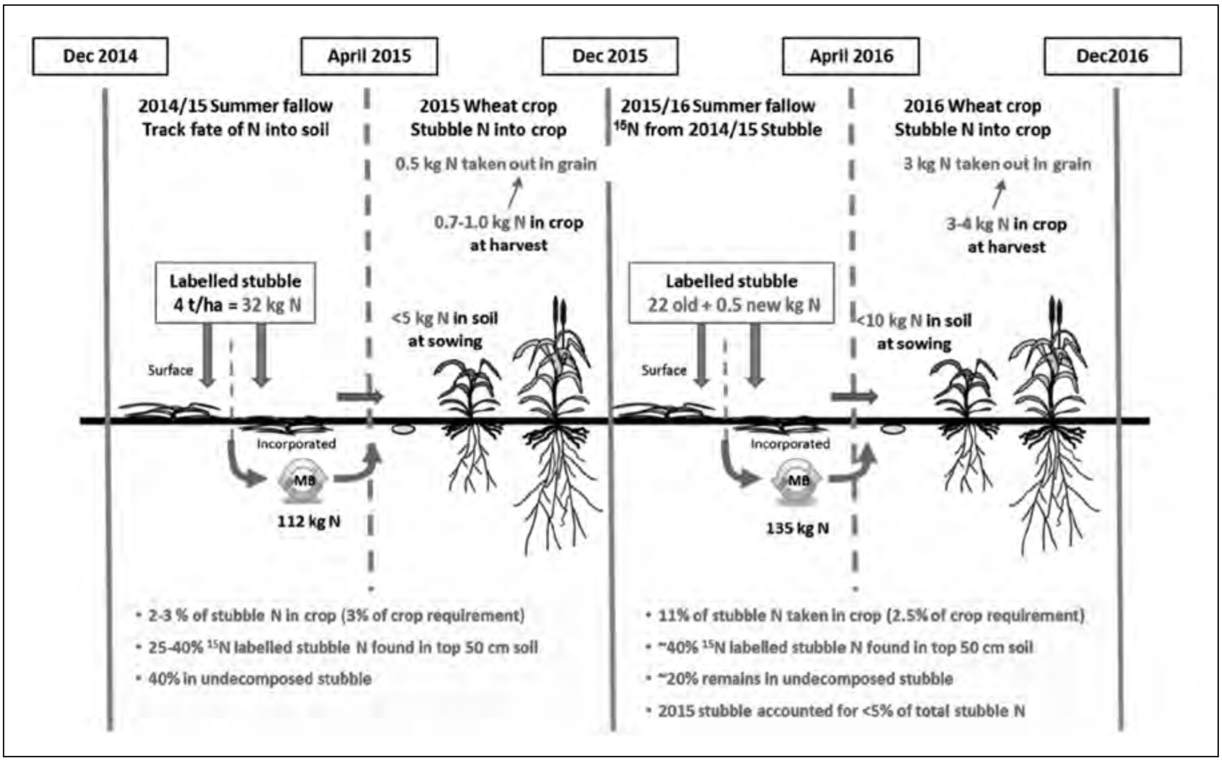

Figure 2. The fate of the N contained in retained wheat stubble over two years in successive wheat crops following the addition of 4t/ha of wheat stubble containing 32kg/ha N. The successive crops took up 2.5% (0.7-1kg N/ha) and 11% (3.5kg N/ha) of the N derived from the original stubble representing only 3% and 2.5% of the crop's requirements. Most of the stubble N remained in the soil (approximately 40%) or was lost (26%). MB – total amount of N (kg/ha) in the microbial biomass in the surface 10cm soil.

N/ha). Thus we can account for approx. 74% of the original stubble N in crop (6%), soil (40%) and stubble (20%) with 26% unaccounted (lost below 50cm and/or denitrified). In similar work carried out in the UK which persisted for four years, crop uptake was 6.6%, 3.5%, 2.2% and 2.2% over the four years (total of 14.5%), 55% remained in the soil to 70cm, and 29% was lost from the system (Hart et al. 1993). The main point is that the N in cereal stubble represented only 2.8% of crop requirements over two years (3% Year 1, 2.5% Year 2) and takes some time to be released through the organic pool into available forms and losses can occur during the process. Similarly, N in cereal stubble represented only 6% and 1.1% of crop requirements over two years at Temora (7.6% Year 1, 4.4% Year 2) and Karoonda (1.2% Year 1, 1.0% Year 2), respectively.

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

Harden long-term site

In a long-term study at Harden (28 years), the average wheat yield has been reduced by 0.3t/ha in stubble retained vs stubble burnt treatments, but the negative impacts of stubble were greater in wetter seasons (Figure 3). Nitrogen tie-up may be implicated in wetter years, due to higher crop demand for N and increased losses due to leaching or denitrification. However, significant differences in the starting soil mineral N pre-sowing were rarely found. For many years, we were not convinced N tie-up was an issue (though there were insufficient measurements to confirm it).

In 2017, two different experiments in sub-plots at Harden were implemented to investigate the potential role of N tie-up in the growth and yield penalties associated with stubble. A crop of wheat (cv. Scepter$^{(b)}$) 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 the 100kg N/ha surface applied with 100kg/N deep-banded below the seed. The pre-sowing N to 1.6m was 166kg N/ha in retained and 191kg N/ha in burnt, but was not significantly different.

Deep-banding the N fertiliser had no impact on crop biomass or N% at GS30, but increased both the biomass and N content of the tissue at anthesis, more in the stubble retained than in burnt stubble (Table 2). Retaining stubble decreased biomass overall, but not tissue N. Nitrogen uptake (kg/ha) at anthesis was significantly increased by deep-banding in both stubble treatments, however the increase was substantially higher in the stubble-retained treatment than in the burnt treatment (38kg N/ha compared with 15kg N/ha). The overall impact of deep-banding on yield persisted at harvest, but there was neither effect nor interaction with stubble retention, presumably due to other interactions with water availability. However, the fact that deep-banding N has had a bigger impact in the stubble-retained treatment provides evidence of an N-related growth limitation related to retained stubble. Its appearance at anthesis, and not earlier, presumably reflects the high starting soil N levels which were adequate to support early growth, but the cold dry winter generated N deficiencies as the crop entered the rapid stem elongation phase. The

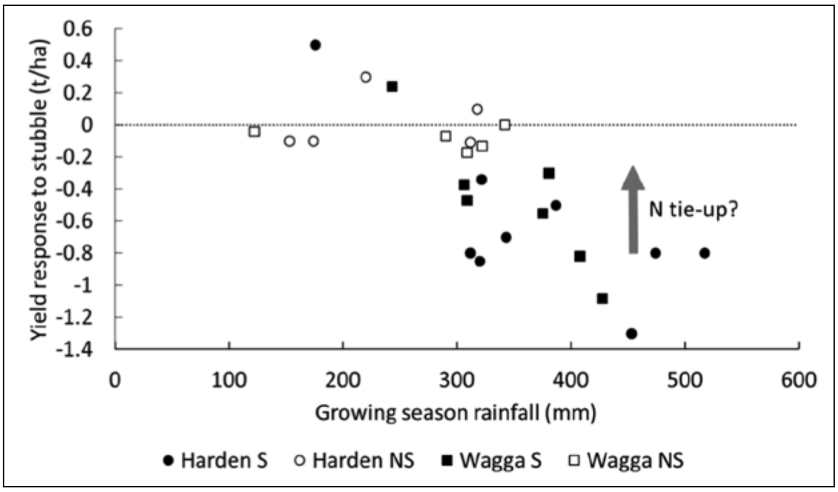

Figure 3. Effect of retained stubble on wheat yield is worse in wetter seasons at the Harden (circles) and Wagga Wagga (squares) long-term tillage sites. Open symbols where difference between retain and burnt was not significant (NS), solid where significant (S).

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

increased protein content related to both burning and deep-banding and its independence from yield suggest an N deficiency effect throughout the growing season generated by stubble retention.

Temora site

At Temora, a nine year experiment managed using no-till, controlled traffic, inter-row sowing (spear-point/press-wheels on 305mm spacing) in a canola-wheat-wheat system investigated the effects of stubble burning and stubble grazing on soil water, N and crop growth (Hunt et al. 2016). In the stubble-retained treatment, stubble was left standing through summer, and fallow weeds were strictly controlled. Stubble was burnt in mid-late March and the crop sown each year in mid-late April. Nitrogen was managed using annual pre-sowing soil tests, whereby 5kg/ha N was applied at sowing and N was top-dressed at Z30 to attain 70% of maximum yield potential according to Yield Prophet® (Swan et al. 2017).

Burning

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

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 4). However, we believe the level of N loss due to waterlogging in the wet winter and the significant overall N

Table 3. Effect of stubble burning on grain yields at Temora in Phase 1 and Phase 2. Crops in italics are canola and bold are the second 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. Effect of deep banding vs surface applied N (122kg N/ha as urea) at seeding at Temora NSW in 2016 (starting soil N, 58kg/ha). The crop captured more N early in the season which increased biomass and yield in a very wet season (data mean of three stubble treatments). *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*

deficiency may have masked these effects, which were more obvious at Harden in 2017.

Karoonda long-term site

At Karoonda, five years of experiments on a dune-swale soil system (at Lowaldie, north east of Karoonda, SA), in a no-till stubble retained continuous cropping system, the application of all the N fertiliser at seeding time has consistently produced the highest cereal crop yields (on average 4% to 10%) demonstrating the importance of early N fertiliser in these soils where immobilisation is likely to be proportionally more important (Table 5). Continuous wheat crops were sown in May of 2010 to 2014 (following opening rains of at least 20mm with fertiliser treatments of (i) nil fertiliser inputs, (ii) low fertiliser inputs (9kg N/ha at sowing), (iii) higher N inputs at sowing (40kg N/ha with 10kg P/ha), and (iv) higher N inputs split (9kg N/ha at sowing and 31kg N/ha first node with 10kg P/ha at sowing). The N inputs split treatment received the second application of N at an earlier stage in 2013 and 2014, applied at early tillering. There was a notable absence of significant response to the management strategies imposed over the five years of experimentation on the swale soil (including a lack of difference between nil and plus N fertiliser — data not shown) (Table 5). The difference between supplying extra N in fertiliser at sowing compared with in-season was less consistent, especially on the swale. In general, the best yields were achieved with the extra fertiliser N applied at sowing and in some instances, there was a penalty for delaying to an in-season application (Table 5). The season type did not appear to drive the effectiveness of the in-season N application and in all cases, the in-season N was applied with impending rainfall. Generally, sandy soils with lower organic matter have lower N supply potential, hence the imbalance between mineralisation to immobilisation plays an important role in early season N nutrition of a cereal crop.

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 is 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, especially during the early crop growth period. At the Horsham site, based on the amount of MB, an 8t/ha stubble load could cause 40kg to 60kg N/ha of N tie-up depending upon seasonal conditions.

Conclusions

In stubble-retained systems, cereal stubble contributes only a small percentage (1% to 6%) of the N requirement for a following cereal crop, hence it should mainly be considered as a source of C for soil microorganisms. Our studies have confirmed a risk of N tie-up by surface-retained and standing cereal residues which may occur in-season, in addition to during the summer fallow, and so may not be picked up in pre-sowing soil mineral N measurements. Yield penalties from retained residues, especially to successive cereal crops,

Table 5. Wheat yield (t/ha) in response to time of fertiliser application and season (2010-2014) on different soil types in a dune-swale system in the Mallee region of SA (McBeath et al. 2015b).

Fertiliser Treatment	2010	2011	2012	2013	2014	Average
Swale						
High N upfront	4.3	3.4	3.2	1.3	3.0	3.04 (4.1%*)
High N split	4.0	3.3	2.9	1.4	3.0	2.8
Mid-slope						
High N upfront	3.2	3.8	2.4	1.8	3.5	2.94 (7.3%)
High N split	3.1	3.6	1.7	1.8	3.5	2.74
Dune						
High N upfront	2.0	2.9	1.5	1.6	2.1	2.02 (9.8%)
High N split	2.0	2.5	1.3	1.6	1.8	1.84

*Note: Within a season and soil, yield values in response to fertiliser strategies that are significantly different ($P < 0.05$) are shown in bold. * Values in brackets indicate percentage higher than 'High N split' application.*

could be reduced by reducing the stubble load or by applying more N (approximately 5kg N per t/ha of cereal residue) and applying it earlier to the following crop. However, it is important to note that stubble provides the much needed C source to soil microorganisms in Australian agricultural soils. Deep placement of the N improved N capture by crops irrespective of stubble management, but was especially effective in stubble-retained situations. Although N tie-up is a temporary issue, it could be potentially costly as early N supply is important for plant nutrition and health. 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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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. We would especially like to thank Darryl Moore (Horsham), the Coleman family (Temora), the O'Connor family (Harden) and the Loller family (Karoonda) for the long-term use of their land for these experiments. We also acknowledge the expert technical assistance provided by CSIRO staff (Steve Szarvas, Stasia Kroker, Bill Davoren, Willie Shoobridge, Brad Rheinheimer, Mel Bullock, John Graham), BCG staff (Claire Browne) and FarmLink Research (Paul Breust, Tony Pratt, Colin Fritsch) who managed and measured the experiments. Funding was provided through GRDC projects CSP00174, CSP00186, MSF00003, BWD00024 and CSP00186.

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Blackleg in canola - an update on resistance, Upper Canopy Infection and a new management App

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GRDC project codes: UM00051, MGP004, CSP00187, DAW0028

Keywords

- canola, phenology, flowering time, fungicide, disease control, resistance, Upper Canopy Infection (UCI).

Take home messages

- In 2017, blackleg leaf infection and resultant crown canker severity was low due to dry conditions in May and June during early seedling growth. Susceptible cultivars still had some level of disease but were well protected by fungicides applied at sowing which were highly effective due to the lower disease pressure. Application of foliar fungicides at the 4 to 6 leaf stage was generally not warranted.
- Upper Canopy Infection (UCI) is the collective term for blackleg flower, peduncle, pod, main stem and branch infection but does not include leaf lesions or crown canker.
- In 2016 and 2017, UCI caused large yield loss (up to 1t/ha) but the prevalent symptoms varied between years: pod lesions in 2016, stem and branch lesions in 2017.
- Delayed flowering after mid-August reduced severity of UCI in medium rainfall environments. Although flowering time is one important factor in the development of UCI, seasonal conditions relating to spore development and release, as well as infection events interact to produce UCI. Further research is required to understand and predict these interactions.
- Effective major gene resistance provides control of pod, branch and stem infection. Fungicides also control UCI however, further research is required to determine robust recommendations for foliar fungicide timing and determining the economic returns.
- The Blackleg Management App ('BlacklegCM' due for release February/March 2018) has been developed to provide growers and advisers with an interactive interface to explore the economic outcomes of different blackleg management strategies and their relative importance.

Blackleg resistance

There are two types of blackleg resistance genes in Australian canola cultivars; major and minor resistance genes. Major resistance genes stop the fungus from infecting the plant which results in complete protection against the blackleg pathogen. This is evidenced in the field by lack of leaf lesions and crown canker. A cultivar can have none, one or multiple major resistance genes. In Australia, all commercial canola cultivars are classified into Resistance Groups which describe the major genes present in the cultivar. For example, Group A cultivars have a single major resistance gene, Group ABDF cultivars have four major resistance genes. Blackleg is rapidly able to change and major gene resistance imposes strong selection for only those isolates of blackleg able to infect the plant. Therefore, major resistance genes can be overcome quickly in the field so cultivars dependant on major resistance genes tend to become more susceptible over time, sometimes becoming completely ineffective in as little as three years. Minor gene resistance (sometimes called quantitative, adult plant or crown canker resistance) reduces the severity of crown canker but does not inhibit leaf lesions and upper canopy infection. As the name suggests, each gene provides a minor level of crown canker resistance. However, the combined effect of a number of minor genes in the same cultivar can create very high levels of crown canker resistance. As blackleg is able to infect plants with minor gene resistance, selection of isolates able to overcome these genes isn't as strong, and therefore, can be robust for many years. At present, there is no rapid screening technique such as that used for major resistance genes, to identify the presence of minor resistance genes in cultivars. The Blackleg Rating classifies cultivars according to their overall level of resistance and includes both major and minor gene resistance. As major resistance genes inhibit infection of the plant, it is not until this resistance is overcome that it is then possible to determine the presence of minor resistance genes.

It is important to know the Resistance Group and also the Blackleg Rating when selecting a cultivar. In the field, cultivars with effective (not yet overcome) major gene resistance will be completely protected (no leaf lesions, crown canker or upper canopy infection). Crops with major gene resistance that has been overcome will be susceptible to leaf lesions and UCI but may still be resistant, or partially resistant to crown canker if minor resistance genes are present in the cultivar in combination with major resistance genes. An example of various levels of minor gene resistance is ATR Bonito$^{\phi}$ and ATR Mako$^{\phi}$. Both cultivars are in Resistance Group A, and therefore, have the same major resistance gene which in many locations has been overcome (Table 1). The Blackleg Rating of ATR Bonito$^{\phi}$ is moderately susceptible (MS) while ATR Mako$^{\phi}$ has a higher rating of moderately resistant (MR). As these cultivars are not completely susceptible to blackleg, this indicates that minor and major resistance genes are present in combination but ATR Mako$^{\phi}$ has better minor gene resistance.

In Australia, all cultivars classified in Resistance Group C have no effective major gene resistance and are therefore solely reliant on minor resistance genes with those with a higher Blackleg Rating more resistant to crown canker.

Periods of infection by blackleg for different plant parts

Blackleg is able to infect all parts of the canola plant. Figure 1 shows the relationship between the period of blackleg spore release and symptom development on different plant parts. Lesions form on leaves throughout the growing season however, severe crown canker is most likely to develop when plants are infected during the early seedling stage. The fungus grows from the cotyledons and leaves asymptomatically through the vascular tissues to the crown where it causes necrosis resulting in a crown canker at the base of the plant. Yield loss results from restricted water and nutrient uptake by the plant. Protection during the seedling stage is critical to reduce crown canker severity. Lesions can also develop on all other plant parts and these infections may go on to develop cankers as described further within this paper.

Winter is the main period in which conditions are generally most conducive for infection as rainfall triggers release of mature spores from crop residue and provides ideal conditions for the fungus to survive while it infects the crop (Figure 1). Once the plant has begun to flower, infection of flowers, peduncles, pods, main stem and branches of the plant has collectively been termed UCI (Figure 2). Any plant parts of susceptible cultivars exposed to spores during the winter period are likely to become infected and potentially cause yield loss. Upper canopy infection has become increasingly prevalent over recent years. Earlier flowering times and changes in farming systems with increased retention of stubble may contribute to higher disease severity. While the cost to yield and control of leaf lesions leading to crown canker is well understood, the factors contributing to UCI and possible control strategies are currently under investigation with current knowledge presented in this paper.

Blackleg crown canker in 2017 — seedling leaf lesions and crown canker severity

Crown cankers result from infection of plants while they are in the early seedling stage usually during May and June. Dry conditions in this period in 2017 resulted in generally low levels of leaf infection resulting in reduced crown canker severity. Predominant use of canola cultivars from the same resistance group (e.g. Group A resistance) in the same locality or region results in blackleg populations with a high frequency of isolates virulent towards that group. Since 2015, the Blackleg Rating of many of the Group A cultivars has fallen from MR to MS, indicating their increased

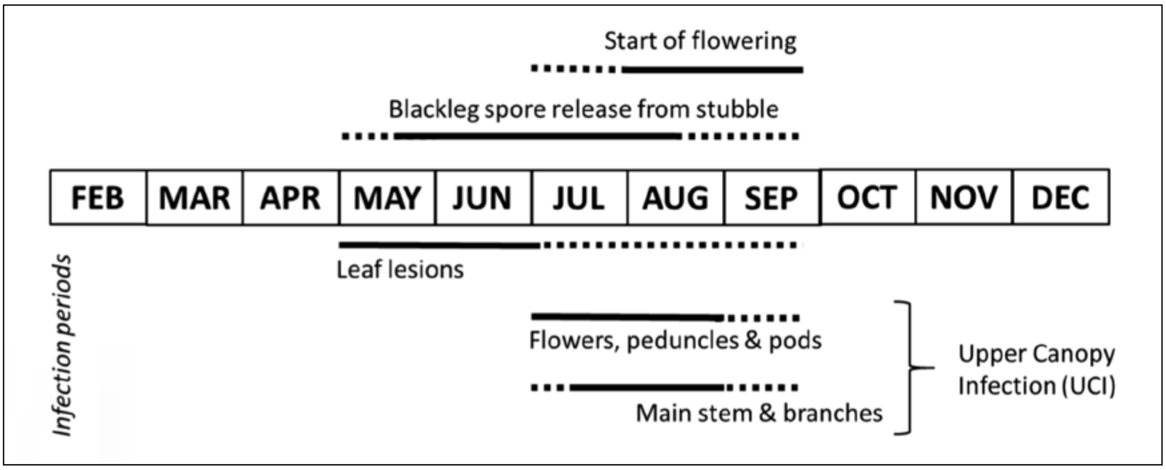

Figure 1. Periods of infection by blackleg for different parts of the canola plant in relation to the period of blackleg spore release and start of flowering in medium and high rainfall zones. Solid lines indicate main periods of infection and dashed lines indicate reduced risk from infection. For start of flowering, solid line indicates the optimal period in which yield is maximised while reducing disease risk.

susceptibility to disease. The severity of crown canker was assessed at 34 locations across the Australian canola-growing regions, and indicates the efficacy of different Resistance Groups (Table 1). Resistance Group H is not represented at these sites as winter cultivars are the only currently commercially available cultivars classified as Group H. At many locations, cultivars in multiple Resistance Groups had a high level of crown canker compared to the site mean. For example, Cootamundra in NSW had high levels of crown canker in Resistance Groups A, B, BF and AS. It should be noted that the cultivar used at these sites to represent Resistance Group C is ATR Stingray$^{\text{(}}$ which has a good level of minor gene resistance with a Blackleg Rating of MR and hence low levels of crown canker (see preceding comments for further discussion). Increased intensification of canola plantings in the past few years has resulted in large areas of canola stubble that can release blackleg spores with the potential to cause significant yield losses in years where spore release coincides with environmental conditions conducive to infection, such as those experienced in 2016. Despite the low disease pressure in 2017, leaf lesions were present in susceptible cultivars but were adequately controlled by fungicide treatments applied to seed or fertiliser at sowing, with foliar fungicide application generally unwarranted. In contrast, wet winter conditions in 2016 produced extreme levels of leaf lesions which warranted the application of foliar fungicides at the 4 to 6 leaf stage to extend the efficacy of seed and fertiliser treatments.

Upper canopy infection

The infection by blackleg of flowers, peduncles, pods, stems and branches is termed UCI. In 2010, cankers on the upper stems and branches were observed in commercial canola paddocks (Figure 2). These cankers appeared to cause yield loss as the pods on affected branches senesced prematurely leading to early pod shatter. Stem/branch cankers are not correlated with the presence of crown cankers. In 2011, 2012 and 2013 stem/branch cankers were observed each year but symptoms were not generally severe and were not present in all regions. In 2014 and 2015, the symptoms were widespread and appeared to cause substantial yield loss. In 2016, research commenced investigating the causes and management of UCI. In contrast to previous years, severe stem/branch infection was not present at most sites in 2016. Data from 2016 clearly showed that flowering during the winter period where conditions for blackleg infection are optimal, consistently resulted in increased UCI. The data also clearly showed that UCI caused large yield losses (data not presented within paper).

UCI yield loss

Field experiments conducted in 2016 and 2017 show that in the absence of sclerotinia or blackleg crown canker, UCI caused yield loss of up to 1t/ha in southern NSW compared to where disease was fully controlled (Figure 3). In both seasons, delaying the onset of flowering after mid-August reduced yield loss. However, in 2016 crops starting to flower in early August had minimal yield loss compared to those in 2017 that had 0.7t/ha yield

Table 1. Blackleg crown canker severity in cultivars from different Blackleg Resistance Groups at monitoring sites in 2017. Disease severity is indicated as high, moderate or low compared to the site average.

Monitoring site	Resistance Group							
	Group A	Group B	Group C	Group AD	Group ABD	Group ABDF	Group BF	Group AS
NSW								
Beckom	High	High	Low	Low	Low	Low	High	High
Bellata	Low	Low	Low	Low	Low	Low	Low	Low
Cootamundra	High	High	Low	Low	Low	Low	High	High
Cudal	High	High	Low	Low	Low	Low	Low	Low
Gerogery	Mod	High	Low	Low	Low	Low	High	High
Grenfell	High	High	Low	Low	Low	Low	Low	Low
Lockhart	High	High	Mod	Low	Low	Low	High	Mod
Mullaley	Low	High	Low	Low	Low	Low	High	Low
Parkes	High	High	Low	Low	Low	Low	Low	Low
Tamworth	High	High	Low	Low	Low		Mod	Low
Wagga Wagga	High	High	Low	Low	Low	Low	Mod	Low
SA								
Arthurton	High	Low	Low	Low	Low	Mod	High	High
Bordertown	High	Low	Mod	High	Mod	Mod	High	High
Cummins	Low	Low	Low	High	Low	Low	Low	Low
Frances	High	Low	Low	Mod	Low	Mod	High	High
Mt Hope	High	Low	Mod	Mod	Low	Mod	High	Mod
Riverton	High	Low	Low	High	Low	Low	Low	Low
Spalding	High	Low	Low	High	Mod	Low	Low	High
Turretfield	Mod	Low	Low	Mod	Low	Low	High	High
Wangary	High	Low	Low	Mod	Low	Low	High	Low
Yeelanna	High	Mod	Mod	Low	Low	Mod	High	Mod
VIC								
Charlton	Low	High	Low	Low	Low	Low	High	Low
Diggora	High	High	Low	Mod	Mod	Low	High	High
Cavendish	Low	Low	Low	Low	Low	Low	Low	Mod
Kaniva	Mod	High	Low	Low	Low	Low	High	Mod
Minyip	High	Mod	Low	Low	Low	Low	Mod	High
Streatham	Mod	High	Low	High	Low	Low	Low	High
Yarrawonga	High	High	Mod	Low	Low	Low	High	Mod
WA								
Corrigin	Mod	High	Low	Low	Low	Low	High	Mod
Gibson	High	Mod	Mod	Low	Low	Low	Mod	Mod
Katanning	Mod	High	Low	Low	Low	Low	High	Low
Kendenup	High	Low	Low	Low	High	High	Low	High
Kojonup	Low	High	Low	Low	Low	Low	High	Low
Williams	High	Mod	Low	Low	Low	Low	Mod	Mod

Figure 2. Upper canopy infection includes blackleg infection of flowers, peduncles, pods, main stems and branches.

loss. This data indicates that although flowering time is one factor important in the development of UCI, seasonal conditions will determine the prevalence and severity of UCI. Spore development and release, as well as infection events interact with crop development stage to produce varying severity of UCI. Further research is required to understand and predict these interactions.

Infection of pods by blackleg can cause complete loss of pods as they break off the plant or shatter prematurely. Grain inside infected pods retained on the plant can also be affected (Table 2). Pods with increasing severity of blackleg lesions have reduced grain size and may have fewer seeds/pod. Severe blackleg lesions (>10mm) reduced grain size by up to 22% indicating that the effects of pod infection occur after seed number is set but that seeds may be aborted if directly infected. In addition, fully formed seed within infected pods and which is retained for future use is infected with blackleg. Plants growing from infected seed can have seedling blight resulting in poor crop establishment. Given the high level of pod infection by blackleg and alternaria (both of which can cause seedling blight) it is recommended that seed from crops with infected pods is not retained for sowing. If retaining seed, grade it for larger seed which is less likely to be infected with blackleg and ensure even and adequate treatment with an appropriate fungicide to control seedling blight.

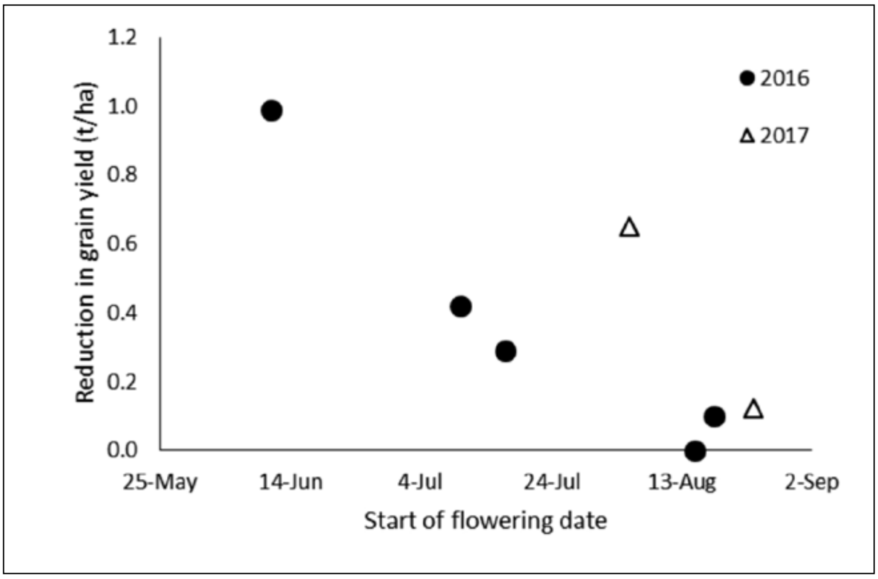

Figure 3. Yield loss caused by Blackleg UCI in cultivar Pioneer®44Y89CL differing in start of flowering date in southern NSW in 2016 and 2017. Yield reduction was the difference between treatments with none or full disease control.

Table 2. The yield components of individual pods with blackleg pod lesions at Canowindra and Wagga Wagga (cv 44Y89CL$^{\phi}$), NSW in 2016 and Horsham (ATR-Stingray$^{\phi}$), VIC in 2017. TGW = thousand grain weight. Values followed by the same letter within each column are not significantly different ($P<0.05$).

Pod blackleg lesion size	2016				Victoria 2017	
	Canowindra, NSW		Wagga Wagga, NSW		Horsham, VIC	
	TGW (g)	Seeds/pod	TGW (g)	Seeds/pod	TGW (g)	Seeds/pod
No lesions	3.69a	19.3a	3.43a	23.4a	2.98a	22.6a
<3mm	3.57b	19.8a	3.26ab	21.7b	3.23a	20.5a
3-5mm	3.45c	19.0a	3.26ab	21.4b	3.14a	19.9a
5-10mm	3.37cd	19.3a	3.20bc	20.4c	2.89a	21.3a
>10mm	3.17d	18.5a	3.06d	18.8d	2.33b	20.8a

Table 3. The yield components of pods harvested from the main raceme of plants with blackleg branch lesions at Wagga Wagga (cvs. Pioneer®44Y89CL, Nuseed Diamond and Archer) in 2017. Pods were collected above the lesions on each plant. The data are the mean of the cultivars as their response to disease was the same. TGW = thousand grain weight. Values followed by the same letter within each column are not significantly different ($P<0.05$).

Severity of blackleg branch lesion	TGW (g)	Seeds/pod
No lesion	3.73ab	12.63a
Moderate	3.92a	11.35b
Severe	3.59bc	9.70c

In contrast to pod lesions which directly affect the developing seed, branch lesions cause a disruption to the flow of nutrients to the developing pods and seeds. In 2017, branch lesions reduced the number of seeds/pod and also seed weight (Table 3). Consistent effects were found in three cultivars with different flowering times: Nuseed Diamond, Pioneer®44Y89CL and Archer.

Control of UCI — what we know and don't know

In 2017, experiments were conducted to confirm the effects of flowering time, cultivar resistance and fungicide use/timing. The results can be summarised as the following:

- Pod infection was the predominant symptom present in experiments in 2017. Later flowering reduced disease severity (Table 4).
- In 2016 levels of UCI infections were low in plants that flowered after July. However, in 2017 although symptoms were reduced in plants that flowered after July there was still some severe pod infection and UCI in late flowering plants (Table 4 and Table 6).
- Cultivars with effective major gene resistance do not get UCI symptoms, including pod infection (e.g. Group ABDF) (Table 4). Cultivars in Resistance Group C have no effective resistance to UCI in Australia. In these cultivars, the Blackleg Rating indicates resistance to crown canker only, not UCI. Although ATR-Stingray⌽ has higher levels of UCI than Archer, this is solely due to the earlier flowering time of ATR-Stingray⌽.
- Fungicides applied during the reproductive growth stages will reduce the severity of UCI. However, the economics of fungicide application at this stage are yet to be determined. The economic return will depend on the severity of symptoms and the timing of fungicide application. For example, ATR-Stingray⌽ sown in March will have a greater return from fungicide application compared to ATR-Stingray⌽ sown in June as it would flower outside the critical window for infection. Archer (later flowering cultivar) did not get enough UCI to warrant control regardless of sowing time. Hyola®350TT (Group ABDF) with effective major gene resistance did not get enough UCI to warrant control regardless of sowing time (Table 5 and Table 6).

Table 4. 2017 Effect of flowering date and cultivar resistance of upper canopy infection symptoms. Experiment undertaken in pots with canola stubble spread around the pots to ensure disease inoculation at Horsham, VIC.

Cultivar + date 1st flower	% flower infection	Stem infection 0-4	Branch infection 0-4	% head infection	% pod infection	% crown canker
ATR-Stingray⌽ MR + Group C ineffective major gene in this experiment						
9-Jul	2.8	0.2	0.5	0.3	33	0
30-Jul	1.5	0.1	0.7	0.2	27	1
25-Aug	1.5	0.1	0.7	0.1	3	8
10-Sep	0.8	0.1	0.2	0.0	1	12
Archer MS + Group C (ineffective major gene in this experiment)						
14-Aug	0.2	0.6	0.6	0.2	4	5
29-Aug	0.0	0.5	0.6	0.1	3	22
9-Sep	1.0	0.2	0.6	0.1	1	37
19-Sep	0.5	0.1	0.1	0.0	0	38
Nuseed Diamond R + Group ABF (partially effective major gene in this experiment)						
28-Jun	2.8	0.1	0.4	0.2	7	1
20-Jul	0.3	0.0	0.2	0.1	17	1
13-Aug	1.5	0.0	0.5	0.1	2	12
8-Sep	0.5	0.0	0.5	0.0	1	7
Nuseed GT42 Group ABDF (immune in this experiment)						
7-Jul	0.0	0.0	0.0	0.0	2	0
7-Aug	0.0	0.0	0.0	0.0	0	0
2-Sep	0.0	0.1	0.0	0.0	0	1
16-Sep	0.0	0.0	0.0	0.0	0	1
Hyola®350TT Group ABDF (immune in this experiment)						
7-Jul	0.0	0.0	0.0	0.0	2	0
27-Jul	0.2	0.0	0.0	0.0	0	0
25-Aug	0.7	0.0	0.0	0.0	0	2
9-Sep	0.3	0.0	0.0	0.0	0	1

The 0 to 4 scale: 0=no symptoms, 1=symptoms present, 2=symptoms common, 3=symptoms causing significant damage, 4=stem or branch death.

Table 5. Effect of flowering date and fungicide application on upper canopy infection symptoms and yield. Experiment undertaken in pots with canola stubble spread around the pots to ensure disease inoculation. UT = untreated, Full = full control. Cultivar ATR-Stingray(b).

Fungicide application timing	% flower infection	Stem infection 0-4	Branch infection 0-4	Head	% pod infection	% crown canker	Yield % of untreated
1st flower 9 July							
Untreated	1.7	0.6	0.2	0.58	34	0	100
30% bloom	0.8	0.2	0.0	0.30	34	0	116
Full	0.2	0.1	0.0	0.01	2	0	155
1st flower 25 August							
Untreated	3.7	0.9	0.2	0.10	4	4	100
30% bloom	1.7	0.3	0.0	0.02	2	5	97
Full	1.3	0.1	0.0	0.02	1	5	116

The 0 to 4 scale: 0=no symptoms, 1=symptoms present, 2=symptoms common, 3=symptoms causing significant damage, 4=stem or branch death.

Table 6. 2017 Effect of flowering date and fungicide application on upper canopy infection symptoms and yield. Experiment undertaken in the field at Longerenong, VIC, sown in plots exposed to natural blackleg inoculum. There were only very low levels of blackleg crown canker, no sclerotinia and no other diseases present.

		Cultivar	
Fungicide application timing	ATR-Stingray(b) MR Group C Early flower	ATR-Gem(b) MS Group A Mid flower	ATR-Wahoo(b) MS Group A Late flower
1st flower date			
Sown 14-April	17 Aug	13 Aug	28 Aug
% flowers infected			
Untreated	12	10	11
30% bloom	5	7	9
Full control	5	0	0
Stem infection (0-4 scale, 4 =stem death)			
Untreated	0.5	0.9	0.4
30% bloom	0.1	0.6	0.4
Full control	0.2	0.1	0.2
Branch infection (0-4 scale, 4 =branch death)			
Untreated	1.2	1.1	0.9
30% bloom	0.5	0.5	1.0
Full control	0.5	0.2	0.2
% pods infected			
Untreated	13	20	14
30% bloom	10	6	6
Full control	6	3	5
Yield (% of untreated control)			
Untreated	100	100	100
30% bloom	110	112	108
Full control	118	112	121

The 0 to 4 scale: 0=no symptoms, 1=symptoms present, 2=symptoms common, 3=symptoms causing significant damage, 4=stem or branch death.

- Data indicates that spraying at 30% bloom for sclerotinia control may reduce UCI symptoms if the season is conducive to disease development (Table 5 and Table 6).
- There is insufficient knowledge to recommend spraying solely for UCI control.
- In both 2016 and 2017 the yield responses to controlling UCI appear to be greater than the reduction in levels of visible symptoms of UCI. That is, small reductions in symptoms have resulted in significant yield increases. Infection by the blackleg fungus does not always produce visible symptoms. Symptomless infection of the crown can cause significant damage to the plant vascular tissue, and evidence suggests that branch and stem infection is similar. Further research is required to understand how UCI is causing yield losses (Table 5 and Table 6).

Blackleg management App — BlacklegCM

The current Blackleg Management Guide (https://grdc.com.au/__data/assets/pdf_file/0017/236051/blackleg-management-guide-2017-autumn-variety-ratings.pdf.pdf) contains information on the management factors that influence the severity of blackleg in your crop. It specifically lists cultural practices such as crop rotation and distances to canola stubble (inoculum source), the appropriate scenarios for fungicide application and presents the Blackleg Rating and Resistance Group for each cultivar. The Management Guide is updated twice yearly as the resistance status of individual cultivars can change as the blackleg fungus overcomes host resistance genes.

Although the Management Guide provides useful information, it has some limitations in its current form. Currently, it is difficult to consider complex interactions. For example, the use of cultivars with different Blackleg Ratings in high or low rainfall environments and the effect of fungicide use. Consequently, there has been a need to develop a management tool that can provide disease forecasting based on the management principles proposed by the manager of an individual paddock. This has led to the development of the new Blackleg Management App. 'BlacklegCM'.

BlacklegCM assists you to manage blackleg disease in Australian canola crops by integrating the information provided in the Blackleg Management Guide and producing a predicted economic outcome. BlacklegCM can be modified to account for some of the major factors that relate to risk of yield loss due to blackleg disease in your paddock. It allows you to compare the likely relative profitability of different disease management strategies including paddock selection, cultivar choice, seed dressing, banded fungicide and sprayed fungicide.

BlacklegCM takes account of costs, yield benefits and grain prices to give you best case, worst case and most likely estimates of economic return.

BlacklegCM accounts for the major factors that influence blackleg severity. The user has the option to change each parameter to tailor the output to their cropping circumstance. Consequently, the user can explore their options for disease control and understand the relative importance of each factor. For example, distance to one year old stubble has a large influence on disease severity, while two year old stubble has a minor influence. Foliar fungicide has a small influence if used in isolation but is very effective if used in combination with a seed dressing fungicide. Foliar fungicide on a one tonne crop is likely to cause an economic loss while fungicide on a three tonne crop is more likely to result in a large profit.

The strength of the App is that it allows the user to make as many comparisons as they wish in order to determine the best and most profitable way for them to reduce disease and increase profits.

The App is a result of 30 years of blackleg research. It has had input from all members of the GRDC investment 'National canola pathology program' and has been built by the 'National pathogen management modelling and decision support project'. The App has already been extensively tested by advisers and the interfaces were determined based on advisers' recommendations (Figures 4, 5, 6 and 7) .

BlacklegCM App loads with many options. The user can set these options to best match their circumstance (Figure 4).

Figure 4. Options available with use of BlacklegCM App.

Crop circumstances

The user puts in basic parameters such as target yield, production costs, grain price, and regional canola intensity (Figure 5).

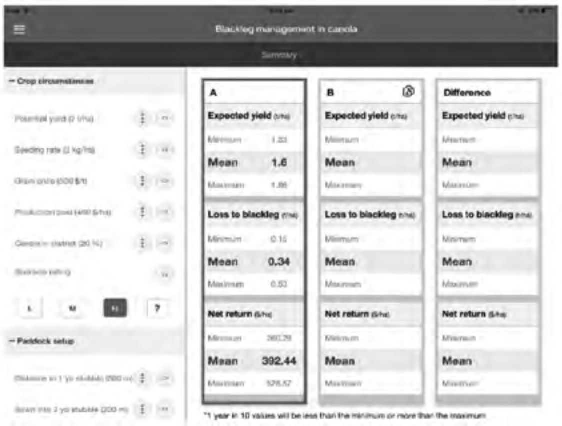

Figure 5. BlacklegCM App interface to collect information regarding crop circumstances.

Paddock set up

Within the paddock set up section, it's possible for the user to fill in distance to one and two year old stubble and whether the stubble has been left standing or has been knocked down (Figure 6).

Figure 6. BlacklegCM App interface to collect information regarding paddock set up.

Management options

Within the management options section the user is able to choose your cultivar, and indicate whether your cultivar has reduced resistance in your region. This can be determined from monitoring past crops, but if unknown the App will default to 'Not reduced'. If major resistance changes have occurred there will be published warnings, such as 'Group D resistance warning on the Eyre Peninsula in 2012'.The management options section also enables the user to add their fungicide plans, seed treatment, fertiliser amended or foliar application (Figure 7).

Figure 7. BlacklegCM App interface to collect information regarding management options.

Once all of the parameters have been entered, the real power of the App becomes apparent as it determines the likely blackleg severity, yield loss and economic return from the parameters that have been entered. But unlike the current paper management guide, the App can calculate an immense number of interactions. For instance, in a low rainfall environment the App will determine that most management options do not results in yield loss and fungicide use may even result in economic loss. Whereas in the high rainfall, high canola intensity regions even small changes in management may result in varying levels of disease. The App also enables the user to compare different management options.

Case study

In 2018 a grower has ATR-Bonito$^{(b)}$ seed which formerly had a blackleg rating of MR, however, it has fallen to Blackleg Rating MS. Should the grower use their ATR Bonito$^{(b)}$ seed as intended or get new seed of a more resistant cultivar?

The grower puts in their parameters:

Potential yield: 2t/ha
Seeding rate: 3kg/ha
Grain price: $500/t
Production cost: $400/ha
Canola in the district: 20%
Spore maturity risk: High
Distance to one year old stubble: 10metres
Distance to two year old stubble: 200meters
Two year old stubble: standing
Cultivar: ATR Bonito$^{(b)}$
Seed treatment: No
Fungicide with fertiliser: No
Fungicide spray: No

The predicted yield loss from blackleg is 20%.

The grower can now change parameters:

New cultivar with R rating = 20% yield loss reduced to 0% yield loss.

ATR Bonito⁽ᵖ⁾ with seed dressing and foliar fungicide = 20% yield loss reduced to 4% yield loss.

ATR Bonito⁽ᵖ⁾ sown with increased distance to one year old stubble = 20% yield loss reduced to 10% yield loss.

The App will also be updated continuously to ensure that it has all the current canola cultivars and their current blackleg rating. All new knowledge will also be incorporated; for instance, knowledge on UCI and different fungicide timings will be incorporated in the near future.

The App can also be used during the growing season, for instance in 2016 many growers planned for a 2t/ha crop but soon realised that yield potentials were much higher. Members of the canola pathology team then warned of a very high blackleg lesion severity. In this scenario in July, growers could have re-run the App with 3t/ha rather than 2t/ha yield target and compared plus or minus foliar fungicide.

It is envisaged that this App will continue to grow and evolve with the canola industry and become the mainstay for blackleg knowledge in Australia.

Useful resources

https://grdc.com.au/resources-and-publications/all-publications/publications/2017/09/blackleg-management-guide

www.nvtonline.com.au

Acknowledgements

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

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Notes

Latest research on brome grass and susceptibility of emerging weed species to harvest weed seed capture and control

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ΦExtra technical comment by Protech Consulting Pty Ltd

GRDC project codes: UA00156, UQ00080

Keywords

- brome grass, weed seed dispersal, management.

Take home messages

- Increasing incidence of brome grass in cropping paddocks in southern Australia appears to be associated with selection of biotypes with greater seed dormancy by crop management practices used by growers.
- Higher levels of seed dormancy allow brome to germinate and establish after pre-sowing weed management, resulting in greater in-crop weed establishment. This change in weed behaviour also appears to be associated with increased seedbank persistence from one year to the next (approximately 25%). Therefore, multi-year control strategies are required to exhaust brome seedbanks to low levels. Growers need to plan a three year management program for their cropping rotations.
- Several experimental herbicides have been evaluated alone or as tank mixtures with Avadex®[Φa] and Terbyne®[Φb] for brome control in wheat. Whilst some experimental treatments provided effective weed control (>80%), crop safety was inadequate in cereals.
- Weed seed dispersal prior to crop harvest differed greatly between weed species. Bedstraw, statice, turnip weed and Indian hedge mustard showed no dispersal (100% retained), seed retention was much higher for bifora (50%) and brome grass (75%) relative to sowthistle (<35%) and barley grass (<6%). Barley grass is extremely prone to early seed dispersal and harvest weed seed control (HWSC) tactics are unlikely to improve weed management.
- Prickly lettuce seed production occurred after crop harvest, thereby limiting the effectiveness of HWSC — weed control should focus on post-harvest management (i.e. non-selective herbicides).
- A preliminary kiln study showed that temperatures in excess of 450°C for at least 40s were required to guarantee the complete kill of brome grass seed. As burning standing stubbles is unlikely to provide the required level of heat exposure, narrow windrow burning should be considered to improve weed seed kill.

[Φa] *Avadex is registered for suppression of brome grass in wheat.* [Φb] *Terbyne is registered for use in wheat but not for control of brome grass. In commercial situations, label requirements must be adhered to.*

Brome grass ecology and management

Brome grass (*Bromus diandrus,* great brome) has increased in prevalence across the Victorian Mallee, which appears to be related to increased adoption of no-till farming and intensification of cereal-based cropping systems (i.e. wheat on wheat), where few effective selective herbicides are available for its control. Similar trends of increasing dominance of brome have been observed in the SA Mallee and in the Mid-North and many other areas of the state. Some of the increase in brome grass abundance in crops can also be explained by the adoption of earlier sowing or even dry sowing. In situations where brome grass has become a serious issue, it can reduce wheat yields by as much as 30% to 50%.

On-farm selection for increased seed dormancy and delayed seedling emergence after the opening rains appears to be responsible for the increasing dominance of this weed species. Our research has clearly shown higher levels of seed dormancy in brome grass populations collected from cropping fields than those from non-crop situations such as fence-lines or roadsides (Figure 1). Populations collected from intensively cropped situations at the end of 2015 were much slower to emerge and reach 50% of final emergence (t_{50}) than those sourced from the fence-line (cropped t_{50} approximately 40 d; fence-line t_{50} approximately 20 d). This two-fold difference in seedling emergence time between brome populations was related to the variation in seed dormancy.

These results clearly indicate that management practices used by growers to control brome in cropping paddocks have caused a shift in weed population behaviour. This increase in seed dormancy has been caused by selection of individuals in these populations that possess genes for greater seed dormancy that enables them to escape pre-sowing weed control tactics such as tillage or knockdown herbicides. The process of selection for increased seed dormancy would be very similar, but slower than selection for herbicide resistance. Over time, weed management practices in cropping paddocks would select for biotypes that possess higher dormancy and select against or remove those with low dormancy. Such selection pressure would not occur on the fence-line or non-crop areas or pastures.

Seed of highly dormant populations of brome grass was responsive to chilling (i.e. exposure to 5°C), a process which has been shown to increase gibberellic acid production within the seed, a hormone known to stimulate germination. In the field this means that the dormant brome grass seed requires not only moisture, but also a period of colder temperatures to germinate. Therefore, germination of most of the seedbank of brome would not occur until cooler-moist conditions in late autumn-early winter, thus allowing it to evade early season weed control tactics (e.g. knockdown herbicides). Another biological mechanism that appears to delay seedling emergence in the field is the strong inhibitory effect of light on seed germination in brome grass. Strong photo-inhibition is likely to aid brome infestation in the field by enabling seeds to remain ungerminated on the soil surface, even after adequate rainfall, until after the sowing of the crop, thus preventing seedlings from being killed by seed-bed preparation practices. This feature of brome grass ecology also goes some way to explaining why it has proliferated under no-till,

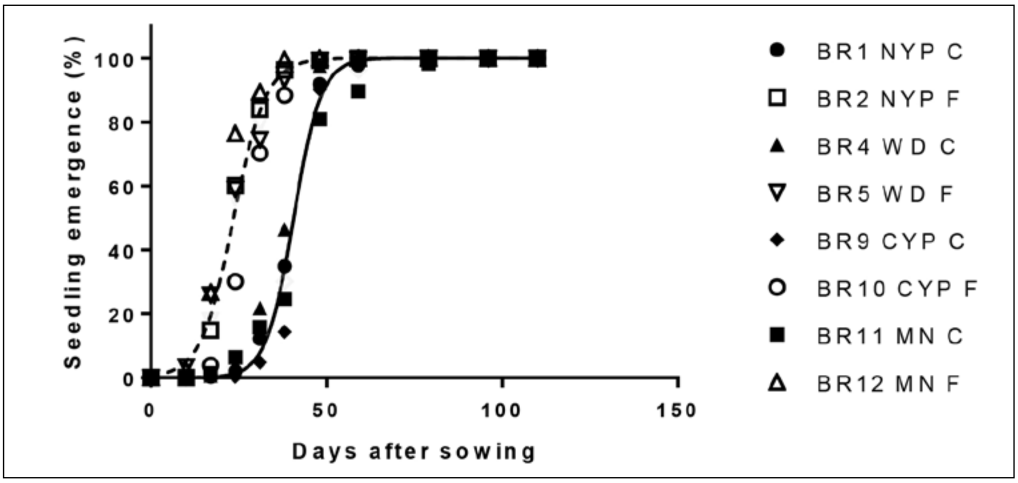

Figure 1. Differences in germination and seedling emergence pattern between cropped (closed symbols — solid line) and adjacent fence-line (open symbols— broken line) populations of great brome collected in 2015 across south-eastern Australia.

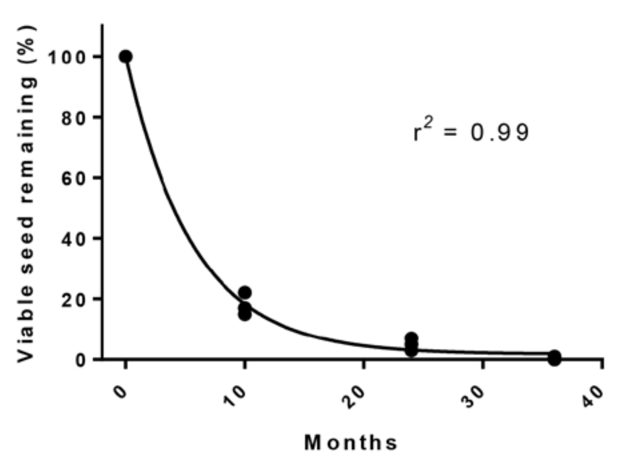

Figure 2. Longevity of brome grass seed in the field at Lock from 2003 to 2006.

where seeds remain on the soil surface until being buried by the sowing pass, which would remove the inhibitory effect of light.

Greater seed dormancy in brome grass populations from cropping fields could have also contributed to the development of a more persistent seedbank. A field study undertaken at Lock showed that 20% of the seedbank of brome persisted from one season to the next, with seeds remaining viable in the soil for up to three years (Figure 2). Similar levels of persistence were also shown in the long-term study at Balaklava, where more than 25% of seedbank persisted from one season to the next. Seedbank carryover of this magnitude could be an important factor in the proliferation of brome grass where crop rotations have often provided effective control just for one year (i.e. pasture-wheat rotation) or under cereal monoculture where no effective herbicide options were available prior to the introduction of the Clearfield® cereals.

Given the nature of seedbank persistence of brome grass, long-term control of brome would need an effective multi-year management program. Fortunately, the introduction of imidazolinone-tolerant wheat (Clearfield®) has widened growers' options for the management of brome in the wheat-phase. Use of break crops such as legume or canola in combination with Clearfield® cereals can provide a range of herbicide options for brome control and can be included in a rotation to prevent seed set. However, brome is a prolific seed producer (80-270 seeds/plant) and weed populations can rebound sharply if weak management tactics are used for its control.

Recognising the need to find alternative herbicide options to the heavily used Group A and B herbicides, several herbicide efficacy trials funded by GRDC (projects UCS00020 and UQ00080) have been undertaken over the past seven years in SA and Victoria (VIC). The trials have compared several new and experimental pre-emergent options against common grower practice of incorporated by sowing (IBS) trifluralin[Φa] plus Logran®[Φb] in wheat. Of the herbicides examined, Sakura®[Φc] plus Avadex®[Φd] provided the highest pre-emergent brome control (averaging >70%) in most of the field trials (Figure 3). However, where moisture conditions were inadequate, or the weed pressure high, this mixture was ineffective (<40%). At low brome infestations, tank mixes of trifluralin with either Stomp®[Φe] or metribuzin[Φf], whilst providing lower control (50% to 60%) have been more cost effective than Sakura® plus Avadex® ($70/ha). Several experimental herbicides have also been evaluated alone or as tank mixtures with Avadex® or Terbyne®. While some of these treatments provided excellent brome control (>80%), crop safety in cereals was inadequate.

[Φa] Trifluralin is registered for suppression of brome grass in wheat (TriflurX label). [Φb] Logran is registered for use in wheat but not for brome grass. [Φc] Sakura is registered for suppression of brome grass in wheat. [Φd] Stomp is registered in wheat but not for brome grass. [Φe] Metribuzin is registered for suppression of brome grass in wheat.

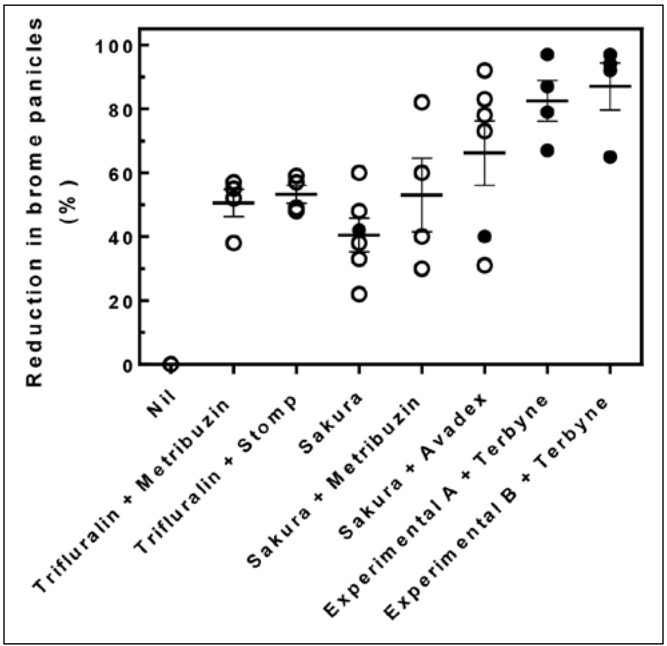

Figure 3. Performance of different pre-emergent herbicides on brome grass from several field trials undertaken across SA and Victoria. Horizontal and vertical bars represent the mean and SE, respectively. Closed symbols represent the mean values for herbicides evaluated from a single trial at Balaklava, SA in 2016.

Weed seed dispersal and susceptibility of emerging weeds to harvest weed seed capture and control

At present, there is growing interest in the grains industry in HWSC including weed seed catchers, weed seed destructor technologies, and narrow windrow burning. The effectiveness and therefore suitability of these practices depend on the amount of weed seed retained on the plant and present above the cutter bar height at crop harvest. Field studies conducted over the past two seasons at Roseworthy have investigated the seed shedding behaviour of several emerging weeds until the crop was harvest-ready (≤12% moisture content). The pattern of seed shedding was determined by regularly collecting seeds from seed traps placed on the soil surface in the crop canopy. A preliminary kiln study was also recently undertaken to investigate the burning temperatures and duration required to provide weed seed control in the context of narrow windrow burning. Here only data for brome grass (Table 2) is presented.

Barley grass (*H. glaucum*) was particularly prone to early seed dispersal and only <6% of seeds produced were retained in panicles at the harvest-ready stage of wheat (Figure 4). Barley grass was also the first weed spp. to reach maturity, producing viable seeds and initiating seed shed at 60 to 65 days, and 43 to 45 days before crop harvest. Relative to barley grass, bifora and brome grass (*B. diandrus*) were slower to reach physiological maturity (30 to 40 days) and initiate seed shed 21 to 25 days before crop harvest. Weed seed retention was much higher for bifora (50%), brome grass (75%) and bedstraw showed no seed dispersal prior to crop harvest (100% retained). Even though brome grass had high seed retention (75%) until harvest, many panicles (30% to 80%) had lodged below the crop harvest height of 15cm (Table 1). The severity of lodging in brome grass increased with weed density, which could be related to weaker stems at its higher density and this could be an important escape mechanism from HWSC for this species.

Preliminary results from the past season showed that more than 65% of sowthistle flowers had already released seed prior to lentil harvest whereas in wheat, seed dispersal was much lower due to greater weed suppression caused by crop competition. Similar to bedstraw, statice, turnip weed and Indian hedge mustard showed no dispersal prior to the harvest-ready stage of both wheat and lentils (100% retained).

Table 1. Effect of brome and barley grass density (low, medium and high) on panicle lodging at the harvest-ready stage of wheat (≤12% moisture content). Panicles found ≤15cm crop harvest height were scored as lodged.

Weed density (plants m^2)	Brome grass	Barley grass
	% panicles ≤15cm harvest height	
Low (10-20)	30 ± 18.2	73 ± 4.1
Medium (35-50)	47 ± 11.4	63 ± 2.7
High (140-200)	80 ± 2.0	68 ± 2.4

Despite prickly lettuce emerging within a month of sowing, flowering was not observed even for the most advanced plants at lentil harvest. As most seed

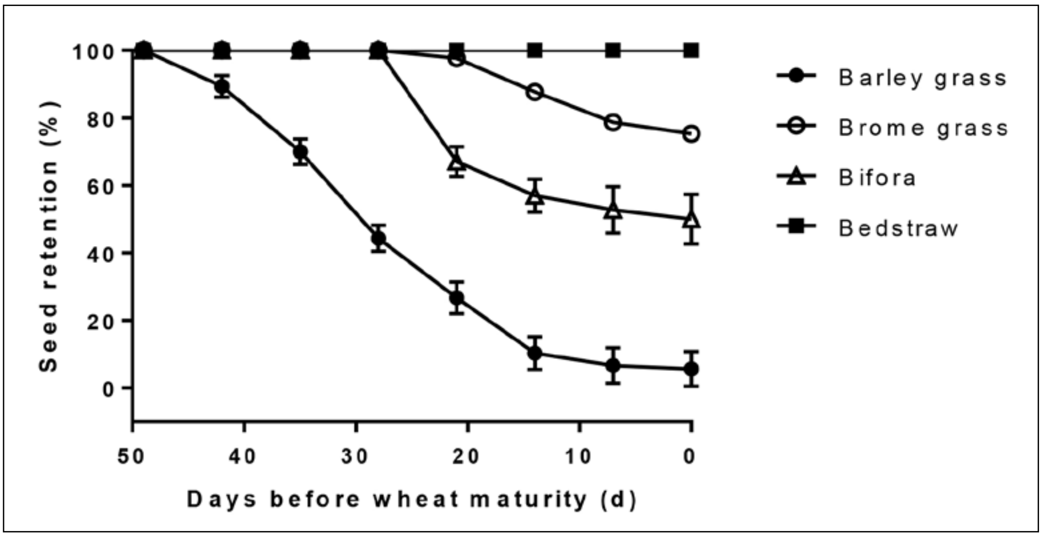

Figure 4. Seed retention of brome grass (O) relative to barley grass (●), bifora (Δ) and bedstraw (■) in relation to wheat maturity (≤12% grain moisture content) at Roseworthy in 2016. Bars show ± SE.

Table 2. Effect of temperature and duration of exposure on the percentage (%) germination (survival) of brome grass seed. Values in mean column with different letters are significantly different (P = 0.05). SAGIT funded project (S416).

Duration (s)	Temperature (°C)					
	200	250	300	350	400	450
20	100 *a*	98 *a*	100 *a*	91 *a*	71 *b*	68 *b*
40	97 *a*	93 *a*	98 *a*	59 *b*	7 *c*	0 *c*
60	98 *a*	89 *a*	72 *b*	2 *c*	0 *c*	0 *c*

production in prickly lettuce appears to take place after crop harvest, HWSC is not a practical option for this weed species. Rather, non-selective herbicides should be used post-harvest, when regrowth is fresh and plants are likely to be more vulnerable to control.

Based on the level of seed dispersal observed in this study, bedstraw, statice, turnip weed, and Indian hedge mustard were the most suitable weed species for harvest weed seed capture. Despite bifora and brome grass shedding some seed prior to harvest, more than 50% of seeds were retained for HWSC. In contrast, sowthistle and barley grass appear to be the least suitable weed species for HWSC and show a high level of shed seed prior to crop harvest.

Results from a preliminary kiln study showed that both temperature and duration of exposure were important factors for killing weed seeds (only brome grass data presented). Temperatures in excess of 450°C for at least 40s were required to achieve complete kill of brome grass seeds (Table 2). Even at these high temperatures (450°C), short exposure (20s) failed to completely kill brome seeds with more than 68% remaining viable after the treatment. These preliminary results clearly suggest that short hot burns associated with burning standing stubbles are likely to be inadequate for achieving a high level of weed seed kill. Therefore, narrow windrows of high biomass are required to generate the temperatures and exposure times needed for killing brome grass seed.

Even though our studies have shown that several weed species retain most of their seed until crop harvest, little is known about the proportion of weed seed that subsequently exits in the grain, straw and chaff fractions under commercial harvest conditions. An important factor in many HWSC systems (i.e. chaff carts, chaff lining and HSD) is that they only target the portion of weed seed exiting the harvester in the chaff fraction. Narrow windrow burning is the exception and will control weed seeds exiting both in the straw and chaff fractions provided a hot and long burn is achieved. Further research is therefore required to clarify this aspect of weed seed collection to determine the relative effectiveness of each HWSC system in the long-term management of these emerging weeds.

Acknowledgments

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

We are also grateful to Jerome Martin and Malinee Thongmee from UA for providing technical assistance. We also acknowledge the South Australian Grains Industry Trust Fund for funding the project (S416) – Burning of weed seeds in the low rainfall systems project.

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Notes

Improving barley performance in the low rainfall zone

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Birchip Cropping Group.

GRDC project code: DAN00173

Keywords

- barley, RGT Planetᶲ, barley agronomy, weed competition, phenology, time of sowing.

Take home messages

- Barely varieties Fathomᶲ, La Trobeᶲ, Spartacus CLᶲ, Rosalindᶲ, Hindmarshᶲ and Compassᶲ are consistently yielding the highest in the Victorian (VIC) Mallee and Wimmera National Variety Trials (NVT).
- Compassᶲ is very quick to mature and performs better in terms of yield and management at a later sowing time.
- RGT Planetᶲ yielded well at the Mallee and Wimmera NVT sites in 2016 and 2017 (in above average seasons). The variety performs best in a longer season environment (medium to higher rainfall areas).
- 'Compass type' barley varieties with good early vigour, combined with a prostrate growth habit are the best competitors (Compassᶲ, Fathomᶲ, Scope CLᶲ, RGT Planetᶲ).
- 'Hindmarsh type' and 'Urambie type' varieties with very slow early vigour are poor competitors (Hindmarshᶲ, Spartacus CLv, Urambieᶲ).
- Three years of data have reinforced that certain varieties can be used as a non-herbicide option for grass weed control.

Background

As part of the GRDC funded 'Barley agronomy for the Southern region' project, the Birchip Cropping Group (BCG) has been investigating varieties and their agronomic management, in particular phenology, time of sowing (TOS) and the competitive nature of varieties.

Grain yield is typically maximised by matching flowering time to an optimal flowering window where there is a compromise between moisture availability, frost and heat risk. New barley varieties differ in phenology, and therefore their suitability to different sowing windows to achieve an optimum flowering time to minimise these risks.

For a given variety, TOS is the main management factor that can influence grain numbers and grain yields. The advantages of sowing early have been evident over the past decade, especially those years with dry finishes. Though early sowing reduces the risk of heat stress during grain filling, it increases the frost risk during flowering. By matching variety to sowing date, seasonal risks can be minimised.

As a secondary part of the project, the competitive nature of barley, when sown into high weed burdens, was investigated. The increasing resistance issues throughout Australia deem it very important to look for alternative weed control methods, as part of an integrated weed management approach. Non-herbicide methods, such as sowing competitive barley varieties, are options that growers need to be considering when planning their paddock rotations. Determining the competitive ability of varieties helps to form management packages around new varieties to aid in variety selection.

Method

TOS and phenology

In 2017, a trial was established at Corack (Northern Wimmera) including three sowing times — 19 April (early for the region), 1 May (close to grower practice) and 1 June (late TOS). The trial included 12 barley varieties with differing maturities — Biere, Commanderᶲ, Compassᶲ, Fathomᶲ, La Trobeᶲ, RGT Planetᶲ, Rosalindᶲ, Spartacus CLᶲ, Urambieᶲ, Westminsterᶲ, WI4952 and AGTB0015.

In 2016, a trial was located at Kalkee (Wimmera) and included two sowing times — 18 May (earlier and close to grower practice) and 20 June (late TOS). The trial included eight barley varieties including Compassᶲ, La Trobeᶲ, Hindmarshᶲ, Spartacus CLᶲ, Rosalindv, Scope CLᶲ, Commanderᶲ and Fathomᶲ.

Weed competition

Trials have been established at Nhill (West Wimmera) in 2013 and 2016 and at Curyo (Southern Mallee, VIC) in 2017, with six barley varieties (as main plot) with plus and minus weed plots (as sub plot). Durackᶲ oats were used to simulate brome grass and were chosen for their vigorous early growth and early maturity.

In 2017, barley varieties chosen aimed to represent different plant architectures and growth habits that may influence competition (Table 1). This may then be used to categorise other similar varieties into these groups.

Results and discussion

Phenology and flowering time of barley varieties

In 2017, over the flowering period (between August 1 and November 1), the Corack site encountered 29 frost events that fell below zero degrees. During this time, TOS 1 was badly affected through the flowering period, with nearly 100% frost damage in all varieties. It was interesting to note the compensatory ability of barley after a severe frost event, when adequate rainfall for retillering occurred. Barley yields ranged from 0.8t/ha to 1.8t/ha, purely from secondary tiller yield (TOS 1 data not shown because of variability).

TOS 2 was also affected by frost, but to a lesser extent. On average, approximately 10% to 50% of the heads were affected in 50% of the plot. Some varieties that were later maturing were less affected (Urambieᶲ) and Biere was the most affected (due to its very early maturity, 10 days earlier than Hindmarshᶲ). TOS 3 flowered when some frosts were present, but there was only very minor (top few grains on head in later varieties) or no damage seen.

The TOS slightly influenced flowering (GS49) date (Table 2). On average, TOS 2 reached flowering four days after TOS 1, and TOS 3 was quicker, four days earlier than TOS 1. In terms of days to emergence, TOS 3 took a lot longer (19 days after sowing), compared to TOS 1 (8 days), due to cooler soil temperatures when sown later, reducing the rate of plant growth.

As sowing time became later, the time it took for varieties to reach GS31 (first node) extended, whereas time to flowering and maturity shortened.

Most varieties in all sowing times followed their maturity classification, apart from Compassᶲ and Rosalindᶲ. Compassᶲ (rated as moderately early) is quick to mature, around the same time as Spartacus CLᶲ and La Trobeᶲ (rated early), despite its slightly later rating.

Rosalindv (rated as mid maturing) is quick to progress through early growth stages (GS31 and GS49) when sown earlier (TOS 1 and TOS 2). It was quicker than most early maturing varieties, and was reaching maturity at similar times to Spartacus CLᶲ and La Trobeᶲ (early maturing).

Biere is a very quick maturing variety (10 days earlier than Hindmarshᶲ) and was noticeably quicker to reach flowering in all sowing times. Urambieᶲ

Table 1. Visual assessments of plant structure and characteristics that can influence competition.

Category/type	Height	Canopy structure	Early vigour	Representative varieties in trial
1. ‘Hindmarsh type’ plant	Short	Erect	Slow	Spartacus CLᶲ, La Trobeᶲ
2. ‘Compass type’ plant	Moderate - tall	Prostrate	Fast	Fathomᶲ, RGT Planetᶲ
3. ‘Westminster type’ plant	Short -moderately tall	Prostrate	Moderately slow	Westminsterᶲ
4. ‘Urambie type’ plant	Short	Very prostrate	Very slow	Urambieᶲ

Table 2. The average days to emergence, plants/m^2, days to first node development, awn peep and maturity for the three sowing times at Corack in 2017.

TOS	Days to emergence	Plants/m^2	Days to first node development (GS31)	Day to awn peep/flowering (GS49)	Days to maturity (GS90)
1	8	131	64	128	189
2	11	129	74	132	179
3	19	100	82	122	159
Sig. diff.	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001
LSD (P=0.05)	0.44	11.14	3.02	1.02	0.52
CV%	2.0	5.4	2.4	0.5	0.2

and Westminster$^{(b)}$ are long season varieties, and were six to 12 days later than Compass$^{(b)}$ to flower. Urambie$^{(b)}$ is a true winter variety and requires vernalisation (cold temperature) to flower and can therefore be sown earlier than all other varieties, however it is better suited to a long season.

The new variety RGT Planet$^{(b)}$ flowered later than Compass$^{(b)}$ and all other quick developing varieties when sown in April and May, however it was earlier than Fathom$^{(b)}$ and Commander$^{(b)}$.

All varieties matured within a few days of each other for each sowing time and this was influenced by the drier finish at the site, as moisture stress became an issue.

The interaction between flowering date and yield is shown in Figure 1 for some of the varieties. The earlier the flowering date, the greater the yield reduction due to frost damage. Varieties within TOS 2 and TOS 3 that flowered during mid-September, produced the greatest yields until the end of September and were not as at risk to frost events. This highlights the suitability of longer season varieties to an earlier sowing window, and how a variety as quick as Compass$^{(b)}$, adapts and yields better to a later sowing time.

Time of sowing and variety performance

In 2016 at Kalkee, the earlier sown crops (TOS 1) were taller and produced substantial biomass (Table 3). When heavy rains and winds occurred in spring, significant lodging happened in susceptible varieties during flowering and at maturity. Compass$^{(b)}$, Commander$^{(b)}$ and Scope CL$^{(b)}$ were the most affected. Later sowing of these varieties reduced the extent of lodging.

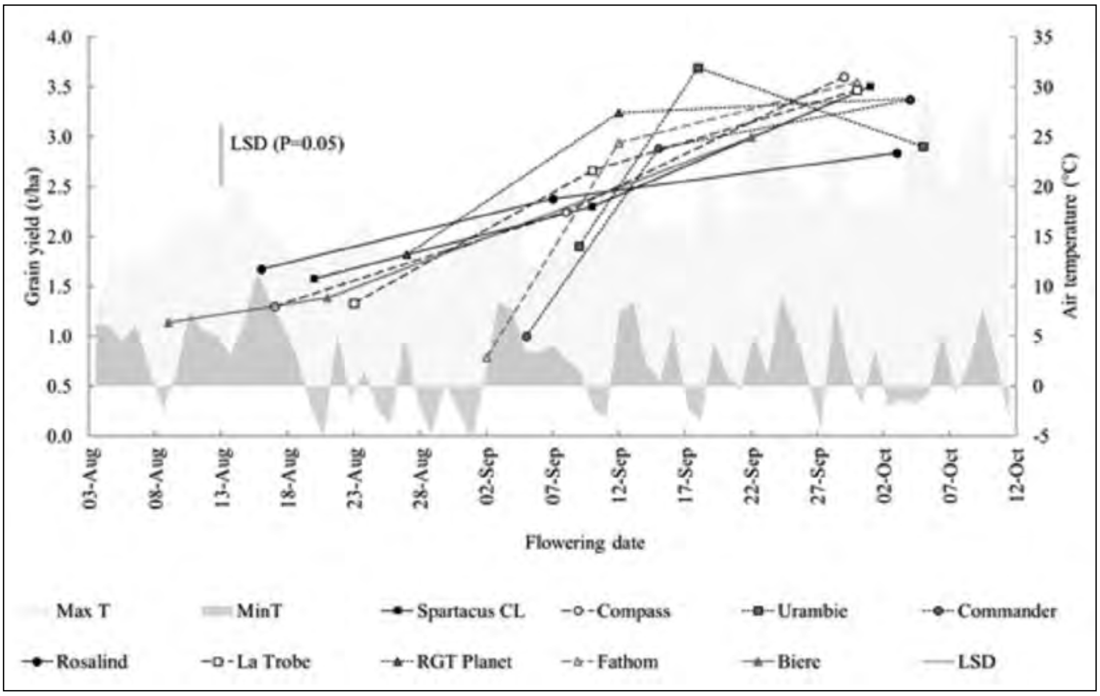

Figure 1. The interaction between flowering date and grain yield between the different sowing times, also highlighting the frost events experienced through this period (Corack 2017).

In terms of yield, there was no measurable difference between sowing time with the mean of both sowing times being the same. However, different varieties performed better when sown at specific sowing times. Fathom$^{\phi}$, Scope CL$^{\phi}$ and Spartacus CL$^{\phi}$ all yielded significantly higher when sown earlier, whereas Compass$^{\phi}$ favoured a later time of sowing with a 0.8t/ha yield benefit.

All other varieties did not differ in their performance as a result of sowing time. The highest yielding varieties at both sowing times were Rosalind$^{\phi}$ and Fathom$^{\phi}$.

In 2017, between TOS 2 and TOS 3 (TOS 1 data excluded due to variability), all earlier to mid maturing varieties performed better in TOS 3 due to no frost damage (Table 3).

Urambie$^{\phi}$ was the highest yielding, followed by RGT Planet$^{\phi}$ in TOS 2. These varieties are later maturing, so were less affected by frost damage as their flowering window was slightly later than early rated varieties. Very early maturing varieties suffered yield penalties in TOS 2, due to the short season and being affected by frost during flowering.

In TOS 3 Compass$^{\phi}$, Fathom$^{\phi}$, Spartacus CL$^{\phi}$, La Trobe$^{\phi}$, RGT Planet$^{\phi}$, Commander$^{\phi}$ and W14952 similarly yielded the highest. It highlighted again that Compass$^{\phi}$ is better sown slightly later due to its quick maturity. This can also help manage the variety in terms of susceptibility to lodging and head loss.

A risk with late sowing is potential heat stress at the end of the season. Late maturing varieties, Urambie$^{\phi}$ and Westminster$^{\phi}$ yielded the lowest in TOS 3 as the season was cut too short for them due to moisture stress.

When selecting a variety, looking at the long-term performance of a variety is very important to assess performance over a range of different seasonal finishes. Figure 5 compares the 2017 average of all Mallee NVT sites (grain yield as a percentage of the site mean) to the long-term (six year) average of each variety at the Mallee NVT sites.

RGT Planet$^{\phi}$ again yielded well across all sites in an average to above average year. Note, this variety has only been trialed for two years and not

Table 3. Grain yield (t/ha) between TOS 1 and TOS 2 from Kalkee site in 2016 and TOS 2 and TOS 3 from Corack site in 2017.

Variety	2016 Kalkee		2017 Corack	
	TOS 1 (18 May)	TOS 2 (20 June)	TOS 2 (1 May)	TOS 3 (1 June)
	Yield t/ha	Yield t/ha	Yield t/ha	Yield t/ha
Hindmarsh$^{\phi}$ (VE)	7.4	7.4	-	-
Scope CL$^{\phi}$ (M)	7.9	7.4	-	-
Rosalind$^{\phi}$ (M)	8.6	8.3	2.6	3.1
Fathom$^{\phi}$ (VE)	8.4	7.9	3.3	3.9
La Trobe$^{\phi}$ (E)	7.8	7.7	2.9	3.8
Spartacus CL$^{\phi}$ (E)	7.7	7	2.5	3.9
Commander$^{\phi}$ (ME)	7.2	7.6	3.2	3.7
Compass$^{\phi}$ (ME)	7	7.8	2.5	4.0
Westminster$^{\phi}$	6	6.4	3.3	2.4
WI4952 (M)	-	-	3.5	3.7
AGTB0015 (E)	-	-	2.3	3.7
Biere (VE)	-	-	1.5	3.3
Urambie$^{\phi}$ (M)	-	-	4.1	3.2
RGT Planet$^{\phi}$ (M)	-	-	3.6	3.7
Sig. diff.				
Variety	P<.001		P=0.005	
TOS	NS		P=<0.001	
Variety x TOS	P<.001		P=<0.001	
LSD (P=0.05)				
Variety	0.33		0.26	
TOS	0.16		0.26	
Variety x TOS	0.5		0.4	
CV%	4.4		5.1	

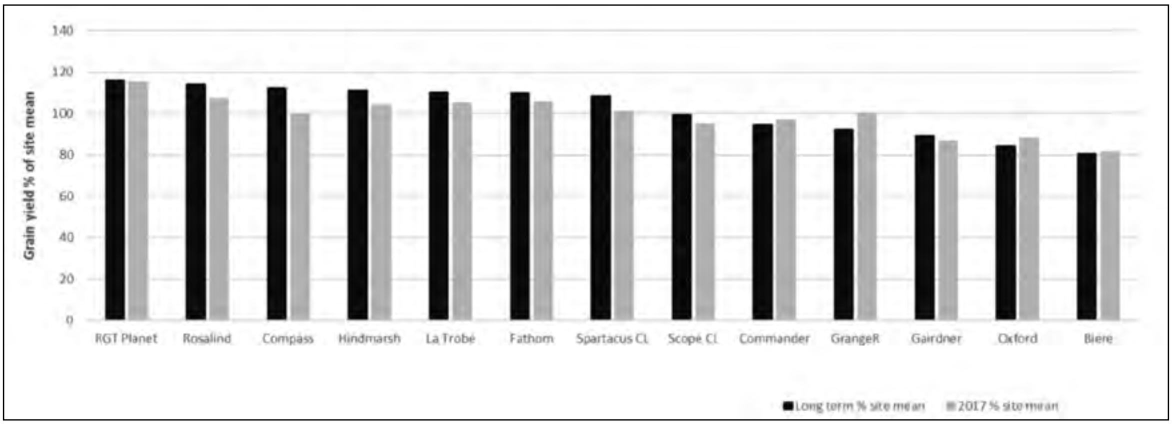

Figure 2. Mallee NVT barley grain yield (% of site mean) comparing 2017 to long-term averages (2012-2017) of 13 varieties at Manangatang, Rainbow, Ultima, Murrayville, Birchip, Hopetoun and Walpeup. Note: RGT Planet$^{\text{(b)}}$ and Biere have only been trialed in NVT for two years and Spartacus CL$^{\text{(b)}}$ and Rosalind$^{\text{(b)}}$ for four years.

in a tough finish like most of the other varieties. Rosalind$^{\text{(b)}}$, Compass$^{\text{(b)}}$, Hindmarsh$^{\text{(b)}}$, La Trobe$^{\text{(b)}}$, Fathom$^{\text{(b)}}$ and Spartacus CL$^{\text{(b)}}$ (four years data) are consistently yielding well across a four to six year average (in a range of seasonal finishes).

In the Wimmera NVT, RGT Planet$^{\text{(b)}}$ and Rosalind$^{\text{(b)}}$ yielded exceptionally well in 2017 (average of all sites in 2017). Long term averages indicate Rosalind$^{\text{(b)}}$, Compass$^{\text{(b)}}$ and Fathom$^{\text{(b)}}$ are yielding well across a range of seasonal finishes. Spartacus CL$^{\text{(b)}}$, Hindmarsh$^{\text{(b)}}$ and La Trobe$^{\text{(b)}}$, while slightly lower (% of site mean) are also still yielding well.

Weed competition

In 2017, biomass at maturity concluded that in the presence of weeds, Urambie$^{\text{(b)}}$ and Westminster$^{\text{(b)}}$ lost a significant amount of biomass (3.1t/ha and 2.1t/ha), while Fathom$^{\text{(b)}}$ had the least reduction (0.6t/ha), indicating a high tolerance to weed pressure, as biomass was not greatly affected (Figure 4).

Taller varieties generally compete better, however RGT Planet$^{\text{(b)}}$ is shorter in height (similar to 'Hindmarsh types'). It is a mid-maturing variety that has a prostrate canopy structure and good early vigour. It offered good competition against grass weeds, incurring the least yield loss (Figure 4). Fathom$^{\text{(b)}}$ ('Compass type') also performed well, incurring a lower yield loss and a good ability to suppress weed seed set (0.4t/ha, the lowest among the six varieties). Good early vigour is very influential in increasing the competitiveness of a variety, in combination with a prostrate growth habit and generally a taller plant height.

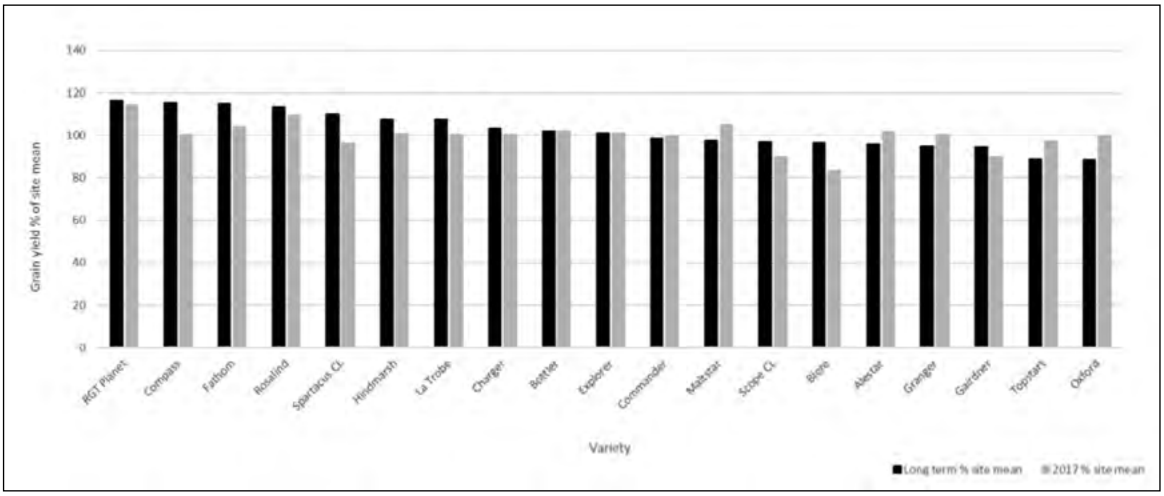

Figure 3. Wimmera NVT barley grain yield (% of site mean) comparing 2017 to long-term averages (2012-2017) of 19 varieties at Horsham, Kaniva, Brim and Minyip. Note: RGT Planet$^{\text{(b)}}$, Bottler, Explorer and Biere have only been trialed in NVT for two years, Topstart for three years and Spartacus CL$^{\text{(b)}}$ and Rosalind$^{\text{(b)}}$ four years.

Urambie$^{\phi}$ (type 4) was the poorest competitor, followed by Spartacus CL$^{\phi}$ ('Hindmarsh type'), both incurring the highest yield losses (22% and 19%, respectively) and had the poorest ability to suppress weed seed set (0.7kg/ha to 0.8kg/ha, respectively). These varieties, while having different canopy structures, exhibit very poor early vigour.

It appears varieties that fall into type 1 ('Hindmarsh type') do not all behave the same. These varieties have poor early vigour and an erect open canopy. While previous research has shown that Hindmarsh$^{\phi}$ and Spartacus CL$^{\phi}$ are poor competitors as would be expected with this plant growth habit, La Trobe$^{\phi}$ still appears to be a slightly better competitor than its phenotypically similar counterparts (slightly lower yield loss and weed seed set over the three years tested).

Figure 5 encompasses three years of data (2013, 2016 and 2017), grouping varieties that were trialed into their respective plant type category (refer Table 1) for comparison. Results are consistent over the three years showing 'Compass type' varieties (plant type 2) that exhibit good early vigour and a prostrate canopy structure have a greater ability to compete (lowest yield loss) and reduce weed seed set. 'Hindmarsh type' varieties (plant type 1) with a slow early vigour and erect growth habit have the poorest ability to reduce weed seed set. 'Urambie type' varieties are the worst competitors, with the highest yield losses over the three years of data (and high weed seed set).

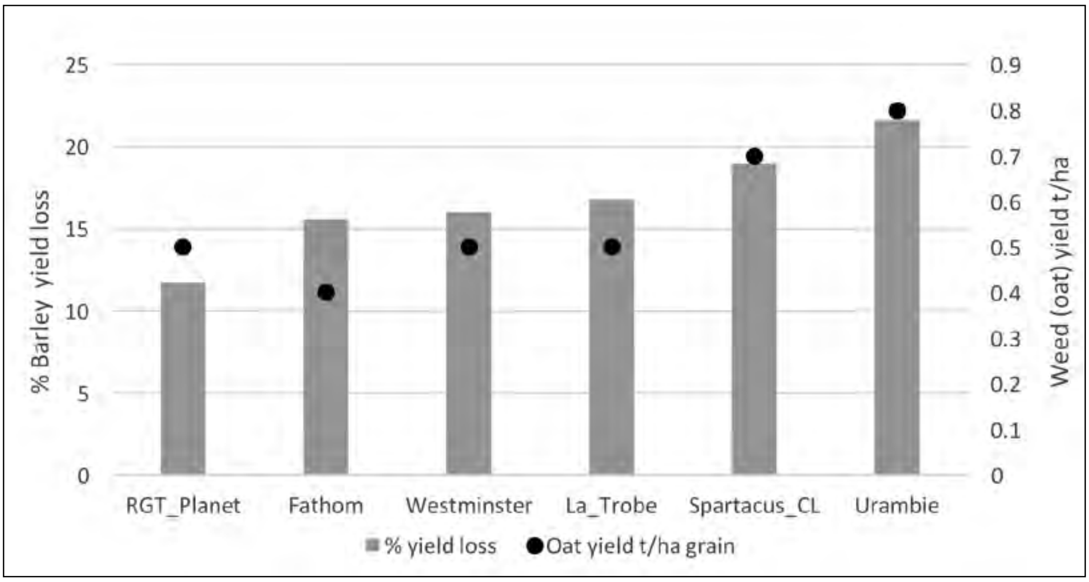

Figure 4. 2017 barley yield loss (%) between varieties and the amount of weed yield (t/ha).

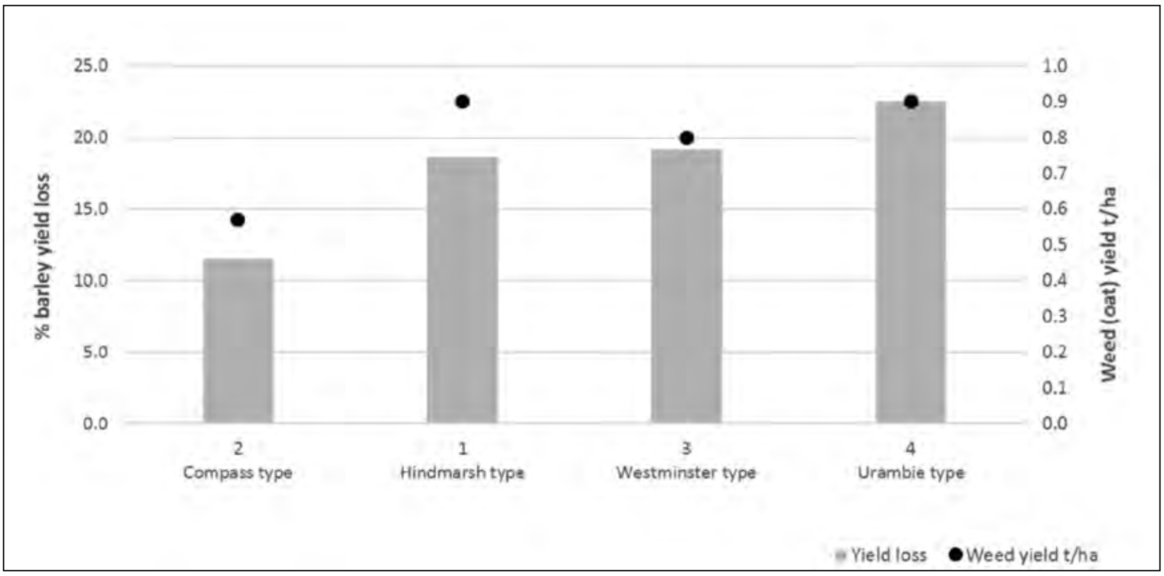

Figure 5. Three-year average of barley grain yield loss (%) of different plant types (based on their phenology) from 2013, 2016 and 2017 data.

Table 4. Different plant types, their competitive ability and similar varieties that fit into those categories.

Category/type	Level of competition	Varieties	Example of best rotation
1. 'Hindmarsh type'	Poor	Hindmarsh$^{\phi}$, Spartacus CL$^{\phi}$, La Trobe$^{\phi}$*	Sow into weed-free paddock *La Trobe$^{\phi}$ offers slightly better competition than other Hindmarsh type varieties.
2. 'Compass type'	Good	Fathom$^{\phi}$, Scope CL$^{\phi}$, Compass$^{\phi}$, RGT Planet$^{\phi}$, Commander$^{\phi}$	Best option if sowing into high weed burdens
3. 'Westminster type'	Poor to moderate	Westminster$^{\phi}$, Oxford, Grange R$^{\phi}$	Preferable to sow into weed-free paddock
4. 'Urambie type'	Very poor	Urambie$^{\phi}$	Sow into weed-free paddock

Table 4 summarises where additional varieties fit, enabling growers to use this as a tool for variety selection.

Selecting a barley variety is a decision that should be viewed as part of a long-term strategy, with an overarching aim to reduce seed bank levels and to maintain or improve the productivity of the paddock. Choosing a competitive variety and managing it to be competitive will help to reduce weed burdens and potentially reduce the amount of yield loss, when used as part of an integrated approach to weed control.

Conclusion

The 2017 season was characterised by numerous severe frost events during the growing season, in particular during critical flowering windows. It must be noted that the frost events this year were extreme and early May sowing is genuinely favoured to maximise yield potential. The 2016 trial and other previous research highlight the benefit of sowing barley earlier to gain a yield advantage. However, it does also highlight that some varieties are better suited to a later sowing, such as Compass$^{\phi}$, due to its quick maturity. This can also help manage the variety in terms of susceptibility to lodging and head loss.

The 2017 trial, though frosted, provides some useful examples of varieties that flowered at similar times, yielding differently. This suggests some varieties are better adapted to the region, for example, RGT Planet$^{\phi}$ versus Westminster$^{\phi}$.

A sound understanding of the phenology of varieties will help to ensure that varieties are sown in the appropriate sowing window to maximise crop potential. Growers should endeavour to learn how to assess their crop growth stage, a practice essential for effective communication between grower and adviser. It provides a common reference for describing the crop's development so that

Table 5. An overview of the top yielding varieties and ratings for delayed harvest, weed competition, disease and grade status.

Variety	Grade status	Delayed harvest rating	Weed competition rating	Overall disease rating	Optimum sowing window
RGT Planet$^{\phi}$	Feed – undergoing malt accreditation (target 2019)	Good standability (head retention not tested).	Good	Poor	April to June
Spartacus CL$^{\phi}$	Feed – undergoing malt accreditation (target 2018)	Very good head retention and standability	Poor	Moderate to poor	April- May
Rosalind$^{\phi}$	Feed	Good head retention and standability	Moderate	Moderate	April- May
Fathom$^{\phi}$	Feed	Moderately good head retention and standability - poor in above average season	Good	Good	April-May
Hindmarsh$^{\phi}$	Food	Good head retention and standability	Poor	Moderate to poor	April-May
Compass$^{\phi}$	Feed – undergoing malt accreditation (target 2018)	Poorer head retention and standability	Good	Moderate	May
La Trobe$^{\phi}$	Malt	Good head retention and standability	Moderate to poor	Moderate to poor	April-May

agronomic decisions can be implemented, based on a common understanding of which stage the crop has reached.

Looking at variety long term performance provides the best indication for guidance when selecting a variety. RGT Planetᶲ offers a unique phenology pattern, being slightly later than current well adapted spring lines La Trobeᶲ, Fathomᶲ, Compassᶲ, Spartacus CLᶲ and Rosalindᶲ. Its yield performance has been above average in many environments, particularly in higher than 4t/ha yield environments, while in lower yielding environments its performance has been more similar to the earlier maturing spring lines. It is a variety to watch over the next few seasons to grasp a true indication of its fit in a range of different seasonal finishes (in low and higher rainfall areas).

Hindmarshᶲ is still performing well, although La Trobeᶲ, an accredited malt variety, offers a good replacement. Fathomᶲ, Rosalindᶲ, Compassᶲ and Spartacus CLᶲ are yielding consistently well. Aim for yield by choosing one of these varieties and then look at their individual agronomy packages (disease susceptibility, head loss and lodging risk, competitiveness against weeds, grade) to determine the best fit for your farm and when planning rotations (Table 5).

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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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Final session
Day 1

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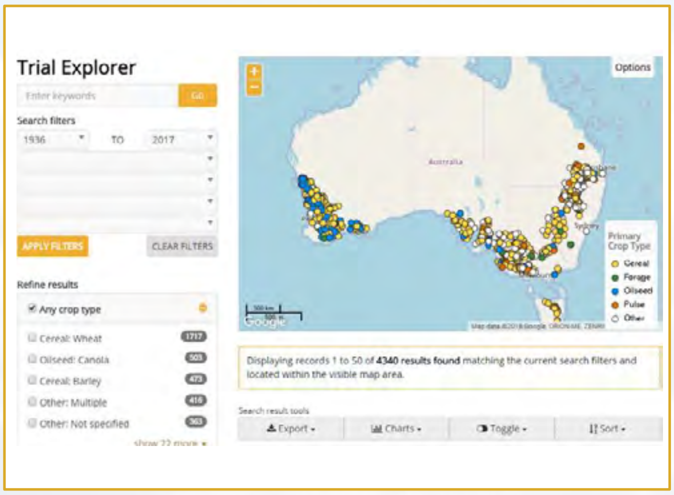

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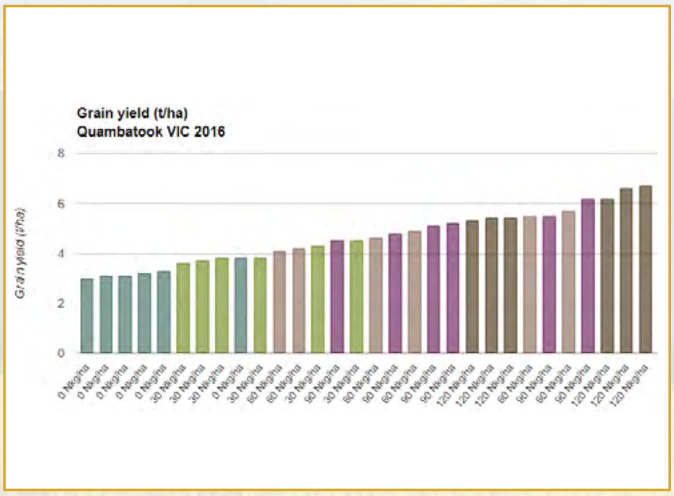

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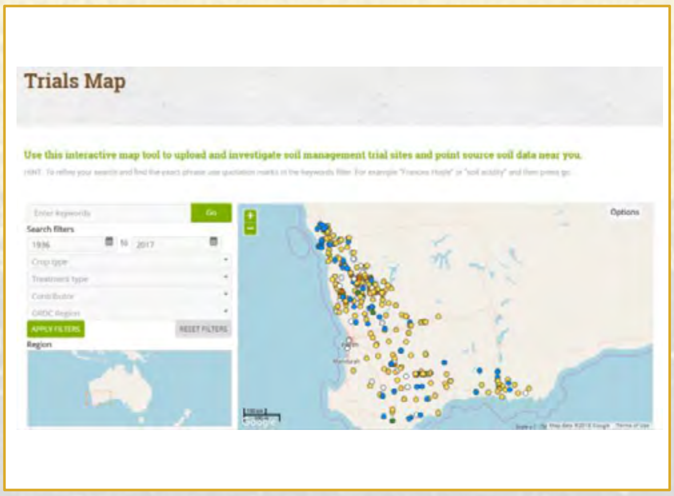

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National Variety Trials update

Tom Giles[1], Rob Wheeler[1], Ky Mathews[3], Neale Sutton[2], Ben O'Connor[2] and Tatjana Karov[2].

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GRDC project codes: SFS00035, BWD00029, EAS00003, CAS00003

Keywords

- National Variety Trials (NVT), Factor Analytic (FA) models, Long Term Multi Environment Trial (MET) reporting tool, Variety x Environment Interactions (VEI).

Take home messages

- NVT interpretation and reporting tools will require continuous development to ensure growers can fully exploit opportunities afforded by the NVT program.
- A simple web tool for viewing the vast datasets encountered in the NVT system is being developed.
- An opportunity now exists to help growers understand and interpret Variety by Environment Interactions (VEI) observed in NVT.

Overview

The National Variety Trials (NVT) is the world's largest grains variety trialling network, initiated in 2005 with funding from GRDC and formerly managed by the Australian Crop Accreditation System (ACAS).

Each year, approximately 2000 near-release or released varieties across 10 crops are evaluated in approximately 650 trials nationwide. This represents a substantial logistical undertaking that is 100% funded and administered by the GRDC on behalf of Australian grain growers.

The NVT generates highly valuable comparisons for variety performance characteristics including grain yield, disease and pest resistance (used to produce variety ratings) and grain quality and agronomic traits for all major crop types.

The dataset, assembled since 2005, in the NVT database is enormous and provides an exciting and valuable opportunity to create new research outcomes that will underpin greater profitability for growers. Specifically, the datasets that exist provide an unrivalled platform for the development of new analytical models and methodologies, including the latest Factor Analytic (FA) models used by both breeders and NVT to understand and explain how variety rankings change between locations and years.

However, increasing sophistication of variety performance data, in conjunction with more specific

user preferences, means that NVT interpretation and reporting tools will require continuous development to ensure growers can fully exploit opportunities afforded by the NVT program.

NVT reporting

NVT uses an improved Google Map interface for reporting yield and grain quality data to users. New features in 2018 include automated live updates when trial information becomes available, and trial marker flags for all trials including those abandoned or yet to be harvested. This helps identify the fate of local trials near you if they have failed and not been released.

After harvest, trial pins will appear on the exact location of the trial site. Numbered balloons will show the count of trials at the location, and clicking these balloons will pop-out all trial pins for that location. The previous system adjusted the marker locations so they did not appear on top of each other when trials were only metres apart, but this meant it did not always show a true reflection of the site location.

Access to single site data via PDF or Excel is provided, as well as a link to the Long Term Multi Environment Trial (MET) reporting tool. The Long Term MET data is more accurate and reliable than single-site data and is the newly developed reporting tool and the preferred method for interpreting yield performance.

A 2017 'Unreleased Trial Report' is also available as an independent download from the NVT website. This report is provided as a means of transparency for grower investments in the NVT program. It includes 'unreleased' results from severely frosted trials and those deemed as failures for other environmental reasons or data integrity measures. Data from this report cannot be reproduced, replicated or copied and is prohibited for use in any other publications.

Interpreting long term yield data

The long-term yield data presented in crop sowing guides, for example, Winter Crop Summary, is an output of the new NVT Long Term MET analysis. NVT implements trials in all cropping regions of Australia and uses a minimum five-year rolling dataset in the MET analysis.

A FA mixed model approach is used in the MET analysis drawing on expertise from the GRDC supported Statistics for the Australian Grains Industry (SAGI) program. This approach uses raw plot data to simultaneously model the individual trial variation and the Variety by Environment Interactions (VEI) observed across years and geographical locations to develop the NVT long-term variety by environment predictions. In this way, NVT long-term predictions better exploit the true power that exists within the NVT database which now encompasses more than 8000 individual trials.

To gain the full benefit of these world leading statistical outputs, users should study variety rankings across locations and seasons relevant to their farming system. However, presenting this level of detail is difficult within hardcopy publications which are left needing to average across regions and/or yield groupings. Averaging does simplify the data and allows for broad sweeping generalisations, but also actually masks variety performance comparisons that might otherwise be observed for specific environments, effectively undoing the sophistication of the new analysis.

To overcome this challenge, the NVT team has continued to develop a simple web tool for viewing the vast datasets encountered in the NVT system and it is available at https://app.nvtonline.com.au.

When using the tool, the results are most accurate and reliable when viewed at the individual location (site) level, but the option is still provided for regional or multi-site selections for ease of use and/or more generic interpretations. In addition, users can still choose to view data on Year or Yield based groupings, both in chart or table format and they can also filter wheat varieties by delivery classification.

The more advanced user can set their tolerances for data Accuracy (Acc) and % Variance Accounted For (%VAF) levels above or below the recommended NVT default setting of 0.8% and 50%, respectively.

The app is designed to run on all web browsing platforms on computers, tablets and phones.

Future outlook

With the increased sophistication afforded by the latest analytical and reporting techniques, an opportunity now exists to help growers understand and interpret the VEI observed in NVT. In particular, research to better explain the environmental drivers of variety performance will assist growers more easily relate NVT results to their growing environment(s).

Finally, the wide range of variety trait information made available through NVT supports more considered variety selection decisions, but again adds complexity. To enable growers to more easily navigate the selection process, the NVT team is investigating options for growers to select their user preferences with regard to sites, varieties and traits of interest.

Acknowledgement

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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Long fallows maintain whole-farm profit and reduce risk in the Mallee

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La Trobe University, Melbourne.

GRDC project code: UHS11009

Keywords

- long fallow, whole-farm economics, crop simulation, break crops.

Take home messages

- Many of the farming system benefits of long fallow can only be quantified at the whole-farm level.
- A long fallow-wheat rotation was more profitable than continuous wheat production and a chickpea-wheat rotation when the price of chickpeas was below $800/t.
- If using fallow tactically, a good rule of thumb for the southern Mallee is to only sow wheat if mineral nitrogen (N) (kg/ha) + plant-available water (mm) at sowing is more than 100 units, and chickpeas if plant available water (PAW) is more than 50mm.

Background

Managing soil nitrogen (N) and water is a vital part of maximising wheat yields in the Mallee. Long fallowing — the practice of leaving a field out of production for an entire growing season — was traditionally used to accumulate soil water and N for future crop use, but declined in popularity during the 1980s as profitable break crops (including pulses and canola) were made available in the region. However, despite the additional income provided by break crops, whole-farm profits across the Mallee have stagnated in recent decades, due to rising input costs and declining growing season rainfall across southern Australia (van Rees et al. 2014).

Previous economic studies have suggested that the yield benefit provided by long fallow to following crops does not outweigh the missed income opportunity that break crops offer. However, these conclusions have been based on simplistic gross margin analyses, and ignore the whole-farm benefits provided by long fallows, such as increased timeliness of operations and reduced income variability. As wheat production in the Mallee now requires increasing investment to return the same profit as previous years, long fallowing may provide growers with an opportunity to decrease exposure to risk and income variability, without sacrificing profit.

This study aimed to use whole-farm economics to reassess the profitability of long fallow-based rotations in the Mallee compared to continuous wheat and wheat-break crop rotations. The project also attempted to calculate a threshold level of soil water or mineral N which, if not met at sowing, indicates a favourable opportunity to fallow.

Method

The Agricultural Production Systems sIMulator (APSIM) was used to simulate crop production at Jil Jil, near Birchip, over a 20-year period (1997 to 2016). A fallow-wheat (FW) rotation was compared to continuous wheat production (WW) and a chickpea-wheat (CW) rotation over a hypothetical farm area of 4000ha. Each rotation was managed as a farming system and therefore received a unique N fertiliser rate to achieve the most economical yield. Urea was applied at sowing (to the WW and CW rotation) and at stem elongation (to all rotations) to maximise the number of years in which wheat grain protein fell between 10.5% and 12.5%. A whole-farm environment was simulated through adjusting the sowing window of each rotation to reflect the proportion of 4000ha that was cropped (i.e. the FW rotation was sown in half the time of the WW and CW rotations). APSIM was used to measure annual yield, wheat grain protein and N fertiliser application.

Whole-farm income was calculated using five-year average (2012 to 2016) crop prices for Birchip (Australian Premium White (APW) = $260/t; chickpea = $620/t). Wheat grain proteins were used to determine the grain grade and therefore value of the wheat. Variable costs were calculated based on the 2016 PIRSA Farm Gross Margin Guide, with costs modified for each rotation. It was less expensive to grow wheat after long fallow or chickpeas, as the selective herbicide pyroxasulfone (Sakura®) was only applied to wheat grown after wheat ($40/ha). Weed control during the summer fallow was estimated at $20/ha, with a long fallow costing an additional $60/ha to maintain weed-free with herbicides. The same whole-farm costs (including machinery operating costs, labour and drawings) were applied to all rotations. An additional 6% was added to variable costs to account for interest and borrowing costs. Annual cash flow was calculated as gross income minus all variable, whole-farm and finance costs.

Annual cash flow of all three rotations was examined to determine if there was a common condition between unprofitable years in the WW and CW rotations. The aim was to devise a rule by which growers could know at sowing the likelihood of a crop failing to return a profit, and could elect to fallow. Once traits were identified for each rotation, 'opportunity sowing' rotations were created, in which crops were replaced with fallows if conditions were not met.

Results and discussion

Yield results

Wheat grown after long fallow yielded 1.5t/ha more than wheat grown after wheat (Table 1). Wheat in the long fallow rotation had access to significantly more PAW and mineral N at sowing compared to the other rotations. Wheat grown in continuous sequence required the most urea to achieve economical yield, whilst wheat grown after chickpeas had access to the least PAW.

While previous studies have shown an increase in the yield of wheat grown following a pulse crop such as chickpeas, this is largely due to legume N-fixation. As all rotations were supplied with sufficient N fertiliser to achieve economical yield, wheat grown following chickpeas did not yield higher than wheat after wheat, but did require less N fertiliser. While chickpeas do fix atmospheric N, the low level of mineral N at wheat sowing suggests that sufficient soil water is essential in mineralising N into plant-available forms.

The yield benefit provided by fallow is larger here than estimated in several other studies, due to the whole-farm nature of the research. Reducing the sowing window from 28 days (as seen in the WW rotation) to 14 days (FW rotation) improved wheat yield by 0.2t/ha by itself, while the unique fertiliser rules allowed wheat grown after fallow access to additional N through linking urea applications to soil moisture content.

Profitability and risk

The fallow-wheat rotation was also the most profitable system over the twenty-year period (Figure 1). During the first five years, when rainfall was high, the continuously cropped rotations performed best. However, during the Millennium drought (Years 6 to 13), both the WW and CW rotations made a net loss, while the FW rotation returned a series of small, but consistent profits. The value of long fallowing is therefore highest when in-crop rainfall is low.

The FW rotation not only returned more profit than other rotations, it also carried the least risk (Table 2). Long fallows reduce total costs and therefore a farm's exposure to risk in years of low in-crop rainfall, depressed grain prices or high input prices. The low standard deviation of the FW rotation also indicates less variability in profit between years. While returns are lower than continuous cropping during good years, income was more reliable across the entire 20 years.

Table 1. Mean plant-available water (PAW), N and yield results for all rotations averaged for the period 1997to 2016.

Rotation	PAW at sowing (mm)	Mineral N at sowing (kg/ha)	Urea applied (kg/ha/year)	Wheat yield (t/ha cropped)	Chickpea yield (t/ha cropped)
WW	56	60	102	1.8	
CW	36	53	87	1.7	0.9
FW	190	155	63	3.3	

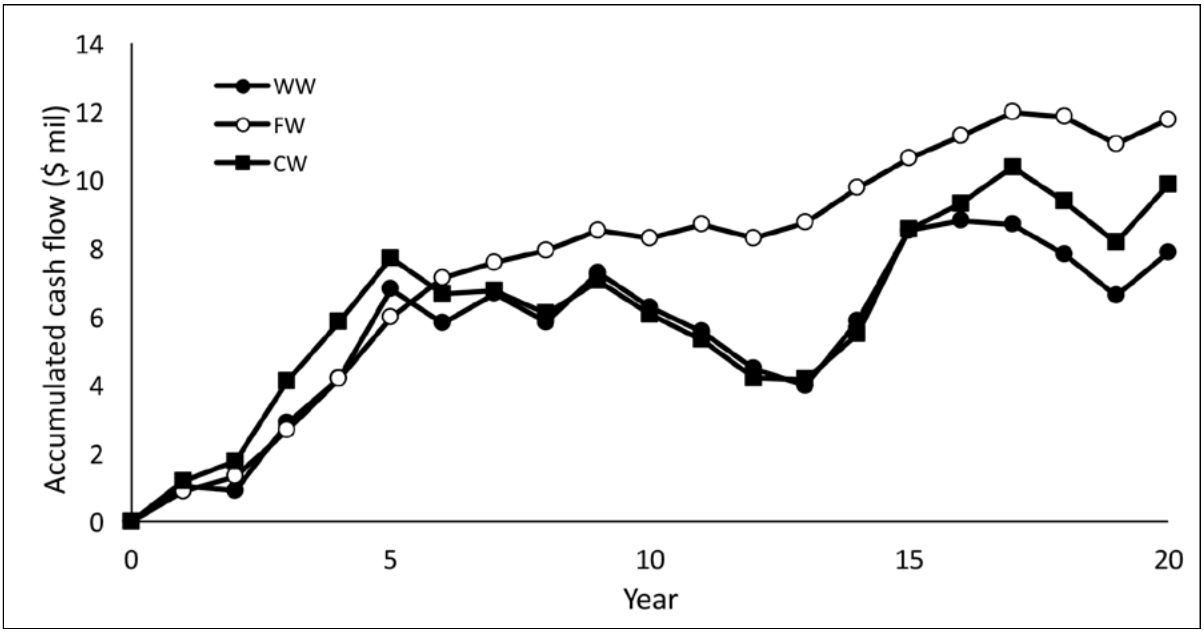

Figure 1. The accumulation of cash flow over 20 years (1997to 2016) for all rotations.

Price sensitivity

The profitability of all rotations was highly sensitive to changes in grain prices (Table 3). The FW rotation had the greatest advantage over the CW rotation when the price of wheat was high and chickpea prices were low. When the prices of both commodities were depressed, the FW rotation was also preferred. Once the price of chickpeas rose to $800/t, the opportunity cost of the FW rotation was too great to return a higher cash flow than the CW rotation.

Opportunity sowing rotations

Continuous wheat production was profitable in 10 of 20 years (Fig. 1). In eight of 10 loss-returning years, the mineral N content of the soil (kg/ha) plus PAW (mm) at sowing equalled **less than 100 units**. The chickpea phase of the CW rotation was profitable in 11 of 20 years. In eight of the nine loss-returning years, the PAW content of the soil (mm) at sowing was **less than 50mm**. These two criteria were used to create 'opportunity sowing' rotations. These rotations were the same as the WW and CW, except that paddocks were fallowed instead of sown if the PAW and N criteria were not met at the prescribed sowing dates.

Table 2. Total farm costs, annual cash flow and cash flow variability for all rotations.

Rotation	Average total farm costs ($ million)	Average annual cash flow ($ million)	Standard deviation of annual cash flow ($ million)
WW	1.6	0.39	1.3
CW	1.6	0.49	1.3
FW	1.2	0.59	0.6

Table 3. Difference in average annual cash flow ($ million) of FW and CW given a range of wheat and chickpea prices. Negative values represent a higher cash flow for CW than FW.

Chickpea price		$400/t	$600/t	$800/t	$1000/t	$1200/t
Wheat price	$150/t	0.2	-0.2	-0.6	-0.9	-1.3
	$200/t	0.3	-0.1	-0.4	-0.8	-1.1
	$250/t	0.5	0.1	-0.3	-0.6	-1.0
	$300/t	0.6	0.3	-0.1	-0.5	-0.8
	$350/t	0.8	0.4	0.1	-0.3	-0.7

Table 4. Average annual cash flow of set rotations and opportunity sown rotations.

Rotation	Average annual cash flow ($ million)	Annual cash flow – opportunity sowing ($ million)
WW	0.39	0.69
CW	0.49	0.76
FW	0.59	

Using these rules improved cash flow by $0.30 million and $0.27 million for the WW and CW rotations, respectively (Table 4). Cash flow for opportunity-sown rotations was higher than in the standard fallow-wheat rotation. These rules improve whole-farm finances by minimising losses in dry years, and maximising production when stored soil water is high.

Conclusions

When whole-farm finances are taken into consideration, long fallow-wheat rotations appear capable of lowering total farm costs and income variability, and maintaining whole-farm cash flow when compared to continuous wheat production and chickpea-wheat rotations. Incorporating a long fallow into a rotation reduces value-at-risk and inter-annual income variability, as well as reducing the sensitivity of the rotation to changes in crop or input prices. The value of long fallow to whole-farm finances is largest during dry seasons, when crop prices are low, and when the price of urea, fuel and other variable inputs are high. It is important that growers remain flexible and reserve the option to fallow land, particularly when stored soil water and N are low. Long fallows, therefore, continue to be a valuable tool available to grain growers in the Mallee for not only the accumulation of soil water and N for future crop use, but also the reduction of costs whilst maintaining profit margins.

Reference

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Acknowledgements

The scholarship for this work was provided through the GRDC and its support is gratefully acknowledged. We also thank Bill Malcolm for helpful discussions on this topic.

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Physiological and biochemical responses of lentils to silicon mediated drought tolerance

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GRDC project code: GRS-11011

Keywords

- lentil, drought stress, silicon.

Take home messages

- Silicon (Si) improves seed germination and alleviates drought stress in lentil crops by regulating osmolytes, hydrolytic enzymes and antioxidant defence systems.
- Silicon potentiates photosynthetic efficiency and biochemical defence responses of lentils against drought stress.
- Silicon improves the yield traits in drought stressed lentils.

Background

This project, through investment by GRDC, is focused on elucidating the role of silicon (Si) in conferring drought tolerance in lentils, an important legume crop of Australia. The project investigates the possible physiological, biochemical and molecular mechanisms behind SI mediated drought tolerance in lentils. We have identified drought tolerant genotypes through a screening experiment in glasshouse studies. Another glasshouse experiment was carried out to investigate the role of Si application and drought stress in lentil genotypes. Results from the experiments conducted so far are promising. They revealed that the yield traits, photosynthetic efficiency, the concentration of reactive oxygen species (superoxide radicals and hydrogen peroxide (H_2O_2), and the antioxidant compounds and enzymes in glutathione ascorbate (GSH-AsA) cycle, which were the main factors related to reduced growth and yield in response to drought, increased significantly with Si application under drought stress. Thus, Si could ameliorate adverse effects of drought stress in lentil crops likely by increasing photosynthetic efficiency, reducing oxidative stress and osmotic stress. The results from these experiments would be further validated by field trials and other relevant molecular experiments in the laboratory at The University of Melbourne (UM).

Introduction

Lentils (*Lens culinaris Medik*) are the most ancient cultivated crop among legumes and an important source of protein, minerals and vitamins for the human diet (Yadav et al. 2007). Lentils are classified as a Si excluder and are moderately tolerant to drought stress. Even though lentils are a moderately drought tolerant crop and can grow in reduced water supply, plant productivity can decrease from 6% to 54% under a range of drought stress conditions (Siddique et al. 1999). Severe water stress can lead to total crop failure, especially in semi-arid regions, where they are commonly exposed to intermittent or terminal drought stress conditions.

Lentils are highly sensitive to drought stress at key growth stages, such as seedling, flowering and grain filling (Shrestha et al. 2006). With the forecast of increased water scarcity in the near future, drought stress will remain a major threat to global lentil production. Breeding for drought tolerance remains challenging due to variation in climatic conditions and multigenic origin of the adaptive responses of lentil plants to drought stress (Kumar et al. 2016; Idrissi et al. 2016). Therefore, another more sustainable approach is the use of exogenous compounds, which are easily available and cost effective to incorporate into agronomical practices with negligible detrimental effects to the environment.

Silicon (Si) is the second most ubiquitous element in the earth's crust which has been shown to be effective in improving drought tolerance in some Si-accumulating monocot plants such as rice (Chen et al. 2011), sorghum (Hattori et al. 2007), maize (Sayed and Gadallah, 2014) and wheat (Pei et al. 2010). It has also been shown to be effective in a few dicot plants such as sunflowers (Gunes et al. 2008), cucumbers (Ma et al. 2004), soybeans (Shen et al. 2010), tomatoes (Shi et al. 2016) and chickpeas (Kurdali et al. 2013). Priming of seeds with S has been considered as one of the alternative methods to improve drought tolerance in plants (Hameed et al. 2013; Ahmed et al 2016). Si-seed may fortify plants against future stress events and appears to be a promising and cost-effective procedure. Under drought stress conditions, Si is thought to act as a mechanical barrier to minimise transpiration losses and also mediates many metabolic, physiological and biochemical pathways which subsequently improve drought tolerance. A number of possible mechanisms were proposed through which Si may increase drought tolerance in plants, especially improving the water status of plants, increased photosynthetic activity and ultra-structure of leaf organelles (Coskun et al. 2016). However, most of the studies are carried out in monocots which tend to be high Si accumulators and only little research has been conducted in dicot plants, which usually have low capability of Si accumulation. Thus, studying the role of Si in low Si-accumulating legumes (Meena et al. 2014) such as lentils would help to unravel the actual mechanism and function of Si-mediated drought tolerance in plants and the ability of lentil crops to cope with drought stress conditions with a minimum impact on critical growth stages.

Germination and seedling development are very important stages that determine the successful early establishment of a plant in its growing environment. Water plays a key role in germinating seeds through hydrolytic breakdown of food reserves, solubilisation and the transport of metabolites, osmotic adjustment and enzymatic reactions. However, water scarcity seriously hampers successful seedling establishment (Shi et al. 2016). Hydrolytic enzymes such as α-amylase, β-amylase and α-glucosidase play a pivotal role during seed germination by hydrolysing starch into sugar. The activity of these enzymes is suppressed by drought stress with negative impacts on carbohydrate metabolism. Accumulation of the osmolytes (proline, glycine betaine-GB and soluble sugar) under drought stress in many plants has been positively correlated with water stress tolerance. These compounds are thought to play adaptive roles in mediating osmotic adjustment and protecting subcellular structures in stressed plants (Ashraf & Foolad, 2007; Singh et al. 2015; Blum et al. 2017). Similarly, it is well known that abiotic stresses including drought stress can cause oxidative damage to plants, either directly or indirectly through the formation of reactive oxygen species (ROS), such as superoxide anion- O2 − and H_2O_2 (McCord, 2000; Das & Choudhary, 2016). Plants respond to this oxidative stress by increasing the production of antioxidant enzymes such as ascorbate peroxidase (APX: EC.1.11.1.11), catalase (CAT, EC 1.11.1.6) and superoxide dismutase (SOD, EC 1.15.1.1), which can scavenge ROS and in turn protect the plants from oxidative damage (Noctor et al. 2014; Das & Roychoudhary, 2016). Since their activities and transcripts are altered when plants are subjected to stress conditions, changes in the levels of antioxidant enzymes and ROS have been used to assess the effect of drought stress in plants (Hasegawa et al. 2000; Hernandez et al. 2000). Enhanced germination of seeds by Si application has been shown in different monocots and dicots under controlled conditions (Torabi et al. 2012). Relatively few studies have investigated the effect of Si on seed germination rate and seedling growth under drought stress in plants such as wheat and tomatoes (Hameed et al. 2013; Shi et al. 2014). However, the effect of Si on the concentrations of osmolytes activity of hydrolytic enzymes, activity of antioxidant enzymes, the concentration ROS and the level of lipid peroxides (LPX) under drought stress has not been investigated so far in seed germination studies of crop plants. Moreover, to the best of our knowledge, no studies have been undertaken until now to elucidate the role of Si in drought stressed lentil plants.

Therefore, given the potential of Si for drought tolerance (Liang et al. 2003; Coskun et al. 2016) and lentils being one of the most nutritious plants of the future, the objectives of the present study were specifically (1) to elucidate the role of Si in stimulating seed germination by evaluating the metabolism of osmolytes, antioxidants and the activity of hydrolytic enzymes under controlled and drought stress conditions, and (2) to recommend Si as a source to improve drought stress tolerance in lentil crops.

Materials and methods

See details listed within the GRDC website full version of this paper

Results

Effect of Si on the germination traits assessed by GP, GI and SVI in lentil genotypes

The effects of drought stress and Si treatment on the germination percentage (GP) of seven lentil genotypes, calculated using the Equation 1, are shown in Figures 1 and 2a. PEG 6000-stress significantly reduced the GP of each genotype as compared to the control. However, Si application under drought stress increased GP significantly in all of the genotypes ($p < 0.01$), when compared to drought stressed plants. The effect of Si under drought stress was more pronounced in both the drought-sensitive genotypes, G6 (PI 468898) and G7 (ILL 1796) (2.5-fold increase in GP). Interestingly, irrespective of the drought tolerance capacity, all the studied genotypes exhibited 100% GP by added Si under non-stress conditions.

The GI and SVI values were calculated using Equations 2 and 3. Similar to GP values, Si significantly increased GI and SVI values among all the genotypes under drought stress (Figures 2b and 2c). The Si application did not show any significant

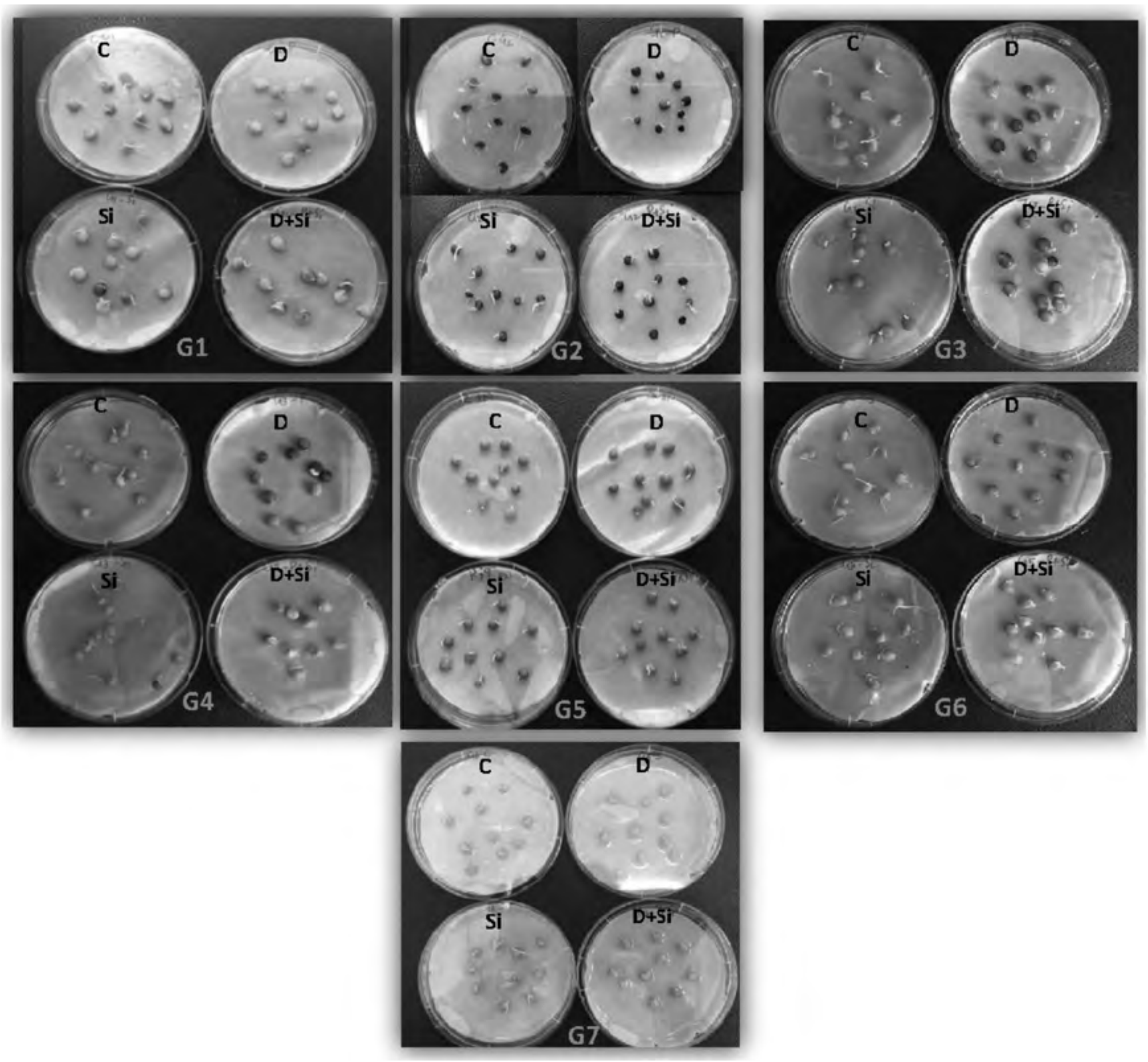

Figure 1. Seed germination of seven lentil genotypes under different drought stress treatments. ILL 6002 (G1), Indianhead (G2), PBA Jumbo 2$^{\phi}$ (G3), Nipper$^{\phi}$ (G4), PBA Flash$^{\phi}$ (G5), PI 468898 (G6) and ILL 1796 (G7) represent different lentil genotypes. Control (C), drought stress (D), drought stress + Si (DSi) and Si alone (Si) are the different drought stress treatments. Different letters denote statistical differences at $p < 0.01$ within genotypes.

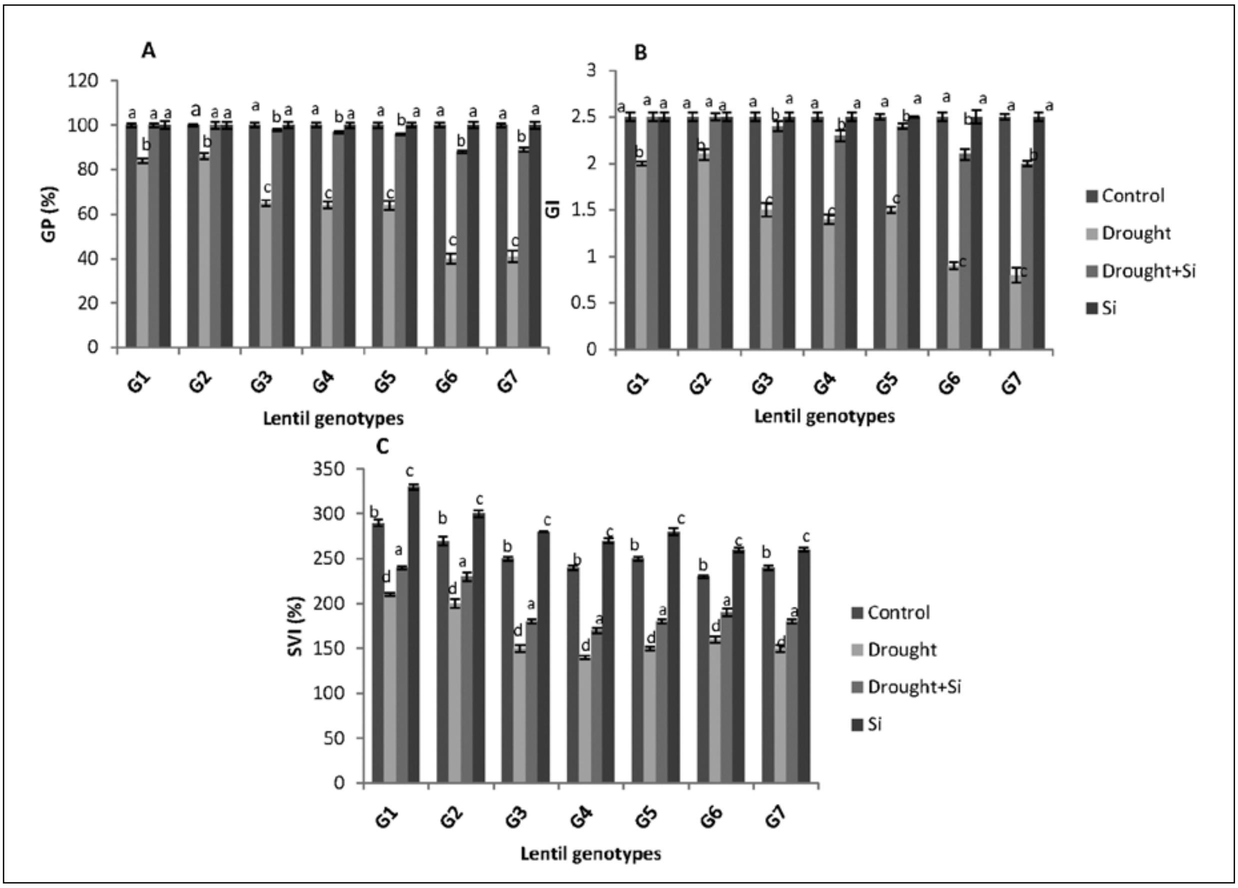

Figure 2a, b and c. Germination percentage (GP %), germination index (GI) and seedling vigour index (SVI-%) of the seven lentil genotypes under different drought stress treatments. ILL 6002 (G1), Indianhead (G2), PBA Jumbo 2$^{\text{⁽ᵇ⁾}}$ (G3), Nipper$^{\text{⁽ᵇ⁾}}$ (G4), PBA Flash$^{\text{⁽ᵇ⁾}}$ (G5), PI 468898 (G6) and ILL 1796 (G7) represent different lentil genotypes. Control (C), drought stress (D), drought stress + Si (DSi) and Si alone (Si) are the different drought stress treatments. Mean values provided with error bars represent the standard error. Different letters denote statistical differences at $p < 0.05$ within genotypes.

effect on the GI of each genotype under non-stress conditions. However, Si application significantly affected the SVI values in all the studied genotypes under drought stress conditions.

Effects of Si application on fresh and dry weight of the seedlings

The fresh and dry weight of the seedlings decreased significantly with exposure to drought stress (Table 1). However, application of Si increased the fresh and dry weight under stress and non-stress conditions.

Effects of Si application on the levels of osmolytes in seedlings of lentil plants

The concentrations of the osmolytes (proline, GB and total soluble sugar) significantly increased in all the lentil genotypes under drought stress, while Si treatment led to a reduction in their values (Figures 3a, 3b and 3c). Figure 3a shows the variation in proline concentration, obtained using the Eq. 4, in all the lentil genotypes under different drought stress treatments. Drought stress alone increased the proline level almost 2-fold compared to the control treatment in all the genotypes. Interestingly, proline concentration was found to be higher in drought tolerant genotypes, G1 (ILL 6002) and G2 (Indianhead), when compared to the drought-sensitive genotypes, G6 (PI 468898) and G7 (ILL 1796) in all the treatments. The application of Si lowered the proline level of drought stressed seedlings by 20% to 25 %. Even though GB accumulation increased significantly in drought stressed seedlings, Si application resulted in 20% to 40% reduction in GB content of drought stressed plants. However, there was no significant difference in GB content of Si treated lentil seedlings under non-stress condition, compared to the control. The accumulation of GB was higher in drought tolerant genotypes, G1 (ILL 6002) and G2 (Indianhead), when compared to the drought sensitive genotypes, G6 (PI 468898) and G7 (ILL 1796) in all the treatments

Table 1. Fresh and dry weight (mg) of the seedlings of seven lentil genotypes under different drought-stress treatments. Mean values provided with error bars representing the standard error. Different letters denote statistical differences at $p < 0.01$ within genotypes.

Fresh Weight (mg)					Dry Weight (mg)			
Lentil genotypes	Control (C)	Drought (D)	Drought +Si (DSi)	Si (Si)	Control (C)	Drought (D)	Drought + Si (DSi)	Si (Si)
G1	120±0.002b	80±0.001d	90±0.001c	130±0.001a	9±0.0001b	4±0.0001c	9±0.0002b	16±0.0001a
G2	80±0.001b	50±0.002d	70±0.002c	140±0.002a	5±0.0001b	3±0.0001c	6±0.0002b	17±0.0002a
G3	120±0.001b	70±0.001c	90±0.003c	160±0.001a	9±0.0001b	0	7±0.0002c	8±0.0002a
G4	90±0.002b	70±0.003c	80±0.001c	150±0.002a	5±0.0001b	0	4±0.0001c	7±0.0001a
G5	120±0.001b	90±0.002c	100±0.002c	150±0.010a	7±0.0001b	0	5±0.0001c	9±0.0001a
G6	180±0.003b	80±0.002d	110±0.001c	190±0.001a	1±0.0001b	0	2±0.0002b	6±0.0002a
G7	50±0.001b	100±0.001d	40±0.002c	80±0.001a	1±0.0002b	0	2±0.0001b	4±0.0002a

(Figure 3b). Similar to proline and GB, considerable variation in the total soluble sugar concentration was observed in all the studied genotypes under Si treated and non-Si treated drought stress treatments (Figure 3c). However, the amount of total soluble sugar in only Si treated plants was similar to that of the control treatment.

Effects of Si application on the activities of hydrolytic enzymes

The activity of hydrolytic enzyme (α-amylase, β-amylase and α-glucosidase) decreased significantly in all the genotypes under PEG 6000-induced drought stress and the effect was reversed by the addition of Si (Figures 4a, 4b and 4c). Under control conditions, the drought tolerant genotypes, G1 (ILL 6002) and G2 (Indianhead) showed the maximum α-amylase activity of 1.5

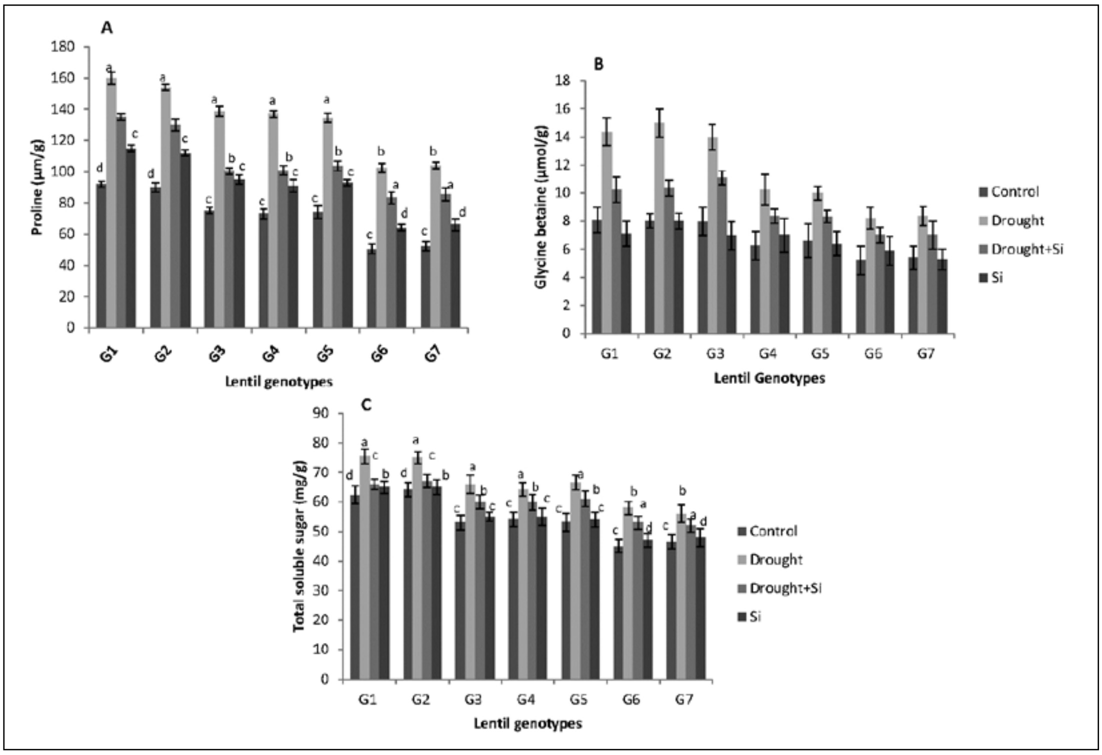

Figure 3a, b and c. Concentration of proline (µm/g), glycine betaine (GB- µm/g) and total soluble sugars concentration (mg/g) in seven lentil genotypes under different drought stress treatments. ILL 6002 (G1), Indianhead (G2), PBA Jumbo 2$^{\Phi}$ (G3), PBA Nipper$^{\Phi}$ (G4), PBA Flash$^{\Phi}$ (G5), PI 468898 (G6), ILL 1796 (G7) represent different lentil genotypes. Control (C), drought stress (D), drought stress + Si (DSi) and Si alone (Si) are the different drought stress treatments. Mean values provided with error bars represent the standard error. Different letters denote statistical differences at $p < 0.05$ within genotypes.

and 1.4µm-1.min-1.g tissue, respectively. The droughtsensitive genotypes G6 (PI 468898) and G7 (ILL 1796), however, displayed lower activity of this hydrolytic enzyme, i.e. 0.83 and 0.86µm-1.min-1.g tissue, respectively. Similar levels of α-amylase activity (1µm-1.min-1.g tissue) were noticed in all the moderately drought tolerant genotypes G3 (PBA Jumbo 2$^{\phi}$), G4 (Nipper$^{\phi}$) and G5 (PBA Flash$^{\phi}$). The percentage of decrease in the α-amylase activity of the genotypes under drought stress was recorded as 30% (G1), 35% (G2), 57% (G3), 54% (G4), 58% (G5), 77% (G6) and 79% (G7). Si supplementation significantly increased the enzyme activity in all the genotypes under drought stress treatments as seen in Figure 4a. A similar trend was observed for the activity profile of the hydrolytic enzymes, β-amylase and α-glucosidase. β-amylase activity under drought stress ranged from 20% reduction in the drought tolerant genotypes G1 (ILL 6002) and G2 (Indianhead) to 65% in drought sensitive genotypes G6 (PI 468898) and G7 (ILL 1796), when it was compared to the control (Figure 4b). However, the activity of α-glucosidase ranged from 20% in the drought tolerant genotypes G1 (ILL 6002) and G2 (Indianhead) to 50% in drought sensitive genotypes G6 (PI 468898) and G7 (ILL 1796) under drought stress. Si supplied under drought stress significantly enhanced the activity of β-amylase and α-glucosidase in all the genotypes (Figure 4c).

Effects of Si application on the concentration of H_2O_2, O_2 − and LPX

Table 2 shows that the concentration of H_2O_2, O2 − and LPX were significantly higher in response to drought stress in all the lentil genotypes, whereas the concentration in response to DSi treatment showed lower values when compared to the control. The drought tolerant genotypes G1 (ILL 6002) and G2 (Indianhead) showed lower accumulation of ROS and LPX when compared to the drought sensitive genotypes G6 (PI 468898) and G7 (ILL 1796) in all the treatments. An increase of 55% to 70% in H_2O_2 content was measured in the drought stressed lentil seedlings, whereas a decrease of 60% to 65% was observed in the DSi treatment. Si treatment even lowered the H_2O_2 content in non-stressed lentil seedlings to 20% to 30 %. Added Si decreased the O2 − content in drought stressed lentil seedlings to 0.5-1-fold, when compared to 1.5-2.5-fold increase under drought stress treatments (Table 2). MDA is a final product of LPX and its content has been considered as an indicator of oxidative stresses in plants (Mittler, 2002). Significant changes in MDA content in lentil seedlings to drought stress and DSi

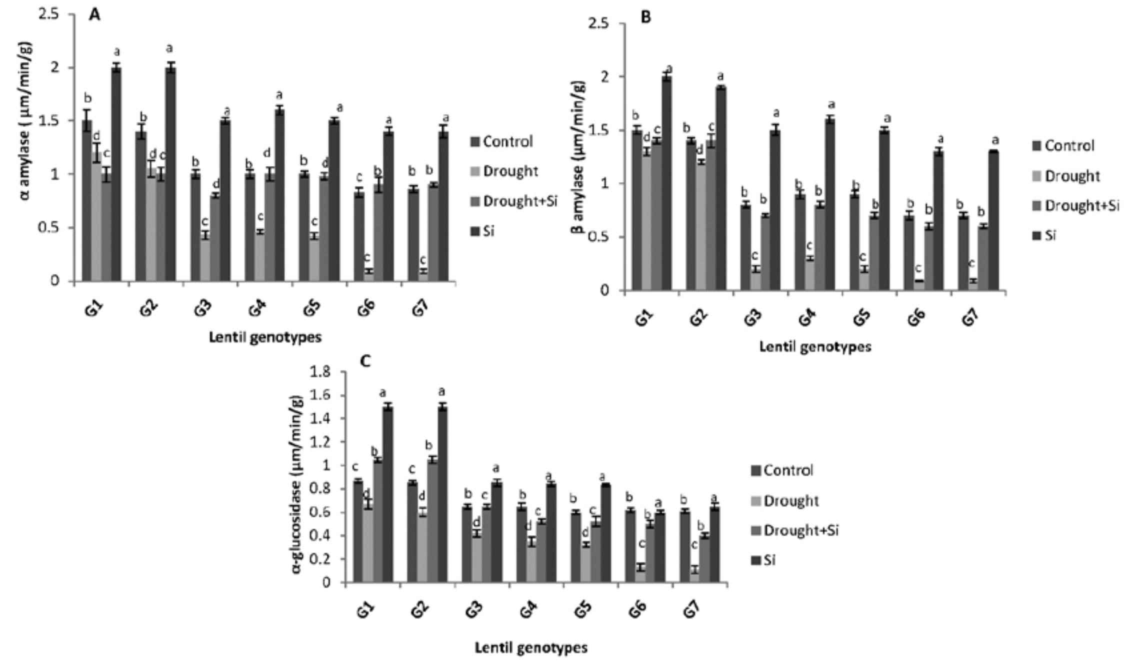

Figure 4a, b and c. Activity of α-amylase, β-amylase and α-glucosidase (µmoles of reducing sugars formed min/g) of the seven lentil genotypes under different drought stress treatments. ILL 6002 (G1), Indianhead (G2), PBA Jumbo 2$^{\phi}$ (G3), Nipper$^{\phi}$ (G4), PBA Flash$^{\phi}$ (G5), PI 468898 (G6) and ILL 1796 (G7) represent different lentil genotypes. Control (C), drought stress (D), drought stress + Si (DSi) and Si alone (Si) are the different drought stress treatments. Mean values provided with error bars representing the standard error. Different letters denote statistical differences at $p < 0.05$ within genotypes.

treatments were observed when compared to their respective controls. Drought stress resulted in a significant increase in LPX in all the lentil genotypes. However, application of Si under drought stress significantly recovered the membrane damage in seedlings as shown from the lower values of LPX. Addition of Si to non-stressed plants did not reveal any significant changes in MDA content (Table 2). Thus, the application of Si seemed to have a protective effect in terms of these parameters under drought stress conditions by lowering the concentration of ROS and LPX.

POX, CAT and SOD in lentil seedlings increased significantly under drought stress as compared to normal plants. However, Si treatment was found to be effective in enhancing the activity of these enzymes under drought stress and normal conditions (Table 3). The drought tolerant genotypes G1 (ILL 6002) and G2 (Indianhead) showed the maximum activity of all the antioxidant enzymes studied, whereas the drought sensitive genotypes G6 (PI 468898) and G7 (ILL 1796) exhibited the minimum values of enzyme activities in all the treatments.

Although drought stress caused an increase in the activity of APX, it was higher in drought stress supplemented with Si (DSi) treatment than in the other treatments (Table 3). Compared to the control, APX activity was significantly elevated up to 62% to 65% in the drought tolerant genotypes, 50% to 60% in moderately drought tolerant and 35% to 50% in drought susceptible genotypes under drought stress. Si treatment again alleviated the enzyme activity by 52% to 54% in drought tolerant seedlings, 65% to 70% in moderately drought tolerant and 80% to 85% in droughtsusceptible genotypes when

Table 2. Concentration of H_2O_2, O2 –, LPX and Si of the seven lentil genotypes under different drought stress treatments. Mean values provided with error bars representing the standard error. Different letters denote statistical differences at $p < 0.05$ within the genotypes.

Genotypes	Treatments	H_2O_2 (µmol-1.g)	O_2 – (µm-1.ml)	LPX (µmol-1.g)	Si (%/g dry weight)
G1	Control	1.22 ± 0.33	167.89 ± 0.23	0.08 ±0.01	0.0042 ±0.006
	Drought	2.08 ± 0.01	425.36 ± 0.49	1.98 ± 0.11	0.0132 ± 0.002
	Drought+Si	0.73 ± 0.32	153.25 ± 0.52	0.97 ± 0.02	0.0324 ± 0.021
	Si	0.87 ± 0.01	165.28 ± 0.53	0.06 ± 0.01	0.0067 ± 0.001
G2	Control	1.24 ± 0.31	163.25 ± 0.27	0.07 ± 0.01	0.0046 ± 0.003
	Drought	2.12 ± 0.01	414.25 ± 0.24	1.87 ± 0.12	0.0142 ± 0.003
	Drought+Si	0.85 ± 0.11	162.32 ± 0.78	0.77 ± 0.01	0.0364 ± 0.022
	Si	0.98 ± 0.21	160.25 ± 0.29	0.07 ± 0.02	0.0051 ± 0.002
G3	Control	1.55 ± 0.02	215.02 ± 0.25	0.15 ± 0.04	0.0047 ± 0.011
	Drought	3.65 ± 0.14	598.21 ± 0.27	2.79 ± 0.10	0.0125 ± 0.010
	Drought+Si	1.37 ± 0.01	204.56 ± 0.45	0.85 ± 0.11	0.0368 ± 0.011
	Si	1.15 ± 0.01	210.89 ± 0.67	0.09 ± 0.01	0.0072 ± 0.003
G4	Control	1.46 ± 0.23	211.19 ± 0.59	0.15 ± 0.02	0.0041 ± 0.023
	Drought	3.58 ± 0.11	564.32 ± 0.27	2.58 ± 0.43	0.0361 ± 0.014
	Drought+Si	1.26 ± 0.02	201.02 ± 0.46	0.72 ± 0.03	0.0078 ± 0.004
	Si	1.02 ± 0.87	200.07 ± 0.97	0.13 ± 0.01	0.0067 ± 0.014
G5	Control	1.57 ± 0.24	208.37 ± 0.83	0.14 ± 0.05	0.0042 ± 0.011
	Drought	3.56 ± 0.52	546.32 ± 0.22	2.86 ± 0.21	0.0328 ± 0.021
	Drought+Si	1.31 ± 0.05	200.03 ± 0.25	0.65 ± 0.11	0.0066 ± 0.013
	Si	1.13 ± 0.11	207.90 ± 0.98	0.11 ± 0.01	0.0049 ± 0.002
G6	Control	2.22 ± 0.31	255.23 ± 0.21	0.22 ± 0.02	0.0041 ± 0.023
	Drought	3.75 ± 0.02	642.35 ± 0.38	2.34 ± 0.23	0.0375 ± 0.014
	Drought+Si	1.44 ± 0.03	224.12 ± 0.27	0.67 ± 0.03	0.0067 ± 0.020
	Si	1.63 ± 0.11	213.25 ± 0.09	0.15 ± 0.04	0.0071 ± 0.004
G7	Control	1.98 ± 0.03	257.01 ± 0.27	0.26 ± 0.10	0.0049 ± 0.021
	Drought	3.25 ±0.03	655.02 ± 0.36	2.45 ± 0.23	0.0321 ± 0.011
	Drought+Si	1.21 ± 0.61	214.20 ± 0.97	0.59 ± 0.11	0.008 ± 0.014
	Si	1.54 ± 0.04	220.01 ± 0.28	0.11 ± 0.01	0.0052 ± 0.013

compared to drought stress treatments (Table 3). Compared to the control, POX activity was subsequently increased to 1-2-fold under drought stress treatments in all the studied lentil genotypes. Si application in DSi treatments caused 1-fold, 0.5-1.5-fold and 1-2-fold increase in POX activity of drought tolerant, moderately drought tolerant and drought susceptible genotypes, respectively (Table 3).

CAT activity in drought stressed lentil seedlings increased by 70% to 80% in the drought tolerant genotypes, 60% to 70% in moderately drought tolerant and 30% to 40% in drought susceptible genotypes when compared to the control. However, with Si treatment, CAT activity enhanced by 25% to 35% in drought tolerant genotypes, 50% to 60% in moderately drought tolerant and 75% to 85% in the drought susceptible genotypes. Similar to other antioxidant enzyme activity profiles, SOD activity also increased in drought stressed lentil seedlings, showing a similar trend to other antioxidant enzymes, under both drought stress conditions and DSi treatments. Compared to the control, 1.5-2-fold, 1-2-fold and 0.5-1-fold increase in SOD activity was noticed under drought stress in drought tolerant genotypes, moderately drought tolerant and drought susceptible genotypes, respectively (Table 3). Even though Si application enhanced SOD activity under DSi treatments in all the genotypes, the enhancement was not very significant.

Effect of Si on the concentration of Si in lentil seedlings

In the present study, Si concentration of drought stressed lentil seedlings increased significantly and is probably related to genotypic differences

Table 2. Activity of the antioxidant enzymes APX, POX, (CAT and SOD of the seven lentil genotypes under different drought stress treatments. Mean values provided with error bars represent the standard error. Different letters denote statistical differences at $p < 0.05$ within genotypes.

Genotypes	Treatments	APX (mmol-1.mg protein)	POX (mmol-1.mg protein)	CAT (mmol-1.mg protein)	SOD (units-1.mg protein)
G1	Control	0.785 ± 0.012	0.321 ± 0.005	0.295 ± 0.006	0.52 ± 0.06
	Drought	1.301 ± 0.014	0.687 ± 0.015	0.512 ± 0.026	1.56 ± 0.01
	Drought+Si	2.010 ± 0.045	1.354 ± 0.008	0.655 ± 0.014	1.87 ± 0.02
	Si	1.110 ± 0.023	0.567 ± 0.017	0.335 ± 0.062	0.88 ± 0.07
G2	Control	0.775 ± 0.022	0.354 ± 0.012	0.275 ± 0.032	0.63 ± 0.01
	Drought	1.400 ± 0.020	0.701 ± 0.012	0.495 ±0.008	1.67 ± 0.02
	Drought+Si	2.130 ± 0.012	1.212 ± 0.007	0.665± 0.012	1.97 ±0.02
	Si	1.010± 0.011	0.435 ± 0.031	0.401 ± 0.037	0.97 ± 0.01
G3	Control	0.301 ± 0.032	0.346 ±0.013	0.201 ± 0.022	0.36 ± 0.05
	Drought	0.454 ± 0.045	0.762 ± 0.017	0.327 ± 0.032	0.87 ± 0.02
	Drought+Si	0.735 ± 0.001	1.301 ± 0.090	0.524 ± 0.014	1.27 ± 0.07
	Si	0.387 ± 0.004	0.511 ± 0.075	0.268 ± 0.016	0.67 ± 0.08
G4	Control	0.358 ± 0.087	0.265 ± 0.036	0.213 ± 0.061	0.32 ± 0.06
	Drought	0.584 ± 0.014	0.529 ± 0.033	0.361 ± 0.030	0.97 ±0.01
	Drought+Si	0.934 ± 0.011	1.125 ± 0.028	0.556 ±0.018	1.89 ± 0.06
	Si	0.398 ± 0.042	0.398 ± 0.028	0.271 ± 0.008	1.1 ± 0.01
G5	Control	0.324 ± 0.038	0.264 ± 0.003	0.221± 0.009	0.38 ± 0.03
	Drought	0.476 ± 0.009	0.545 ± 0.009	0.374 ± 0.007	0.86 ± 0.02
	Drought+Si	0.791 ± 0.089	1.324 ± 0.067	0.567 ± 0.013	1.76 ± 0.01
	Si	0.443 ± 0.014	0.401 ± 0.024	0.312 ± 0.010	0.67 ± 0.03
G6	Control	0.197 ± 0.033	0.234 ± 0.025	0.175 ± 0.007	0.15 ± 0.08
	Drought	0.271 ± 0.002	0.561 ± 0.008	0.241 ± 0.035	0.28 ± 0.03
	Drought+Si	0.497 ± 0.045	1.526 ± 0.045	0.485 ± 0.004	1.21 ± 0.04
	Si	0.235 ± 0.014	0.339 ±0.023	0.265 ± 0.019	0.33 ± 0.08
G7	Control	0.187 ± 0.012	0.231 ± 0.067	0.169 ± 0.015	0.18 ± 0.07
	Drought	0.278 ± 0.007	0.615 ± 0.012	0.301 ± 0.024	0.29 ± 0.09
	Drought+Si	0.505 ± 0.003	1.465 ± 0.011	0.534 ± 0.023	1.35 ± 0.02
	Si	0.261 ± 0.013	0.253 ± 0.023	0.245 ± 0.011	0.76 ± 0.03

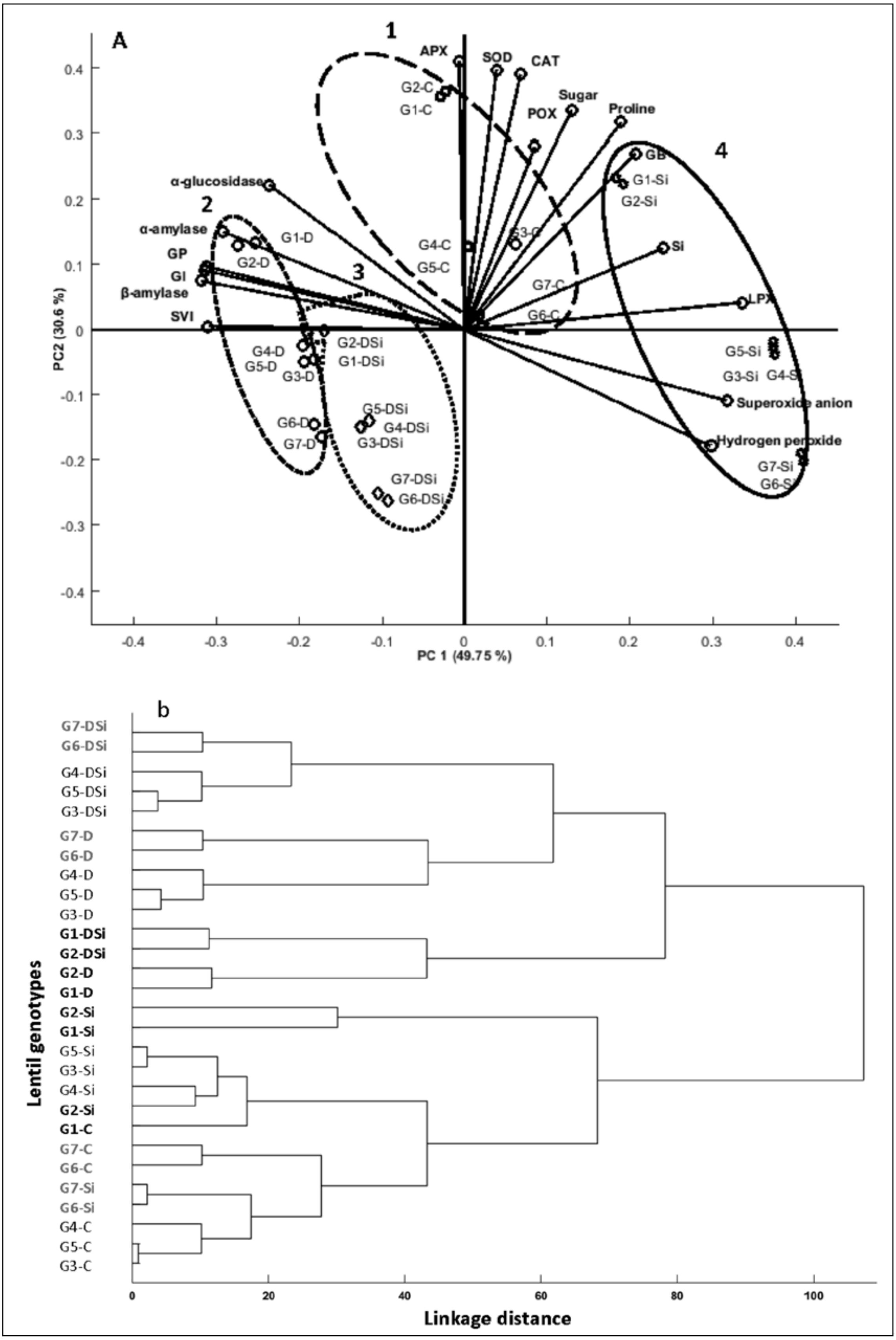

Figure 5a and b. (a) PCA biplot for drought tolerance related traits as vectors and (b) cluster analysis according to the effect of Si on the seven lentil genotypes under control (C), drought stress (D), drought stress + Si (DSi) and Si alone (Si). The abbreviations used in this Figure are ILL 6002 (G1), Indianhead (G2), PBA Jumbo 2$^{\phi}$ (G3), Nipper$^{\phi}$ (G4), PBA Flash$^{\phi}$ (G5), PI 468898 (G6) and ILL 1796 (G7).

or concentration effect of Si caused by reduced growth due to drought stress (Table 2). Moreover, the exogenous application of Si increased Si concentrations of all the lentil seedlings under drought stress (Table 2).

Multivariate data analysis

The results from multivariate data analysis from all the four treatments are shown in Figure 5. The PCA obtained from the seven lentil genotypes under control (C), drought stress (D), drought stress supplemented with Si (DSi), and Si alone (Si) including the germination traits (GP, GI and SVI), osmolytes, hydrolytic enzymes, antioxoidant enzymes, H_2O_2, O2 −, LPX and Si content explained a total of 80.35% (PC1 = 49.7 %; PC2 = 30.60 %) of variability in the data (Figure 5a). The drought tolerance assessment traits (GI, GP, SVI, osmolytes hydrolytic enzymes, antioxidant enzymes and ROS) were significantly correlated among themselves (statistical significance at $p \leq 0.05$, Figure 6). Significant positive correlations were observed between GP and GI, SVI and β-amylase, proline and APX, α-amylase and β-amylase, H_2O_2 and O2 − whereas, GP and LPX, GI and LPX, α-amylase and GB showed significant negative correlations (Figure 6). From Figure 4a, four distinctive groups can be observed with group 1 corresponding to control treatments separated between tolerant, moderately tolerant and sensitive groups. The same pattern was observed for the rest of the groups. As expected, the drought stress treatment presented the lowest values for germination traits and hydrolytic enzymes (Figures 2a, 2b, 2c, 4a, 4b and 4c) with reduced variation for proline and sugar (Figures 3a and 3b). Group 3 from the DSi treatment exhibited increased drought tolerance trait values for all the genotypes positioning the group in between the drought (group 2) and the control (group 1) treatments. The Si treatment, showed higher levels of the drought tolerance trait values studied for drought tolerance, positioning all the genotypes closer to the control treatment (group 1).

The cluster analysis clustered the lentil genotypes into different groups based on different drought stress treatments (Figure 5b). The drought tolerant genotypes, G1 (ILL 6002) and G2 (Indianhead) always clustered together under different drought stress treatments. Similar clustering was observed in moderately drought tolerant and drought sensitive genotypes at linkage distance 50.

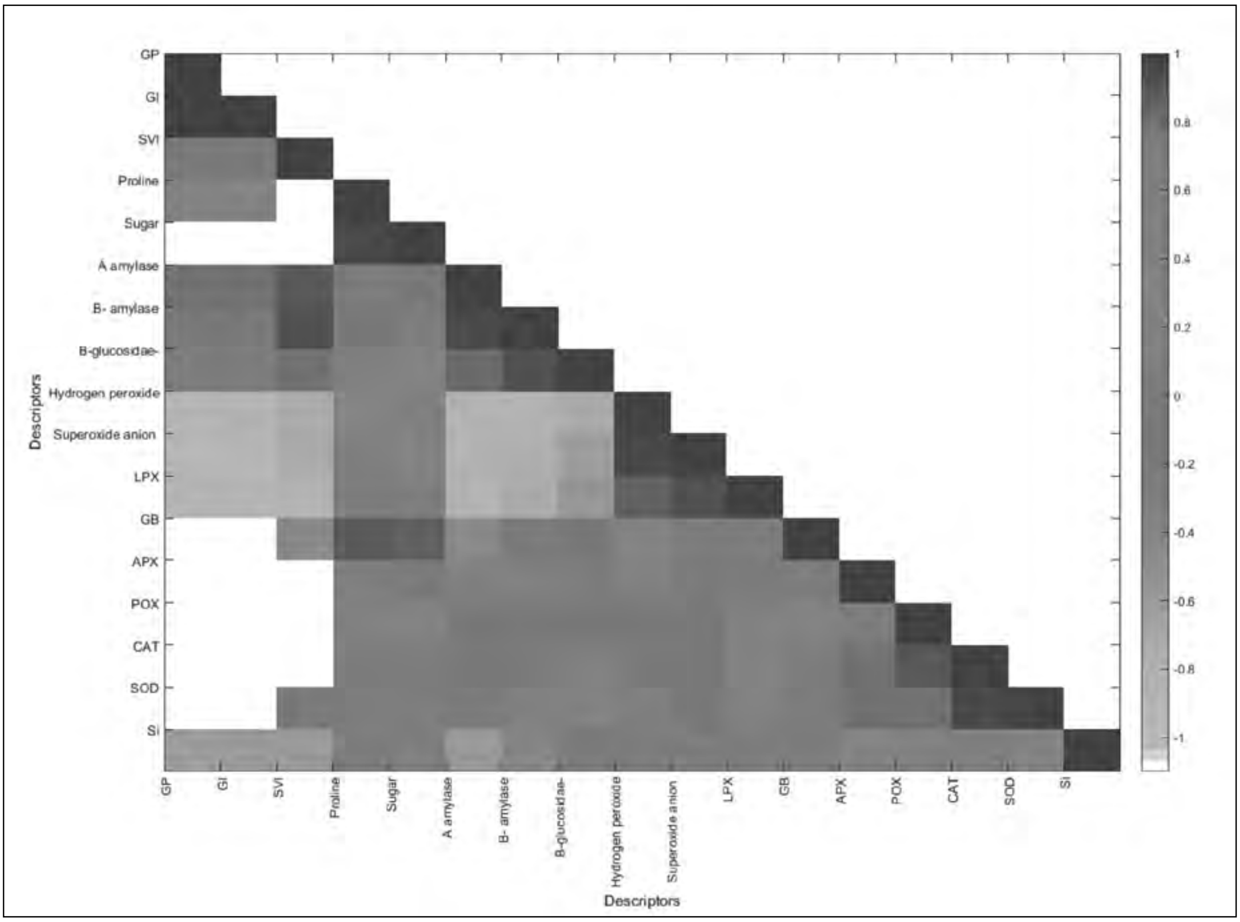

Figure 6. Covariance matrix for the drought tolerance related traits studied in seven lentil genotypes.

Discussion

Seed germination traits

Seed germination and seedling emergence are among the most critical and sensitive stages in the lifecycle of plants. Seeds exposed to drought stress may compromise the subsequent seedling establishment and hence the productivity and quality of seeds. Drought is one of the most critical environmental factors limiting lentil productivity in many regions of the world. Some of the studies have shown that lentil plants are sensitive to drought stress during seedling emergence (Muscolo et al. 2014; Mishra et al. 2016). The decline in water potential gradient between seeds and their surrounding media by the effect of PEG 6000 affects seed germination. A decline in germination traits under drought stress has also been reported in other legumes such as peas (Okcu et al. 2005) and blackgram (Pratap and Sharma, 2010). Blackgram and peas showed a significant decrease in germination percentage, i.e. 70% GP with the osmotic potential of -10 bars and 23% GP with an osmotic potential of -8 bars, respectively. Results from the present study showed that drought stress negatively affected seed germination, which could be improved by the addition of Si, as it was clearly shown by increase in GP, GI and SVI values, especially for the drought sensitive genotypes G6 (PI 468898) and G7 (ILL 1796) (Figures 2a, 2b and 2c). These results are consistent with studies done in tomatoes (a Si excluder), in which the GI, length and fresh weight of seedlings under PEG-simulated drought stress were significantly improved by Si application (Shi et al. 2014). Previous studies have suggested that Si has a positive effect on the physiology and metabolism of different plants against drought stress (Torabi et al. 2012; Ma and Yamaji, 2008; Liang et al. 2003). These findings suggested that Si may be involved directly or indirectly in both morphological changes and physiological processes in plants. Results from the present study also showed that during drought stress, Si played a protective role in normal seed germination. This ameliorative effect of Si may be due to its hydrophilic nature by protecting the plants from drought. Irrespective of the drought tolerance capacity, all the lentil genotypes displayed 100% seed germination with Si treatment. Thus, from the results of the current research, Si is shown to be effective in securing 100% seed germination and enhanced drought stress tolerance at the germination and seedling stages.

Fresh and dry weight

When a seed starts to germinate, its fresh weight will increase due to absorption of water. In this study, the seedling fresh and dry weight of all genotypes declined as expected under drought stress conditions, and there were significant differences among the genotypes (Table 1). Fresh weight of drought tolerant genotypes G1 (ILL 6002) and G2 (Indianhead), and drought-sensitive genotypes G6 (PI 468898) and G7 (ILL 1796) decreased under drought stress. The drought tolerant genotypes G1 (ILL 6002) and G2 (Indianhead) had a higher seedling dry weight than the sensitive G6 (PI 468898) and G7 (ILL 1796) under drought stress. The drought tolerant and moderately drought tolerant genotypes exhibited a reduction in seedling dry weight under drought stress while the drought sensitive genotypes had negligible dry weight showing the sensitivity of these genotypes to drought stress. This could be attributed to reduced photosynthesis, biomass accumulation, respiration and nutrient metabolism (Jaleel et al. 2009). A reduction in plant dry weight under drought stress has also been reported in maize (Ashraf et al. 2007) and chickpeas (Gunes et al. 2007). Si was able to enhance the seedling fresh and dry weight of all the genotypes under non-stress conditions. These results are consistent with Liu et al. (2011) findings, where they reported that Si addition significantly increased the biomass of drought stressed alfalfa seedlings. Thus, this study shows that Si-mediated drought tolerance of lentil seedlings is induced by increased water uptake ability and by modulating sugar levels under stress and non-stress conditions.

Osmolytes (proline, GB and total soluble sugar)

A common stress tolerance mechanism in plants against environmental stresses is the overproduction of different types of osmolytes, such as proline, GB and soluble sugars. The accumulation of these osmolytes in plants might be involved in one or more of the processes such as osmotic adjustment, detoxification of reactive oxygen species, protection of membrane integrity, and the stabilisation of proteins/enzymes and thus contributes to drought tolerance (Blum, 2016). In the present experiment, drought stress resulted in significant accumulation of proline in lentil seedlings. The proline concentration was higher in drought tolerant genotypes, when compared to the drought sensitive and moderately drought tolerant genotypes, as was observed earlier in two drought tolerant lentil genotypes (Muscolo et al. 2014). Contrary to our findings, Oktem et al.

(2008) reported that proline amounts did not differ significantly under drought stress for Turkish lentil genotypes. The present result implies that the accumulation of proline is associated with drought tolerance. Added Si led to a significant decrease in the proline concentration of drought stressed seedlings (Figure 3a), which can be related to the added tolerance effect mediated by Si based on proline biosynthesis/accumulation. The latter can be attributed to the reaction between proline and Si forming silaproline, similar to the mechanism which takes place in humans (Vivet et al. 2000). Similar results were obtained by Gunes et al. (2008) from sunflower genotypes and Mauad et al. (2016) in upland rice plants under drought stress.

GB not only acts as an osmoregulator, but also stabilises the structures and activities of enzymes and proteins, and maintains the integrity of cell membranes against the damaging effects of environmental stresses. PEG-induced drought stress enhanced the concentration of GB in all the lentil genotypes (Figure 3b). Moreover, the drought tolerant genotypes accumulated more GB than sensitive genotypes in all the treatments. Added Si may be responsible for less GB accumulation in all the seedlings which might be a sign of stress injury alleviation. Consequently, regulated levels of GB would make it possible for the plant to regulate low water potential that allows additional water uptake from the stress environment, thus buffering the immediate effect of drought stress within the organism (Blum, 2016).

Drought stress increased the seedling soluble sugar concentration of all lentil genotypes (Figure 3c). This result is consistent with one recent study carried out under drought conditions in lentil genotypes showing an increase in total soluble sugar concentration (Muscolo et al. 2014, Mishra et al. 2016). Compared with the stressed seedlings without additional Si, seedlings with added Si had significantly lower soluble sugar concentration. This shows that drought stress conditions enhanced the anabolism of soluble sugar and adding Si decreased the anabolism of soluble sugar under drought stress. This observation was contradictory to a previous study in which increased soluble sugar levels were observed under Si treatment in drought stressed wheat seedlings (Si accumulator) (Pei et al. 2010). This may be related to the genetic difference between a Si accumulator such as rice, wheat, and sorghum and Si excluder such as lentils and tomatoes. Further studies using different crops from Si accumulators and Si excluders will ascertain such differences. This result also revealed that under a control and Si treatment without stress conditions, no significant effect of Si on the total soluble sugar level was observed in all the genotypes, which may show that Si application is more effective under stress conditions. Similarly to the case of proline and GB, the highest concentrations of soluble sugar were observed in the drought tolerant genotypes, G1 (ILL 6002) and G2 (Indianhead), when compared to the moderately drought tolerant and drought sensitive genotypes during all treatments. Similar to the present findings, high accumulation of soluble sugar was also noticed in drought tolerant pea and wheat plants when compared to drought sensitive ones (Okcu et al. 2005; Pei et al. 2010).

Hydrolytic enzymes

Starch is the principal storage carbohydrate and its degradation is essential for seed germination. In germinating seeds, starch degradation is initiated by hydrolytic enzymes such as amylases (α and β) and α-glucosidase producing soluble oligosaccharides. These are further hydrolysed by α-amylase to liberate maltose, which is finally broken down by α-glucosidase into glucose, providing energy to the germinating seeds. Conversely, the activity of hydrolytic enzymes in germinating seeds is reduced by drought stress. In the present study, PEG 6000 application resulted in reduced water content in the cells of germinating seeds and as a result, the activity of the hydrolytic enzymes also decreased (Figures 4a, 4b and 4c). However, applied Si resulted in an increased enzyme (β-amylase and α-glucosidase) activity in all the genotypes. The effect was more pronounced in drought sensitive genotypes, G6 (PI 468898) and G7 (ILL 1796) with an almost 1.5-fold increase in enzyme activity. The seedlings of the drought tolerant G1 (ILL 6002) and G2 (Indianhead), and moderately drought tolerant genotypes PBA Jumbo 2⦹ (G3), Nipper⦹ (G4) and PBA Flash⦹ (G5) maintained high levels of enzyme activity compared to sensitive genotypes under all the treatments. The increased enzymatic activities of seedlings grown under Si might be explained due to the improved water status of the genotypes with added Si. The drought tolerant genotypes G1 (ILL 6002) and G2 (Indianhead) showed a decline in the activity of α-amylase enzyme with added Si under drought stress when compared to other treatments. However, in the moderately drought tolerant and drought sensitive genotypes, added Si resulted in an increase in α-amylase activity under drought stress. These results suggest that the effect of Si on the enzyme activity involved in carbohydrate metabolism is quite complex and species-dependent. However, further studies are needed to explore how Si stimulates the desired activity of hydrolytic enzymes under drought stress.

Antioxidant enzymes and reactive oxygen species (ROS)

Many metabolic processes in plant result in the production of reactive oxygen species (ROS), such as superoxide anion (O2 −), hydrogen peroxide (H_2O_2), and the hydroxyl radical (-OH). Environmental stresses also increase the formation of ROS that oxidises membrane lipids, photosynthetic pigments, proteins and nucleic acids. The increase in LPX has also been reported in many plants under various environmental stresses (Gunes et al. 2007). Plants with high levels of antioxidants, either constitutive or induced, have been reported to have greater resistance to this oxidative damage. Meanwhile, plants possess efficient antioxidant defence systems for scavenging ROS. APX, POX, CAT and SOD are the major antioxidant enzymes. SOD dismutates O2 − to H_2O_2 in the chloroplast, mitochondrion, cytoplasm and peroxisome, thus preventing the cellular damage under stress conditions like drought. APX is a component of the ascorbate-glutathione pathway, which plays a key role in scavenging H_2O_2. POX also plays an essential role in scavenging H_2O_2, which is a major by-product produced by SOD. CAT eliminates H_2O_2 by breaking it down directly to form water and molecular oxygen, thus this enzyme does not require a reducing power and has a high reaction rate but a low affinity for H_2O_2, thereby only removing the high concentration of H_2O_2.

A significant increase in the O2 − coupled with H_2O_2 production and LPX observed under PEG-induced drought stress in lentil seedlings clearly indicates an oxidative burst, facilitating cellular damage (Table 2). The increase of O2 − and H_2O_2 content caused by drought stress followed by increase of LPX in lentil seedlings appears to be alleviated by Si treatments which reduced O2 −, H_2O_2 accumulation and LPX (Table 2). This might be due to the activity of the compatible solutes such as proline and G, which detoxify ROS by forming a stable complex with them and consequently inhibit LPX (Gunes et al. 2007). These results similar to Si application decreased H2O2 and LPX in leaves of another legume, chickpeas (Gunes et al. 2007), sunflowers (Gunes et al. 2008) and cereal crops such as wheat (Pei et al. 2010) under drought stress. Recently, it is reported that Si application decreased LPX, O2 −, H_2O_2 accumulation and LPX in liquorice seedlings under drought stress (Zhang et al. 2015).

This study confirmed that Si addition significantly increased the activity of all antioxidant enzymes and resulted in more effective H_2O_2 dismutation capacity and O2 − elimination power under DSi and Si treatments (Table 3). Higher activities of antioxidant enzymes in DSi than drought stress treatment might play a role in maintaining low levels of H_2O_2 in the cells under drought stress. Thus, these results suggest that improved activities of antioxidant enzymes induced by addition of Si might protect plant tissues from membrane oxidative damage under drought stress which could significantly contribute to the improvement of drought tolerance. These results are in agreement with the results of Pei et al. (2010), who found that under drought stress, the addition of Si increased the antioxidant activity in wheat plants. This result speculates that Si might be involved in enhancing the expression of genes related to production and activation of antioxidant enzymes in response to drought stress.

Si content

In the current investigation, Si content in lentil seedling was increased by drought stress (Table 2). However, there was no significant variation in Si content among the genotypes. Application of Si under drought stress significantly enhanced Si content in all the genotypes. Although added Si resulted in increased Si content in seedlings under drought stress, lentils are still regarded as a low accumulator of Si, i.e. less than 5mg g dry weight−1 (Meena et al. 2014). The higher content of Si under drought stress in lentils under DSi treatment might be due to deposition of Si in cell walls which can reduce the impacts of drought stress. The deposited Si could strengthen the membranes of plant cells and change their permeability, resulting in improved drought tolerance.

PCA and cluster analysis

The PCA results in this study are in agreement with the criteria established by Sneath and Sokal (1973), who showed that data should represent at least 70% of the total data variability (Figure 5a). The positive correlations were observed among the drought tolerance assessment traits, such as GI, GP, SVI, α-amylase, β-amylase, proline, GB, soluble sugars, antioxidant enzymes and ROS, where the main separator of the treatments was imposed (Figure 6). The latter showed that these traits can be used to assess drought tolerance in plants. In the PCA, the biplot characterised the genotypes into four distinct groups (1 to 4). Under control (C) condition (group 1), all the genotypes were present near to the origin in the positive direction of the vectors, showing normal behaviour of drought tolerance from the specific genotypes as expected. Whereas, under drought stress (D) treatment (group 2), all the genotypes, especially, the genotypes G6 (PI 468898) and G7 (ILL 1796) moved away from the origin in the negative direction showing less drought tolerance according to germination traits and hydrolytic enzyme activity. With Si supplementation under drought stress (DSi), the genotypes moved closer towards the origin (group 3), showing improvement in drought tolerance. Interestingly, when Si was given alone without drought stress (Si), all the genotypes were sited away from the origin in the positive direction showing the positive effect of Si in improving the drought tolerance of lentil genotypes. Thus, this study clearly shows the positive role of Si in mitigating drought stress in lentil genotypes and furthermore, the results also showed that Si application can be used to increase seed germination and seedling vigour under drought stress and non-drought stress conditions by improving the response of moderately tolerant and sensitive genotypes. The distinct group formation was also observed through the cluster analysis, which categorised the genotypes into different clusters at a linkage distance 50 based on their drought tolerance levels and the type of drought stress treatment (Figure 5b).

From the results showed here, Si application positively affected drought related parameters and consequently improved the seed germination of lentil genotypes under drought stress. Si ameliorated the effects of drought stress in lentil genotypes by induced water uptake ability, modulating levels of osmolytes, regulating the activities of hydrolytic enzymes and antioxidant machinery. This beneficial effect of Si might be linked to its hydrophilic nature and Si deposited in cell walls allows the plants to keep water, dilute salts and protect tissues from physiological drought. Again, it is worth noting that Si modulates plant metabolism and alters physiological activities, especially in plants under stress than normal environmental conditions.

Si effect was found to be more pronounced for the drought susceptible lentil genotypes compared to moderately drought tolerant and drought tolerant ones. This variation in stress sensitivity of the contrasting lentil genotypes might be linked to a genetic difference in response of genotypes towards drought stress with added Si or it might be due to the significant role of Si in upgrading the water status of the susceptible genotypes more when compared to the moderately drought tolerant and drought tolerant genotypes. However, in-depth investigation is needed to understand how Si regulates plant tolerance to drought stress at the seed germination stage and also the interactions between Si application and plant responses which may help us to better understand the physiological and biochemical functions of Si. In future, the studied lentil genotypes also need to be tested in the field condition to confirm the role of Si in drought tolerance as terminal moisture stress in arid and semi-arid regions is a serious threat that leads to early maturity and low yields of lentil plants.

Conclusion

Drought stress adversely affected seed germination and early seedling growth in all lentil genotypes. The addition of Si for lentil seed germination has been shown to be a beneficial strategy to effectively mitigate the adverse effects of drought stress. However, further studies are required to understand the physiological and biochemical mechanisms of Si-mediated drought stress in higher plants. This study also showed that G1 (ILL 6002) and G2 (Indianhead) are potential drought tolerant lentil genotypes, along with the latest commercial genotype G3 (PBA Jumbo 2^(⍭)) being moderately drought tolerant. These genotypes could be potentially used as genetic resources for drought tolerance in lentil breeding programs. Furthermore, this is the first report demonstrating the significant role Si plays to alleviate drought stress during seed germination and seedling growth in lentils, especially for moderately drought tolerant and drought sensitive genotypes. There is still a need to better understand Si functions in more species under different environmental conditions to validate the Si-mediated alleviation of drought stress on a large scale. Again, more detailed studies are needed to explore the physiological, biochemical and molecular mechanisms of Si-mediated drought stress tolerance in plants. Taken together, well-designed, large-scale, and long-term field trials are required to evaluate the feasibility of Si application under drought stress in plants. These results are important and should be part of long-term programs involving Si to boost lentil productivity under drought stress conditions in arid and semi-arid regions.

References

See details listed within the GRDC website full version of this paper

Acknowledgements

The research undertaken as part of this project is made possible by the significant financial support in the form of Grain Industry Research Scholarship (GRS) from GRDC — the author would like to thank them for their continued support. The authors are also grateful to University of Melbourne for the Australian Government Research Training Program Scholarship given to Sajitha Biju.

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Notes

Sustainable peak performance for advisers

Mark McKeon.

MMA TEAM Pty Ltd.

Keywords

- stress, recovery time, health.

Take home messages

- Stress in not the problem, the problem is lack of recovery.
- Advisers will benefit from setting firm boundaries with their clients.
- Implementing 'Go, Slow and No Zones' may assist in boosting performance and preventing adrenal fatigue.

Background

Are you are a hard working adviser and a time pauper? Do you feel empathy for your clients who may be struggling due to unfavourable weather conditions, financial stress or other issues? Do you deal with a lot of pressure, seldom without respite and often while living in the same community as your clients?

If the answer is yes then you definitely DO have a problem, but it's something other than stress. Stress is not the problem.

Stress allows us to perform at a level we could never achieve if our lives were stress free. Stress releases adrenaline into our bloodstream along with free floating fatty acids and cortisol. This creates a cocktail of chemicals so powerful it would be illegal if taken as a sports supplement, yet many of us 'use' it every day.

Our heart rate accelerates while our breathing becomes rapid and shallow. Peripheral blood vessels constrict so that more blood and oxygen go to where it's needed most, our central core. Nervous responses become faster and more acute and sensory receptors are blocked so that we won't feel pain if we become ill or injured. Even our eyesight and hearing sharpens. We have more energy, more drive, greater strength and a higher tolerance for pain and fatigue.

When used to your advantage, this heightened state of awareness actually helps you determine and convey excellent advice because it means you are at your best when you are determining the right crop choice, soil treatment or longer term farm plan. Stress drives us to reach levels of achievement and efficiency we would never ever approach without being put under pressure. Stress creates an accelerated level in our entire being that enables us to cope with what in some cases amounts to an almost impossible workload.

Unfortunately, when living in a socially close community, this great strength can also become your Achilles heel. **An empathetic agronomist can be tempted to cross the line from adviser to counsellor. This is a line you should be very wary of crossing.**

Stress enables us to temporarily develop the ability to work longer and sleep less, first as an abnormal state but one that quickly becomes a habit. Stress makes us feel like a machine, but machines break down if not maintained correctly and this is where we uncover what the problem really is.

The problem is lack of recovery

Advisers who are constantly under stress and constantly have a high level of adrenaline in their bloodstream find it impossible to slow down, even when the opportunity does arise. This is the crux of the issue for many people. **They just don't have the down time or the mental space to recover and build their resilience.**

Are the following dot point's issues for you?

- A hectic and busy workload.
- A personal habit of not having firm boundaries with clients.
- A practice of rarely taking true recovery time.

If you could identify with any of the dot points, pre scheduling what I call 'Go, Slow and No Zones' may be a useful strategy for you to implement.

'Go Zones' are planned and prepared periods each day where you focus hard on your most important tasks for that day. It's when you perform at your best without excuse or distraction and with a clear and achievable goal.

'Go Zones' are crucial when researching and preparing advice, anticipating questions and meeting with farmers. 'Go Zones' require pre planned task lists sand incorporate physiological principles (controlling adrenaline, cortisol, etc.) so we reach what I call our 'Ideal Performance State'. Reaching this state is about being at your best more often, as a matter of habit while maintaining the right balance in relationships with your clients.

'Slow Zones' are less intense but still productive. Here we do the routine work but we don't make key decisions or turn up to an important meeting in the 'Slow Zone'. 'Slow Zones' also link to understanding and controlling the previously discussed blood chemistry factors.

'No Zones' are where you refresh, recover and develop skills where you can 'let it go', at least for a little while. Because many of you may socialise with your clients in your local community, it's vital to have at least some effective 'No Zones' by yourself or without clients/friends. This true recovery time is a non-negotiable for you to instigate into your life if high levels of agronomy performance are to be sustained long term.

The 'Go Zone' system is a combination of personal efficiency, disciplines and resilience. It's much more than time management as it includes motivation, embracing change and clear thinking.

Overall it's about having control of what 'Zone' we are in and building strong personal disciplines and resilience to the challenges of getting too close or allowing yourself to enter an area you may not be qualified or skilled in. 'Go Zones' will help you keep your advice professional and within agronomy boundaries.

Lack of recovery can lead to burn out. Busy people with burgeoning responsibilities or opportunities reach the point that they become literally addicted to being busy. They just can't slow down or maintain boundaries any more.

Can you think of a time in your life when you have finally completed a demanding project, have been involved in a family wedding or perhaps played in a sporting final, only to feel an overwhelming sense of being spent and empty when the event has ended? That's when the adrenaline has drained from your body. This is a perfectly natural part of a healthy cycle of performance and recovery and we need to learn to accept it.

This feeling of 'being flat' is your body's way of saying it's time to take a break. Unfortunately, people who are hooked on adrenaline can't allow this to happen so they force their way out of their lethargy by taking on another task, chasing another goal or having a confrontation with a colleague or a client, anything to top up their adrenaline.

Take a break

Athletes understand the need to train hard and then recover, so that they can compete with every ounce of their body and soul and then recuperate. We should think of ourselves as agronomist athletes. It's admirable to be constantly looking to boost performance and help your clients in any way that you possibly can.

We can achieve this and still have a life if we implement two recovery habits to maximise our performance both in agricultural advice and in life.

First, take your holidays. Smart, cutting edge organisations around the world no longer allow people to keep working and build up holiday arrears. They understand that the short-term expedience in the long term creates fatigue and resentful beings that lose productivity, burn out, leave, and become ill or worse. As an individual, you have to take responsibility for yourself and prioritise holiday leave.

Do not 'pass the buck', the holiday brochure stops with you! Everyone can be replaced plus or minus 10% and if for some reason you were no longer advising your clients, someone else soon will be. No one is that important and the size of all or our funerals depends a lot on the weather that day!

I have never ever, even once met someone who said to me, 'Mark, you told me to take a holiday and now I regret it'. Forget the fallacy of quality time and take some quantity time. This is step one.

Step two is to do your absolute best not to feel guilty about the ups and downs of farming life. Remember, your workload is only half the reason, the other half is the pressure you put on yourself.

We all need some time to get out of our normal mind set and allow our subconscious mind to 'reset its default settings', our body to wean itself off adrenaline and get back to being the way we are supposed to be. We need time to relax and recover, and time dedicated to ourselves. This is an investment in you. You will be fresher and sharper, have more natural energy and more ability to provide quality evidence based advice. You will achieve more in less time.

Conclusion

Your aim is to go to bed tired but not stressed. Use stress to challenge you to greater heights. Save adrenaline for when you really need it and plan regular recoveries into your schedule so that you are always ready for the next challenge.

If you want to look after others in life, you must first look after yourself!

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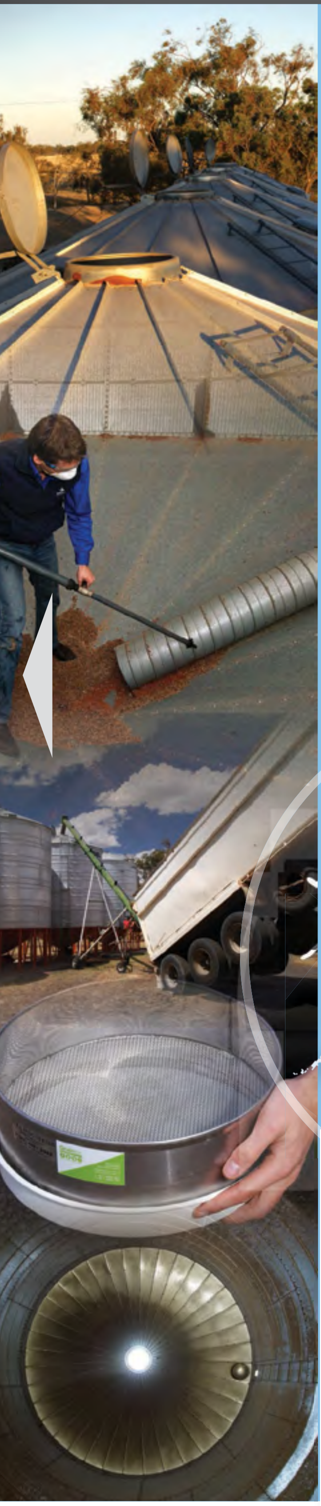

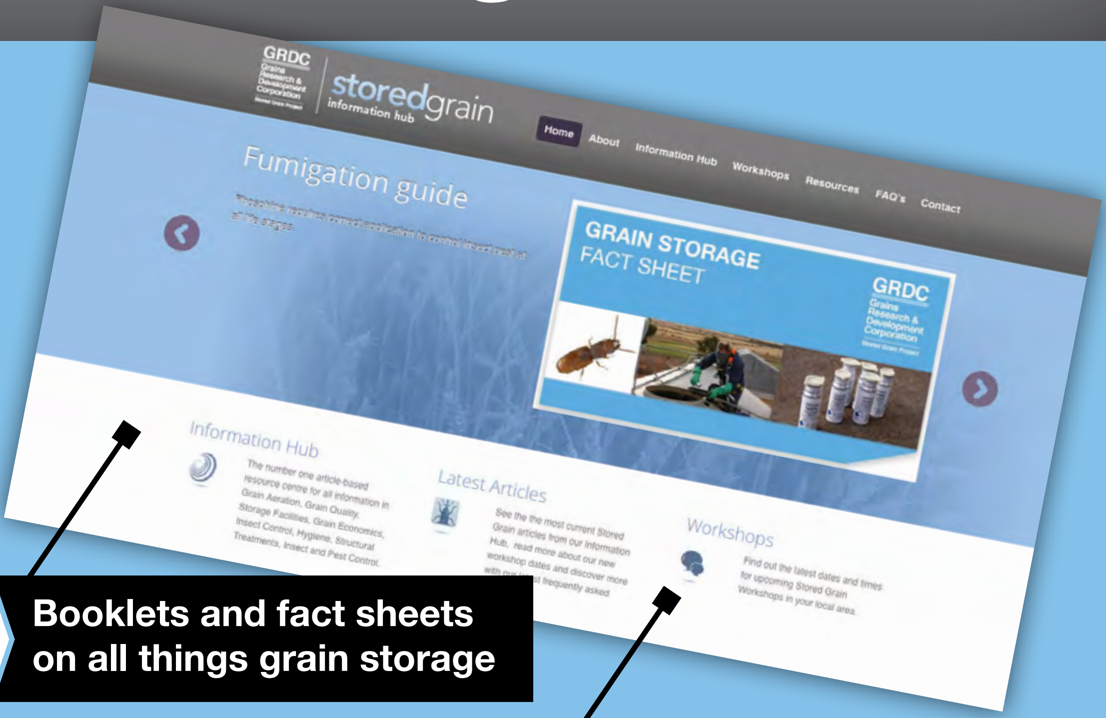

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GRDC Grains Research Update BENDIGO

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STRATEGIC STEPS – ENDURING PROFIT

PROGRAM DAY 2 - FEBRUARY 28th

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9.00 am	**Canola diseases - sclerotinia in the spotlight (R)** - P175 ***Kurt Lindbeck,*** *NSW DPI*	**Refining nitrogen placement in cereals - mid row banding (R)** - P181 ***Ash Wallace,*** *Agriculture Victoria*	**Insects, resistance and control (R)** - P187 ***James Maino,*** *cesar*	**Glyphosate update (R)** - P195 ***Peter Boutsalis,*** *Plant Science Consulting*
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10.20 am	**MORNING TEA**			
10.50 am	**Canola harvest management - new data busts myths (R)** - P223 ***Maurie Street,*** *Grain Orana Alliance*	**Refining nitrogen placement in cereals - mid row banding** - P181 ***Ash Wallace,*** *Agriculture Victoria*	**Filling the yield gap - Optimising yield and economic potential of high input cropping systems in the high rainfall zone (R)** - P231 ***Malcolm McCaskill,*** *Agriculture Victoria*	**Canola diseases - sclerotinia in the spotlight** - P175 ***Kurt Lindbeck,*** *NSW DPI*
11.30 am	**Critical agronomy management points for optimal canola growth** - P207 ***Rohan Brill,*** *NSW DPI*	**Mice - learning from 2017? Looking to 2018** - P217 ***Peter Brown,*** *CSIRO*	**Insects, resistance and control** - P187 ***James Maino,*** *cesar*	**Agricultural machine technology – practical uses now and into the future** - P215 ***Steven Rees,*** *The University of Southern Queensland*

CONCURRENT SESSIONS (40 minutes including time for room change) (R = session to be repeated)

	Ulumbarra Auditorium	Ulumbarra Dance Studio	Ulumbarra Strategem Studio	Ulumbarra Multipurpose Room
12.10 pm	**Glyphosate update** - P195 ***Peter Boutsalis,*** *Plant Science Consulting*	**Achieving the best blend of HWSC methods for your situation** - P201 ***Greg Condon,*** *AHRI, Grassroots Agronomy*	**Canola harvest management - new data busts myths** - P223 ***Maurie Street,*** *Grain Orana Alliance*	**Filling the yield gap - Optimising yield and economic potential of high input cropping systems in the high rainfall zone** - P231 ***Malcolm McCaskill,*** *Agriculture Victoria*

12.50 pm	**LUNCH**	
1.30 pm	**The art of communicating science and recognising the ‘snake oil’** - P241	***Jenni Metcalfe,*** *Econnect Communication*
2.10 pm	**Herbicide resistance - where we are, where we are going and what can we do about it** - P249	***Chris Preston,*** *The University of Adelaide*
2.50 pm	**Wrap up**	
3.00 pm	**CLOSE**	

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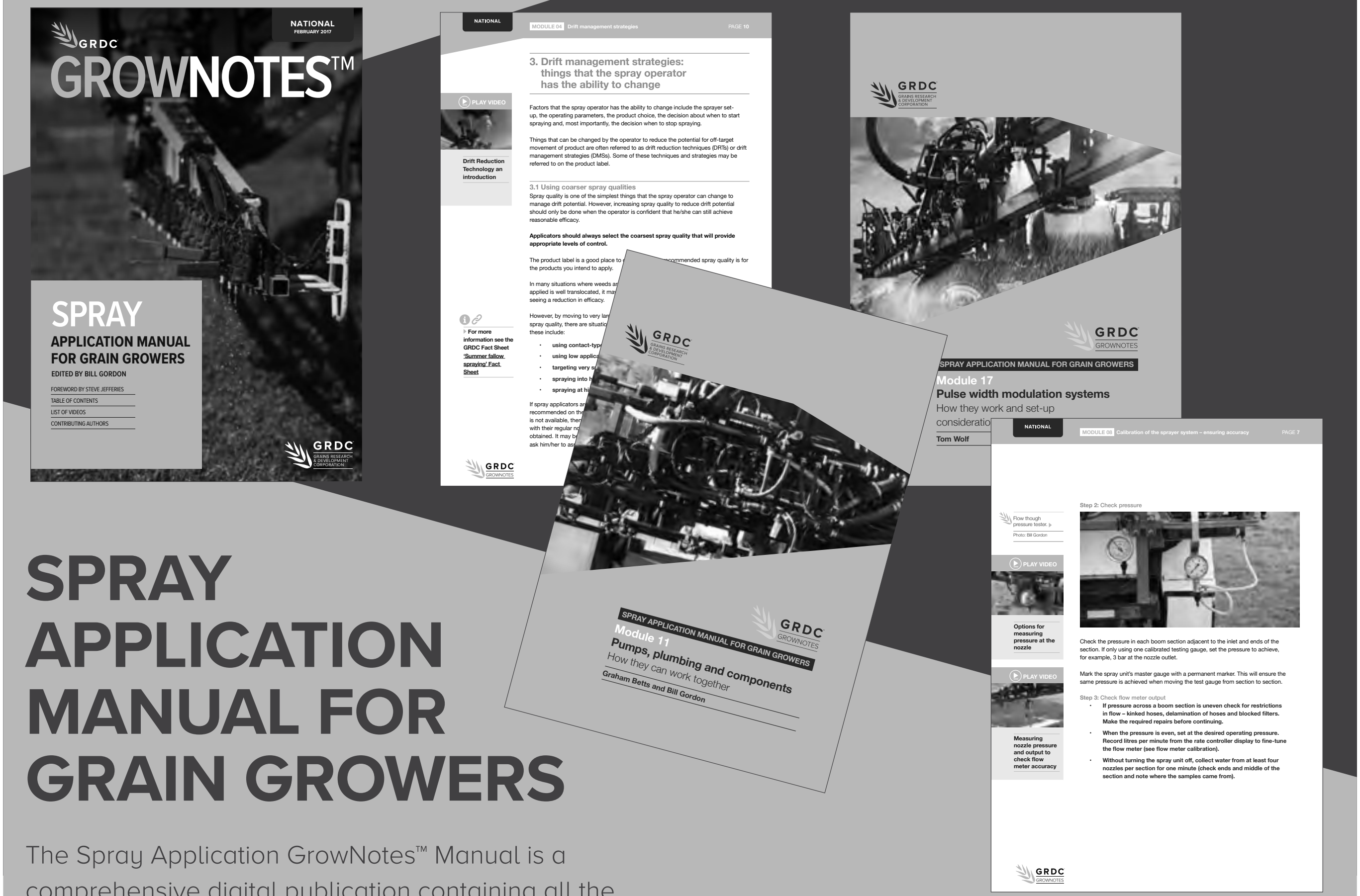
SPRAY APPLICATION GROWNOTES™ MANUAL



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Canola disease update – sclerotinia

***Kurt Lindbeck*[1] , *Audrey Leo*[1], *Stephen Marcroft*[2] *and Gerard O'Connor*[1].**

[1]NSW- Department of Primary Industries, Wagga Wagga Agricultural Institute, Pine Gully Road, Wagga Wagga, NSW; [2]Marcroft Grains Pathology P/L, Grains Innovation Park, Horsham, VIC.

GRDC project codes: DAN00177, UM0051

Keywords

- canola, blackleg, sclerotinia, disease management.

Take home messages

- Sclerotinia stem rot is a production issue where spring rainfall is adequate to provide long periods of leaf wetness in the presence of flowering canola crops.
- If there is a history of sclerotinia stem rot in your district causing yield losses, be prepared to use a foliar fungicide in canola to reduce yield loss.
- Sclerotinia stem rot occurred in those districts with a frequent history of the disease in 2017. Dry conditions in spring kept potential disease levels in canola low.
- Extended periods of leaf wetness (at least 48 hours) trigger epidemics of sclerotinia stem rot.
- Foliar fungicides for management of the disease in canola are best applied at 20% to 30% bloom for main stem protection.

Introduction

Sclerotinia stem rot – 2017 update

Seasonal overview

Drier than average growing season conditions in winter and early spring were unfavourable for the development of sclerotinia stem rot in 2017 in southern NSW and northern Victoria (VIC). Outbreaks of the disease were sporadic depending on rainfall frequency and crop growth stage. The drier conditions in winter were not ideal for the germination and development of apothecia (the fruiting structures of the sclerotinia fungus) with first reports of apothecia in crops not until early August in southern NSW. Dry conditions in spring prevented development of the disease across many districts in the region.

In the western district of VIC, reports of damaging outbreaks of sclerotinia stem rot were few. Seasonal conditions did not favour development of the disease.

How does the disease develop?

The complexity of the disease cycle of sclerotinia stem rot results in disease outbreaks being sporadic compared to other diseases. There are several key stages that must be synchronised and completed in order for plant infection to occur. Weather conditions must be suitable for the pathogen at each stage. These stages of development include:

1. Softening and germination of soil borne sclerotia.
2. Apothecia development and release of ascospores.
3. Infection of petals by air borne ascospores.
4. Senescence of infected petals in the presence of moisture and subsequent stem infection.

Weather conditions during flowering play a major role in determining the development of the disease. The presence of moisture during flowering and petal fall will determine if sclerotinia stem rot develops. Dry conditions during this time can quickly prevent development of the disease, hence even if flower petals are infected, dry conditions during petal fall will prevent stem infection development.

Research findings in 2017

Commercial canola crops and trial sites were monitored for the development of sclerotinia stem rot in high sclerotinia risk districts in 2017. These crops were located in southern NSW and northern VIC where the disease is a frequent problem. Observations within these crops confirmed the strong relationship between prolonged periods of leaf wetness and stem rot development. A targeted petal survey was again conducted across southern NSW and northern VIC in 2017. The aim of this survey was to investigate the relationship between petal infestation with the sclerotinia fungus and stem rot development.

Stem infection

Infection levels at disease monitoring sites were generally low — less than 10%. Dry conditions in winter and spring were highly effective at keeping potential disease levels low. However, some reports were received of higher levels of stem infection in some commercial crops, depending on where rainfall events occurred and crop growth stage. Analysis of environmental data and disease observations confirmed the relationship between extended periods of leaf wetness of at least 48 hours and development of stem infection within canola crops.

Petal testing

For the third year, a petal survey was conducted in central and southern NSW and northern VIC. The highest levels of petal infestation (>90%) were detected in crops grown in higher rainfall districts with a high frequency of canola where then disease is frequently seen within canola crops. Crops further west and north had reduced levels of infestation in general (<60%), with levels fluctuating with environmental conditions.

Infested petals were detected in every canola crop that was sampled at some stage during the growing season, but most crops did not develop symptoms of stem rot. This confirms the wide distribution of the sclerotinia fungus, but also the importance of environmental conditions as the driver of development of the disease.

This season's results confirm previous research findings, which identified no direct correlation between the number of canola petals infested with the sclerotinia pathogen and stem rot development within the crop. **This confirms the importance of leaf wetness within the crop canopy as the driving factor behind development of stem rot.**

Where did the disease occur in 2017?

Traditionally, sclerotinia outbreaks are sporadic in southern NSW and northern VIC and usually restricted to those districts with a history of sclerotinia, high intensity of canola and reliable spring rainfall. Due to below average spring rainfall in 2017, outbreaks of the disease were restricted to the 'traditional' districts where the disease is frequently seen. Reports of damaging levels of stem rot were few, with dry conditions preventing the spread of the pathogen from petals onto canola stems.

What are the indicators that sclerotinia stem rot could be a problem in 2018?

- **Spring rainfall:** Epidemics of sclerotinia stem rot occur in districts with reliable spring rainfall and long flowering periods for canola.
- **Frequency of sclerotinia outbreaks:** Use the past frequency of sclerotinia stem rot outbreaks in the district as a guide to the likelihood of a sclerotinia outbreak. Paddocks with a recent history of sclerotinia are a good indicator of potential risk, as well as those paddocks that are adjacent. Also consider the frequency of canola in the paddock. Canola is a very good host for the disease and can quickly build up levels of soil borne sclerotia.
- **Commencement of flowering:** The commencement of flowering can determine the severity of a sclerotinia outbreak. Spore release, petal infection and stem infection have a better chance of occurring when conditions are wet for extended periods, especially for more than 48 hours. Canola crops which flower earlier in winter (late June to July) are more prone to disease development and exposure to multiple infection events.

If there was sclerotinia in my canola crop last year, what should I do this season?

There are a number of steps that can be taken to reduce the risk of sclerotinia:

1. **Sow canola seed that is free of sclerotia.** This applies to growers retaining seed on-farm for sowing. Consider grading seed to remove sclerotia that would otherwise be sown with the seed and infect this season's crop.

2. **Rotate canola with non-host crops.** Continual wheat/canola rotations are excellent for building up levels of viable sclerotia in the soil. A 12 month break from canola is not effective at reducing sclerotial survival. Consider other low risk break crops such as cereals, field pea or faba bean.
3. **Follow recommended sowing dates and rates for your district. Be aware of the maturity rating of the variety and time of sowing.** Early flowering crops are more prone to developing sclerotinia stem rot by increasing opportunities for infected petals to lodge in a wet crop canopy. Wider row spacing can also help by increasing air flow through the crop canopy to some degree and delaying the onset of canopy closure.
4. **Consider the use of a foliar fungicide.** Weigh up yield potential, disease risk and costs of fungicide application when deciding to apply a foliar fungicide.
5. **Monitor crops for disease development and identify the type of stem infection.** Main stem infections cause the most yield loss and indicate infection events early in the growing season. Lateral branch infections cause lower levels of yield loss and indicate infection events later in the growing season.

Use of foliar fungicides

At this time, there are no commercial canola varieties available on the Australian market with resistance to sclerotinia stem rot. Management of the disease relies on the use of cultural and chemical methods of control. Foliar fungicides should be considered in those districts which are at a high risk of disease development (for example, districts where the disease frequently occurs, a long flowering period and reliable spring rainfall). There are several foliar fungicides currently registered for use in Australia to manage sclerotinia stem rot including Aviator® Xpro®, Prosaro® and products containing procymidone or iprodione.

To maximise the economic benefits from foliar fungicides, consider the factors that lead to disease development. All three factors (host, pathogen and environment) need to coincide for the disease to develop. Figure 1 shows those factors that lead to stem rot development.

Points to consider when using a foliar fungicide to manage sclerotinia stem rot

1. The most yield loss from sclerotinia occurs from early infection events. Early infection is likely to result in premature ripening of plants that produce little or no yield.

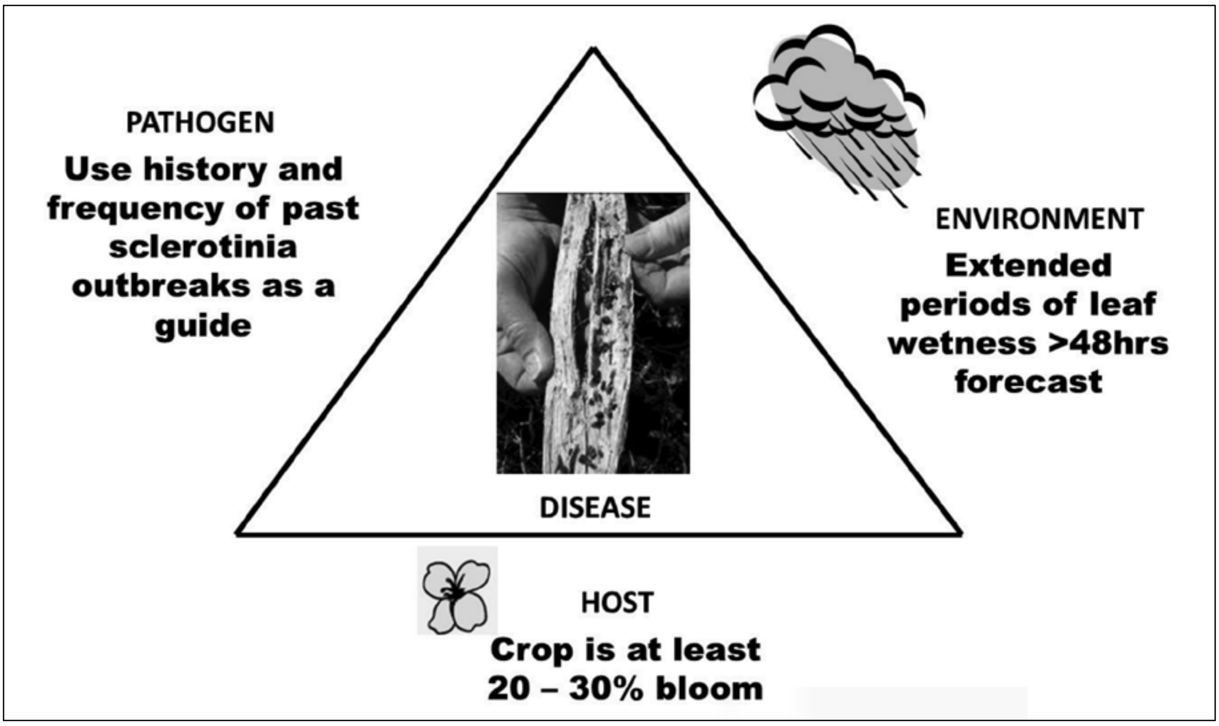

Figure 1. Factors that lead to stem rot development.

2. Plants become highly susceptible to infection once flowering commences. Research in Australia and Canada has shown that an application of foliar fungicide around the 20% to 30% bloom stage (20% bloom is 14 to 16 flowers on the main stem, 30% bloom is approx. 20 flowers on the main stem) can be effective in significantly reducing the level of sclerotinia stem infection. Most registered products can be applied up to the 50% bloom (full bloom) stage.
3. The objective of the fungicide application is to prevent early infection of petals while ensuring that the fungicide also penetrates into the lower crop canopy to protect potential infection sites (such as lower leaves, leaf axils and stems). Timing of fungicide application is critical.
4. A foliar fungicide application is most effective when applied before an infection event (for example, before a rain event during flowering). These fungicides are best applied as protectants and have no curative activity.
5. In general, foliar fungicides offer a period of protection of up to three weeks. After this time, the protectant activity of the fungicide is compromised. In some crops, development of lateral branch infections later in the season is not uncommon if conditions favourable for the disease continue. **The greatest yield loss occurs when the main stem becomes infected, especially early. Lateral branch infection does cause yield loss, but at a much reduced level.**
6. Use high water rates and fine droplet sizes for good canopy penetration and coverage.
7. Fungicide choice is often secondary to timing of application.
8. Be aware that the maximum number of applications of Prosaro® or Aviator® Xpro® in a season is two.

Consult the Sclerotinia Stem Rot in Canola factsheet for further information. This publication is available from the GRDC website (https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/03/grdc-fs-sclerotinia).

Useful resources

NSW DPI Winter Crop Variety Sowing Guide (Disease updates, variety resistance, fungicide products) (http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf).

NSW DPI Southern NSW Research Results 2015

https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/southern-nsw-research-results-2015

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Acknowledgements

This research is a collaborative project between the GRDC and NSW DPI. 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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Notes

Refining nitrogen placement in cereals – mid row banding

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GRDC project code: DAV00143

Keywords

- nitrogen use efficiency, urea, wheat.

Take home messages

- Mid-row banding significantly increased recovery of nitrogen (N) fertiliser by wheat in 2016, improving N use efficiency.
- The impact of mid-row banding on yield and protein has been more variable, but may improve in situations that are more N deficient.
- Adoption of mid-row banding in-season will require consideration of factors including speed of operation, capital requirement and cost of operation and the ability to apply N inter-row to established crops in a given farming system.

Background

Managing nitrogen (N) fertilisers in dryland cropping is a continual challenge for growers and advisers. Matching N rate to crop demand is complicated by a range of factors, not least of which is the relatively poor predictability of seasonal conditions during autumn. As a result, there has been a trend towards tactical, in-season management of N where possible. The challenge, however, with in season N application, such as topdressing urea, is that it can result in loss of N due to volatilisation of ammonia depending on conditions following application. One option to reduce this risk is to apply N below the soil surface (Rochette et al. 2013), however, until the advent of high accuracy GPS guidance, in-season banding was not a practical option.

Mid-row banding, where N fertiliser is applied below the soil surface to every second inter-row, has been tested both internationally and within Australia for N application at sowing (Angus et al. 2014, Campbell et al. 1991). Aside from the potential reductions in loss as ammonia compared to surface application, concentrating N into narrow bands can also slow the nitrification of ammonium (Wetselaar et al. 1972). By restricting the conversion of N to nitrate, this may reduce other losses (such as denitrification) and slow movement of N below the depth of application. High concentrations of ammonium have also been shown to restrict root growth within the fertiliser band. As a result, roots have been shown to proliferate in the surrounding area, eventually encapsulating the fertiliser band over time (Passioura and Wetselaar, 1972). By increasing root growth surrounding the fertiliser band, this may help to improve crop uptake of applied N. The purpose of this research was to test the potential benefits of mid-row banding as opposed to other options for in-season application of N fertiliser.

Method

A series of four field trials were undertaken during 2016 and 2017 testing a range of different methods for in-season application of N fertiliser. Sites were at Longerenong and Quambatook in 2016 and

Longerenong and Ultima in 2017. All sites were sown to Mace$^{\text{(b)}}$ wheat except Ultima in 2017 (Kord CL Plus$^{\text{(b)}}$) on 300mm row spacing and received a starter amount of N at sowing (6kg to 7kg N/ha).

Fertiliser was applied as urea in solution or granular (top-dressed only) at rates of 25kg and 50kg N/ha on two occasions at each site between late tillering and second node growth stages. Application methods tested were:

- Mid-row banded: N placed at 35mm to 50mm depth into every second inter-row using a twin disc opener.
- Mid-row surface: N placed on the surface of every second inter-row.
- Streaming spray: N applied using streaming nozzles spaced evenly across the plot.
- Flat fan spray: N applied using air induction nozzles to produce extra coarse droplets.
- Top-dressed granular.

The purpose of multiple applications at each site was to observe the effect of rainfall following application on the relative response of each method. This was based on the assumption that volatilisation risk should be higher where N is applied in front of a dry forecast and therefore, mid row banding may offer the opportunity to apply N when it suits the grower rather than 'chasing rain fronts'. As a result, the timing of each application was designed to be relatively close together to minimise differences in response due to growth stage. Additional rates of top dressed N were also applied (15kg to 100kg N/ha) to identify the overall N response curve for each site, as well as unfertilised controls, including unfertilised, banded plots to measure the effect of the banding operation on crop growth. Key measurements included soil characterisation at sowing, grain yield and quality and recovery of fertiliser by the crop using 15N 'labelled' fertiliser.

Results and discussion

Crop response to N application method

All sites with the exception of Longerenong in 2017 showed a strong yield response to the addition of N (Figure 1). At both sites in 2016, grain yield continued to increase up to rates of 90kg N/ha, while at Ultima in 2017, yields were more moderate due to a drier season, however N response continued up to a rate of 50kg N/ha. Grain protein also increased significantly with N rate at all sites. In general, protein levels were lower in 2016 (7% to 9%) compared with 2017 (8% to 12%).

Yield response to the method of N application varied across sites and in some cases, the time and rate of application. In 2016, mid-row banding produced the highest average yield at both sites, however this was only significant ($P<0.05$) in comparison to mid-row surface application at Longerenong (Table 1). In 2017 at Ultima, the mid-row surface and flat fan treatments resulted in significant yield reductions — in absolute terms approximately 0.1t/ha. At Longerenong in 2017, the streaming spray treatment was significantly higher yielding than mid-row banding and flat fan applications even though the site showed a low overall N response. While the flat fan treatment resulted in the lowest yields

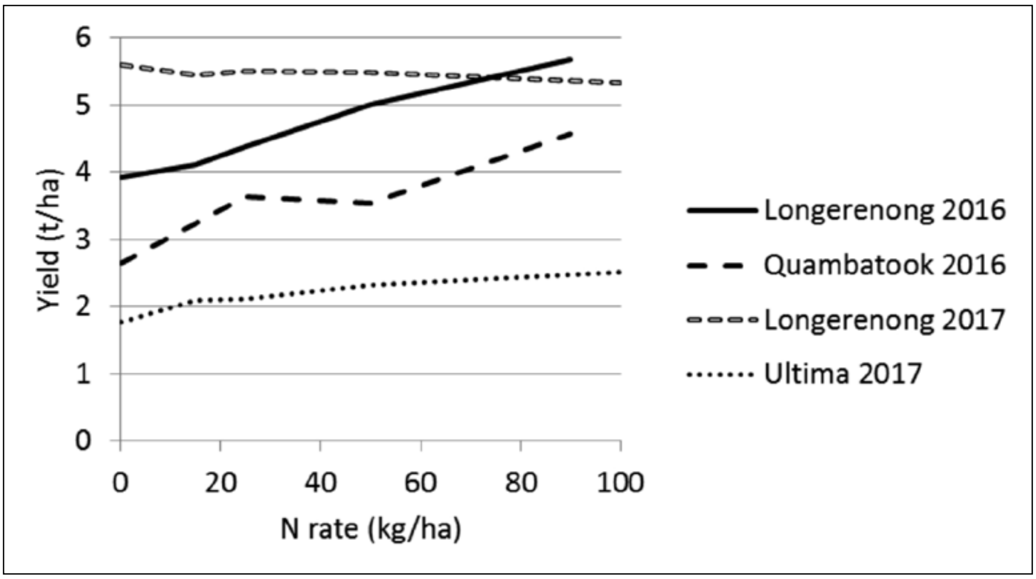

Figure 1. Yield response to rate of N applied as top-dressed urea on the first day of application at each site.

Table 1. Yield and protein response to N application method at each site, averaged across rate and time of application. Superscripts indicate significant differences ($P<0.05$). Treatments followed by the same letter are not statistically different.

Year	Site	Application method	Yield (t/ha)	Protein (%)
2016	Quambatook (50kg N/ha only)	Mid-row banded	4.08	7.8^{a}
		Mid-row surface	3.75	7.5^{ab}
		Top-dressed granular	3.68	7.7^{a}
		Streaming spray	3.84	7.3^{b}
	Longerenong	Mid-row banded	5.04^{a}	8.6
		Mid-row surface	4.51^{b}	9.0
		Top-dressed granular	4.84^{a}	8.5
		Streaming spray	4.83^{a}	8.7
		Flat fan spray	4.80^{ab}	8.4
2017	Ultima	Mid-row banded	2.25^{a}	9.7^{a}
		Mid-row surface	2.17^{c}	8.9^{bc}
		Top-dressed granular	2.25^{a}	9.2_{b}
		Streaming spray	2.28^{a}	9^{b}
		Flat fan spray	2.15^{b}	8.7^{c}
	Longerenong	Mid-row banded	5.42^{bc}	12.2
		Mid-row surface	5.57^{ab}	12.0
		Top-dressed granular	5.53^{ab}	11.9
		Streaming spray	5.65^{a}	12.2
		Flat fan spray	5.31^{c}	12.0

in 2017, visual symptoms of leaf burn in response to application were limited across all sites and years despite relatively high rates of N application.

The effect of application method on grain protein also varied with site. At Longerenong in both 2016 and 2017, no significant differences were observed. However at Quambatook in 2016, application by streaming sprays significantly reduced protein compared with topdressing or mid-row banding. Meanwhile at Ultima in 2017, mid-row banding produced significantly higher protein compared to all treatments, increasing protein by 0.5% to 1%. If mid-row banding is delaying crop access to applied N, this may further complicate the effect on grain protein. It is generally accepted that later applications of N tend to shift crop response from increasing yield to increasing protein. Therefore, depending on how long it takes for the crop to access applied N and how N deficient the crop is, this may shift the effect of application between yield and protein response.

Does banding damage the crop?

At a row spacing of 300mm, the impact of the banding operation was negligible when comparing unfertilised plots. Across all four sites, the biggest difference in yield and protein between unfertilised controls and unfertilised-banded plots was 0.13t/ha and 0.14%. However, this was where stubble loads were moderate, row spacing relatively wide, soil throw was controlled and the accuracy of guidance was good. The impact of banding in-season could vary in circumstances where these factors or crop growth stage are different.

Effect of application method on N use efficiency

Recovery of fertiliser in the crop and soil at harvest

Studies over numerous years have shown that on average, Australian grain crops take up just 44% of the N fertiliser that is applied in a given year (Angus and Grace, 2017). Results from 2016 indicated that mid-row banding in-season has the potential to increase crop uptake of fertiliser N well beyond typical rates. At Quambatook, crop uptake increased from approximately 42% of the N applied to 63%, and at Longerenong this figure increased from approximately 54% to 78% when comparing mid-row banding to mid row surface or streaming applications (Figure 2). By improving crop uptake of applied N, this also resulted in a significant reduction in N 'lost' to the environment — shown by the proportion of applied N not present either in the crop or soil at harvest.

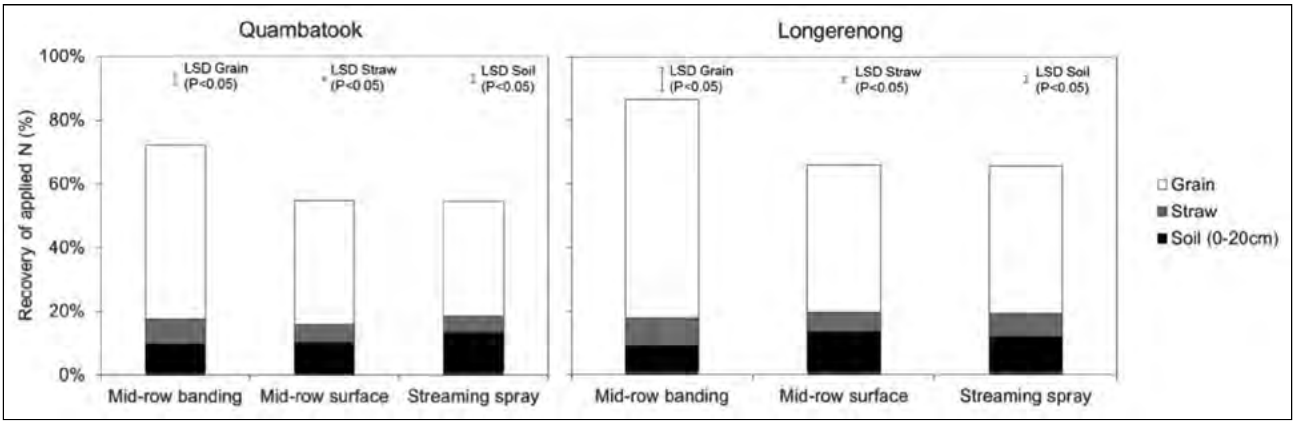

Figure 2. Recovery of applied N in grain, straw and soil (0-20cm) at harvest for a range of application methods at Quambatook and Longerenong in 2016 based on 15N mass balance. Data is the average of two application times at a rate of 50kg N/ha. (Wallace et al. 2017).

Effect of rainfall following N application

One of the reasons that growers might look to adopt mid-row banding in-season is the potential to reduce loss of N as volatilised ammonia in situations where rainfall following application is limited. By applying N on two occasions at each site, it is possible to compare the benefit of mid-row banding with varying amounts of rainfall after application. In 2016, at Quambatook, rainfall in the 10 days following the first application was 14.2mm compared with 4.6mm for the second application. At Longerenong, a total of 5.6mm was received following the first application and 75.2mm following the second. Table 4 shows that where follow-up rainfall was lower at each site, the relative benefit of mid-row banding (measured by recovery of fertiliser N in grain) compared to other application methods was greater.

What about mid-row banding at sowing?

Mid-row banding has been tested both locally and overseas for N application at sowing. Most recently this has been undertaken by a group led by Graeme Sandral at NSW DPI in Wagga Wagga — a link to their work from 2016 is listed under useful resources. In this situation, they have observed that mid-row banding at N rates of 95kg to 135kg/ha conserved significant amounts of N as ammonium in the top 20cm of soil and encouraged root growth around the fertiliser band resulting in improved N use efficiency.

In addition to the potential benefits of mid-row banding presented here, applying N using mid-row banding at sowing may offer the additional benefits of:

- Reduced risk of fertiliser toxicity, allowing higher rates of N to be applied at sowing.
- Restricting crop access to N early in the season thus reducing the risk of hay-off.
- Ability to apply N by mid-row banding where narrow row spacings or poor trafficability restrict the ability to band N in-season.

Table 2. Recovery of applied N in grain at harvest for a range of methods and times of application at Quambatook and Longerenong in 2016 based on 15N mass balance. Superscripts indicate significant differences ($P<0.05$). Treatments followed by the same letter are not statistically different (Wallace et al. 2017)

Site	Application method	N recovery in grain (%)	
		1st time of application	2nd time of application
Quambatook	Mid-row banded	52.7^{a}	56.5^{a}
	Mid-row surface	43.0^{b}	34.9^{c}
	Streaming spray	36.6^{c}	35.2^{c}
Longerenong	Mid-row banded	70.6^{a}	67.1^{a}
	Mid-row surface	40.0^{c}	52.9^{b}
	Streaming spray	36.8^{c}	56.1^{b}

Conclusion

The effect of mid-row banding N fertiliser in-season compared with other application methods varied across sites and years. In 2016, mid-row banding resulted in the highest average yields, but in 2017, the effects were more mixed. In 2016, mid-row banding was also shown to significantly improve crop uptake of fertiliser N. It is possible that in more N deficient situations than those tested, the potential benefit of mid-row banding may increase. Further testing is also required in conditions where rainfall following N application is lower to better test the potential to reduce N loss to volatilisation. Adoption of mid-row banding in-season will require careful consideration of a range of practical and economic factors including the ability to accurately apply N inter-row at a given row spacing and stubble load, speed of operation, cost of capital and ongoing operating costs plus unforeseen impacts such as the potential for increased weed germination following inter-row soil disturbance. However, initial indications for improving N use efficiency are positive and similar research will continue in 2018.

Useful resources

Wallace A., Nuttall J., Henry F., Clarke G and Marsh J. (2017). Mid-row banding nitrogen fertiliser in-season: Improving nitrogen use efficiency of cropping systems of southern Australia.

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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. This work was funded by the 'Improving practices and adoption through strengthening D&E capability and delivery in the southern region', Regional Research Agronomists program (DAV00143) as part of the GRDC and Department of Economic Development, Jobs, Transport and Resources, Bilateral Research Agreement. The authors also wish to acknowledge the assistance of Birchip Cropping Group staff in delivery of the experimental program.

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Notes

Insects, resistance and control

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ΦExtra technical comment by Protech Consulting Pty Ltd

GRDC project codes: CES00003, UM00057, CES00004

Keywords

- redlegged earth mite, green peach aphid, Russian wheat aphid, insecticide resistance, neonicotinoids.

Take home messages

- Insecticide resistance issues continue to outpace novel control options.
- Redlegged earth mite (RLEM):
  - Insecticide resistance in RLEM has been detected for the 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.
- Aphids:
  - Green peach aphid (GPA) has acquired low level 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 (RWA), with the length of protection differing between products.
- The implementation of recently published resistance management strategies (RMS) is vital to maximising the long-term viability of chemical options for pest management.
- Looking to the future:
  - Growth in the use of neonicotinoids will likely see increased insecticide resistance issues and the disruption of beneficial insect services in Australia.
  - Cutting edge forecasting tools are helping to identify patterns in insecticide resistance outbreaks.

Background

Insecticide resistance issues in broad-acre cropping continue to outpace the expansion of novel control options. In this paper, the latest findings on two major pest species that have developed resistance to key chemical groups, the redlegged earth mite (*Halotydeus destructor,* RLEM) and the green peach aphid (*Myzus persicae*, GPA) are discussed.

New research on the efficacy of seed treatments against Russian wheat aphid (*Diuraphis noxia*, RWA) is also presented.

The paper concludes by discussing the future risks of increased reliance on neonicotinoid insecticides and the application of forecasting approaches managing insecticide resistance.

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 Western Australia (WA) for a decade, in 2016, insecticide resistance in RLEM was detected for the first time in eastern Australia (Maino, Binns and Umina, 2017). In WA, resistance to SPs is widespread, while OP resistance is comparatively more restricted (Figure 1). In 2016, following reports of a field control failure in the Upper South East district in South Australia (SA), resistance testing determined this SA population was resistant to SPs and OPs (Figure 2). In 2017, two additional SP resistant populations were confirmed on the Fleurieu Peninsula (approx. 30km apart from each other, and approx. 200km from the 2016 detection).

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 (approximately 200 000 times the resistance of a susceptible population) leading to complete spray failures (Figure 2). 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.

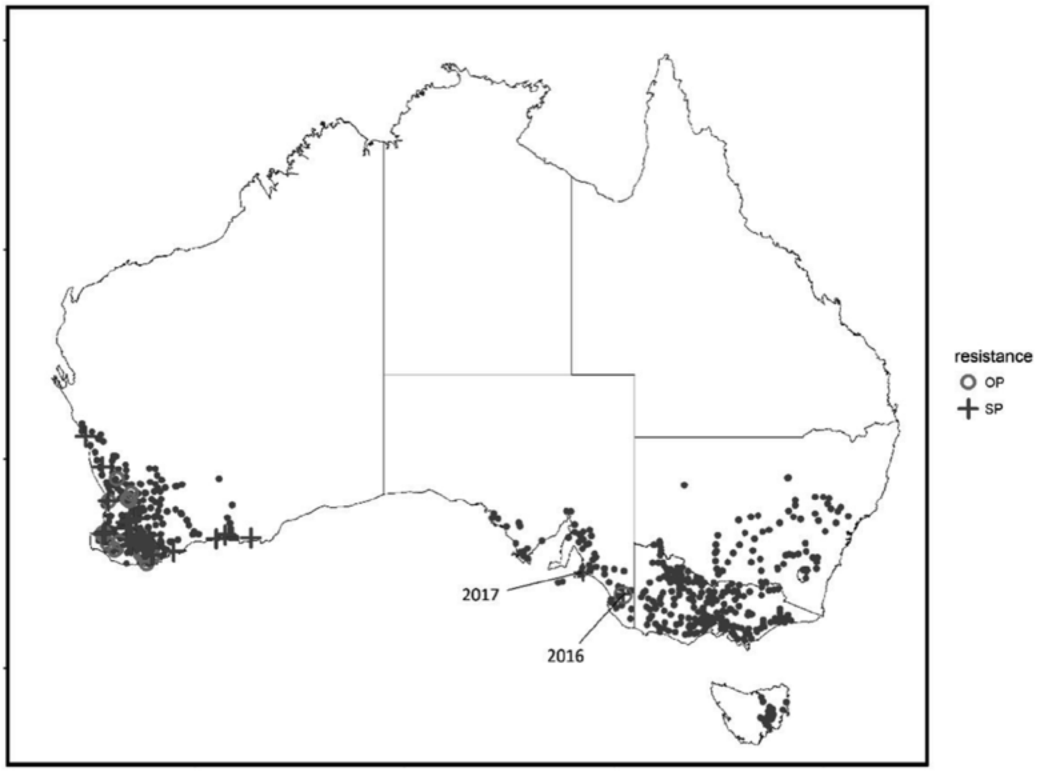

Figure 1. The current known distribution of *H. destructor* in Australia (adapted from Hill et al., 2012) shown as full circles, overlaid with the known distribution of SP and OP resistance across Australia at 2017.

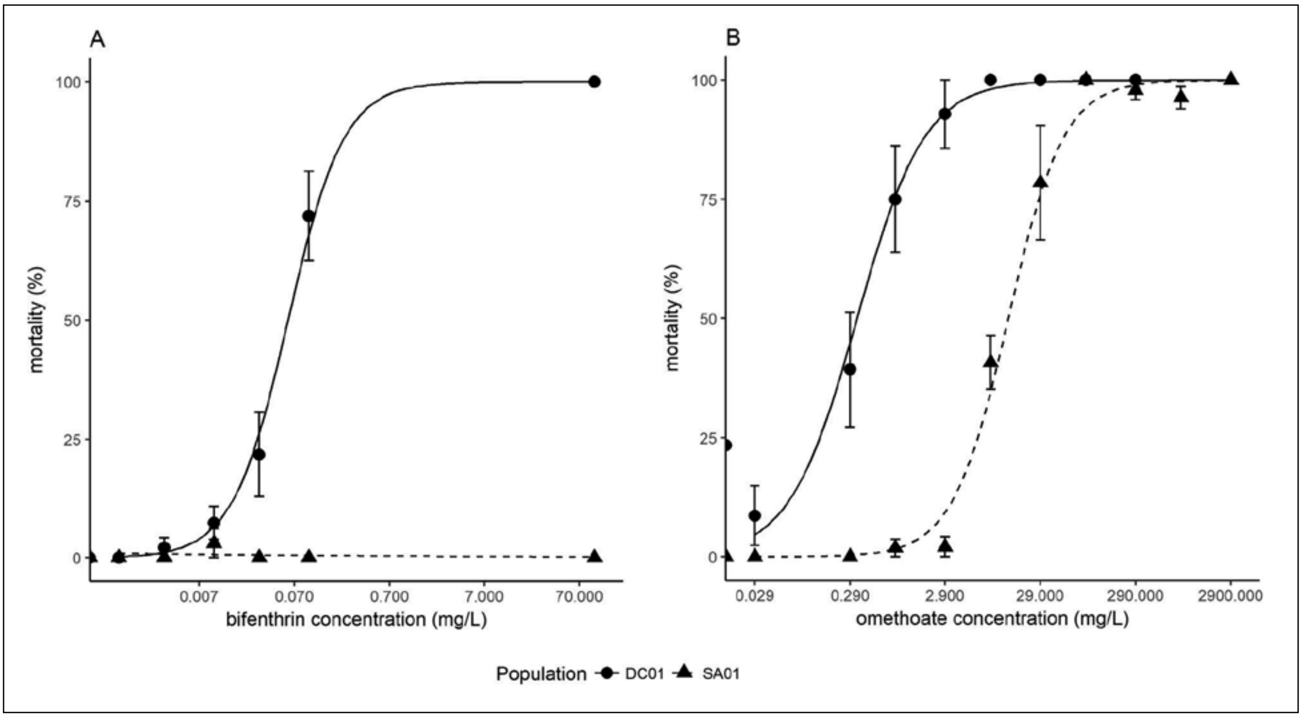

Figure 2. Concentration-mortality curves for redlegged earth mite from a susceptible (DC01) and resistant (SA01) populations when exposed to a synthetic pyrethroid — bifenthrin (A) — and an organophosphate — omethoate (B) — after 8 hrs exposure. Vertical bars denote standard errors. Lines represent fitted values from fitted logistic regression models.

To increase management options for RLEM populations with dual resistance to OPs and SPs, trials run by the University of Melbourne and **cesar** are testing the impact of different management regimes on mite abundance and chemical tolerance in a dual-resistant population. Preliminary results have shown that both foliar applied insecticide groups are largely ineffective on populations with SP and OP resistance, but that high rates of omethoate can still provide control in OP-resistant populations, though the long-term sustainability of this strategy is unlikely. A novel mode-of-action group was also tested as part of this trial and found to be highly effective at suppressing mite numbers, indicating no cross-resistance.

Green peach aphid acquires new resistances

Green peach aphid (GPA) 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); SPs (Group 3A); OPs (Group 1B); neonicotinoids (Group 4A); and sulfoxaflor (Group 4C). Paraffinic spray oils are also registered for suppression of GPA.

Together with CSIRO, **cesar** has been mapping the extent of insecticide resistance in GPA across Australia for the past few years. 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 aphid specific carbamate chemical pirimicarb$^{\Phi}$ in GPA populations (Figure 4), this pesticide remains important to the control of other canola aphid species of similar appearance (e.g. cabbage aphid and turnip aphid). Thus, it is important to properly identify aphids before spray decisions are made. Figure 3 highlights some key features that can be used to distinguish GPA (with a hand lens) from other similar species found on canola. If a hand lens is unavailable, GPA will usually be found on the lowest, oldest leaves, typically in sparse family groups, while turnip aphid and cabbage aphid are more commonly found in large colonies on flower spikes.

$^{\Phi}$Products containing pirimicarb are not registered for control of turnip aphid in canola. In commercial situations label specification must be adhered to at all times.

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

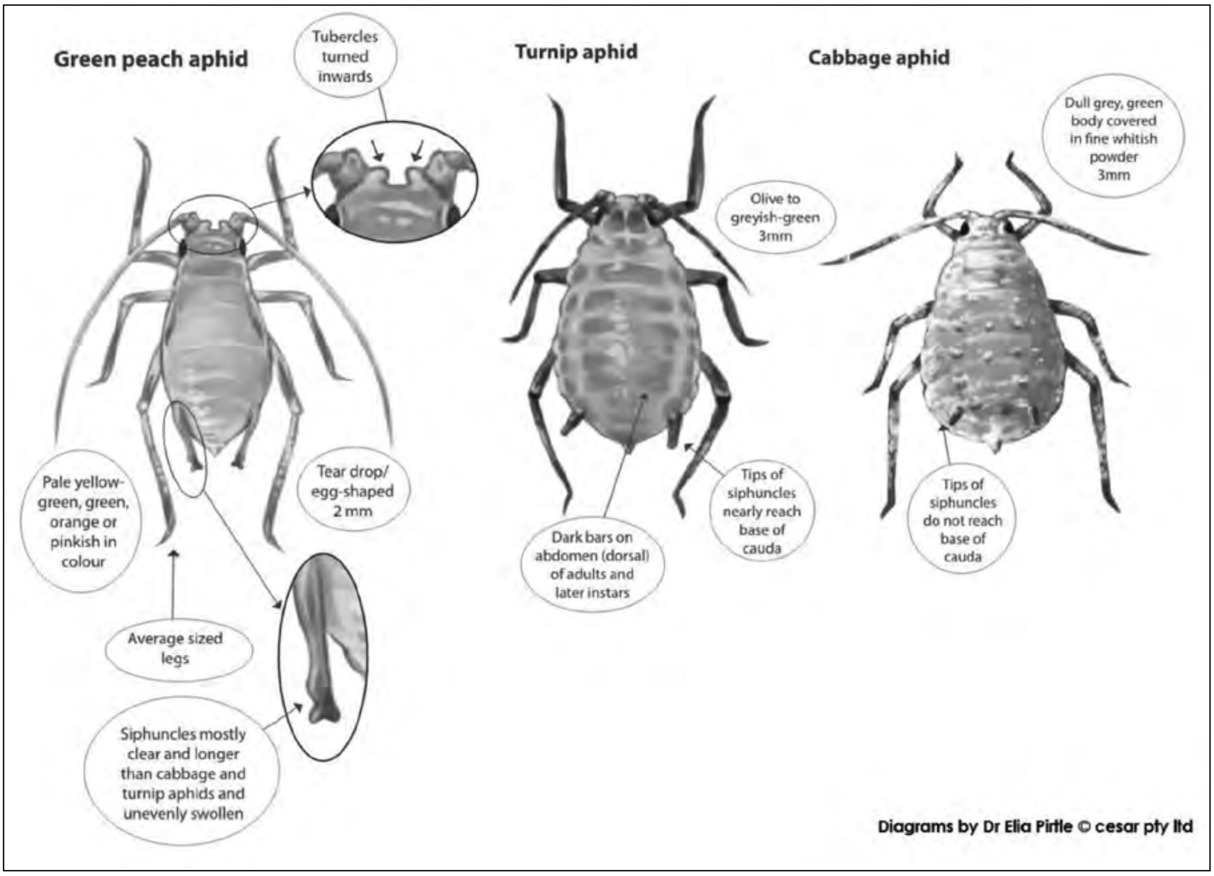

Figure 3. To assess the applicability of pirimicarb to other non-resistant aphid species of similar appearance, green peach aphid should be distinguished using diagnostic traits. If a hand lens is unavailable, green peach aphid will usually be found on lowest, oldest leaves, typically in sparse family groups, while turnip and cabbage aphid are more commonly found in large colonies on flower spikes

revealed these aphids to be approximately 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 approximately 1000 times resistance to neonicotinoids resulting in field control failures, as well as cross-resistance with group 4C chemicals such as sulfoxaflor. Australian GPA populations may acquire this high level neonicotinoid resistance if neonicotinoid selection pressures remain high, or if there is an incursion of overseas GPA carrying the R81T mutation.

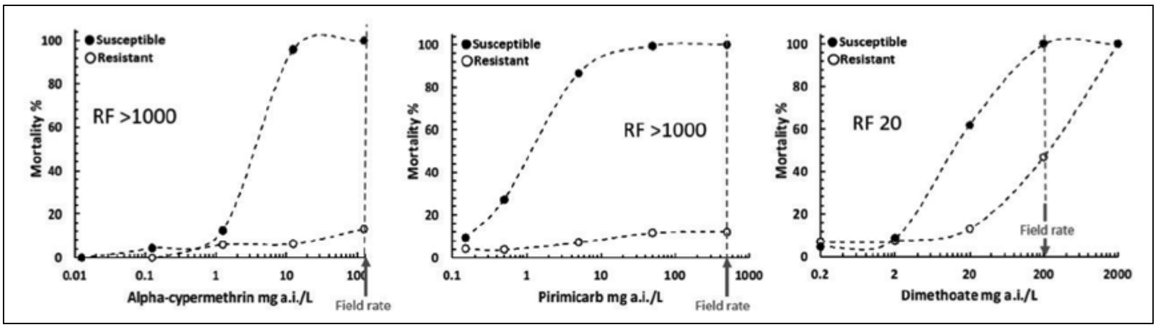

Figure 4. Sensitivity of a typical Australian susceptible and resistant green peach aphid population to the synthetic pyrethroid, alpha-cypermethrin (left panel), the carbamate, pirimicarb (middle panel) and the organophosphate, dimethoate (right panel). RF = Resistance Factor.

Resistance management strategies

With resistance evolution continuing to outpace the discovery of new chemistries with novel modes of action, resistance management strategies (RMS) are more than ever essential to maintain the viability of pest control tools.

RMS for major grains pests have been made available through the National Insecticide Resistance Management (NIRM) working group of the Grains Pest Advisory Committee, a GRDC funded project, which provides strategic advice to GRDC on pest issues. Across these strategies, there are both general and pest-specific practices that can help maintain the viability of chemistries into the future.

General RMS strategies include:

- If applying multiple insecticides within a season, rotate chemistry mode of action.
- Utilisation of non-chemical control options that suppress pest populations.
- Using economic spray thresholds to guide chemical applications.
- Using selective chemicals, if chemical application deemed necessary, in place of broad-spectrum options.
- if using broad spectrum chemicals, consider the secondary impacts to non-target pests and beneficials.
- Compliance with all directions for use on product labels and ensuring proper application coverage.

RMS strategies specific to GPA include:

- Managing the green bridge (in particular, the control of brassica weeds and volunteer crops) on which GPA may persist through summer.
- Stubble retention to decrease visual contrast between seedlings and soil (landing cue for GPA).

RMS strategies specific to RLEM include:

- Control of spring populations immediately before the production of over-summering (diapause) eggs through cultural control (grazing, broadleaf weed removal), or a Timerite® spray (if required) to reduce pest pressure at crop emergence/RLEM hatching the following autumn.

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
- 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*).

[Φ] *None currently registered for use in Australia, but their use is permitted under the following permits: PER81133, PER82304 and PER83140.*

All seed dressings tested provided effective aphid control up to five 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.

Balancing the scales of neonicotinoid seed treatment use

Neonicotinoids are currently the most used insecticide group globally. This over-reliance may be explained by the increased resistance issues surrounding older chemistries like the OPs and SPs. Also contributing to this trend is the convenience of neonicotinoids, in particular, as seed treatments, which are applied at the time of sowing at no extra application cost.

Despite the advantages of neonicotinoid seed treatments, their indiscriminate usage as commonly seen, carries some important costs. Continued wide-scale use of neonicotinoid seed treatments will select for resistance, as is currently being seen in GPA in Australia (de Little et al. 2017). Overseas, where neonicotinoids have been used for longer and more extensively, more cases of resistance have been documented (Sparks and Nauen, 2015). In addition to resistance concerns, widespread neonicotinoid use is likely to impair ecosystem services provided by some beneficial invertebrate and microbial communities, as has been shown in international studies. Industry stewardship and good resistance management are paramount to ensuring neonicotinoid usage is balanced against these issues, and remains a long-term viable control option for grains pests.

Before making a management decision, the question should be asked, is a neonicotinoid seed treatment warranted in this paddock, in this year?

- Wherever possible, assess the risk of damaging pest infestations (or virus risk), based on the prior paddock and seasonal history. In the case of RLEM, for example, a high-risk situation would be indicated by: (i) canola or lucerne to be sown, (ii) high mite numbers the previous year, and (iii) no Timerite® spray the previous spring.
- Unless the pest risk is deemed high, avoid using neonicotinoid seed treatments in consecutive years, preferably no more than one in three years in any given paddock.

With seed treatments, which are not applied in response to immediate pest pressure, the challenge, of course, is the ability to accurately forecast the timing and severity of pest (and virus) occurrences

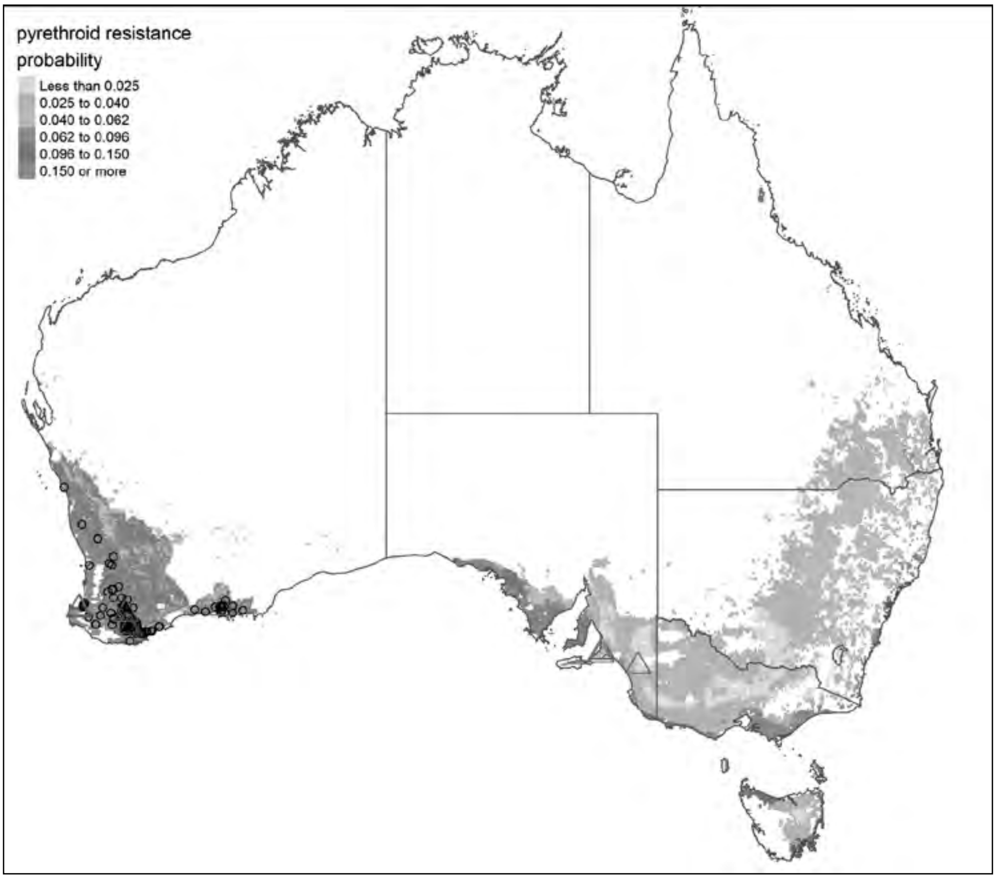

Figure 5. Predicted pyrethroid resistance risk (probability) for RLEM adapted from Maino et al. (*in press*). Known resistant populations used to calibrate the model (open circles) as well as newly detected populations (open triangles) are overlaid.

well ahead of time. Predictive tools may provide useful information here, but are currently not being used for such purposes, or simply do not exist for a particular species of interest.

Forecasting future resistance issues

To bring further focus to the resources directed to resistance management, researchers from **cesar** and the University of Melbourne have applied modern forecasting approaches to identify spatial relationships in the evolution of resistance. This novel approach synthesised large data sets on resistance, land usage, and environmental factors, and found that resistance in RLEM is related to chemical pressure (average number of chemicals used annually), but more surprisingly is also more likely to develop in regions with particular climatic properties (Figure 5). The study highlighted risks in eastern Australia before the recent detection of resistance in SA, and will be used to guide resistance management in the future.

Useful resources

https://grdc.com.au/resources-and-publications/all-publications/factsheets/2015/07/grdc-fs-greenpeachaphid

https://grdc.com.au/FS-RLEM-Resistance-strategy-West

https://grdc.com.au/FS-RLEM-Resistance-strategy-South

https://grdc.com.au/TT-RWA

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de Little, S. C. et al. (2017). ‘Discovery of metabolic resistance to neonicotinoids in green peach aphids (*Myzus persicae*) in Australia’, Pest Management Science, 73(8), pp. 1611–1617. doi: 10.1002/ps.4495.

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Maino, J. L., Umina, P. A. and Hoffmann, A. A. (no date). ‘Climate contributes to the evolution of pesticide resistance’, Global Ecology and Biogeography, p. n/a--n/a. doi: 10.1111/geb.12692.

Sparks, T. C. and Nauen, R. (2015). ‘IRAC: Mode of action classification and insecticide resistance management’, Pesticide Biochemistry and Physiology. The Authors, 121, pp. 122–128. doi: 10.1016/j.pestbp.2014.11.014.

Umina, P. A. et al. (2016). ‘Science behind the resistance management strategy for the redlegged earth mite in Australian grains and pasture’.

Acknowledgements

The research presented here is made possible by the significant contributions of growers through both trial cooperation and the support of the Grains Research and Development Corporation. The authors would like to thank them for their continued support. We would also like to acknowledge other collaborators including Julia Severi (**cesar**), Ary Hoffmann (University of Melbourne), Owain Edwards (CSIRO), Jenny Reidy-Crofts (CSIRO), Svetlana Micic (DAFWA), and Alan Lord (DAFWA). The authors also acknowledge the assistance of Ken McKee and David Landmeter (Syngenta Australia), Shane Trainer (Bayer Crop Science) and Colin Edmondson (Advanta Seeds).

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Notes

Does glyphosate formulation affect the control of glyphosate resistant weeds?

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ΦExtra technical comment by Protech Consulting Pty Ltd

GRDC project codes: UCS00020, UA00158

Keywords

- glyphosate resistance, annual ryegrass, herbicide formulations, weed survey.

Take home messages

- Glyphosate resistance has been detected in annual ryegrass and sowthistle.
- Initial trials suggest significant differences in efficacy between glyphosate products.
- Treating younger plants at lower temperatures can improve glyphosate efficacy on resistant biotypes.
- Crop topping with glyphosate is not effective on glyphosate resistant ryegrass.

Glyphosate resistance

The GRDC has invested in random weed surveys of cropping regions across WA, SA, VIC and NSW since 2005, to monitor for resistance levels in key weed species. In the latest round of weed surveys, glyphosate has been included in the suite of herbicides tested. The methodology involves collecting weed seeds from paddocks chosen randomly at pre-determined distances, at harvest. Weeds were tested in outdoor pot trials under natural growing conditions. The incidence of resistance to glyphosate identified in these surveys is presented in Figure 1.

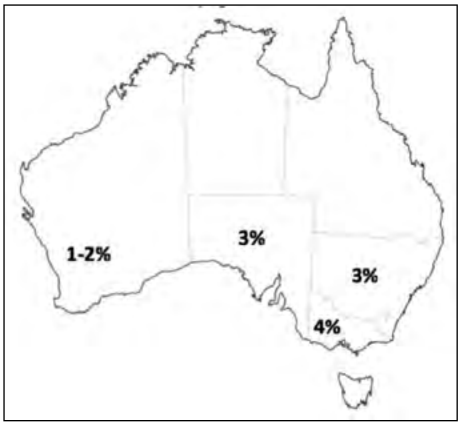

Figure 1. Incidence of paddocks containing glyphosate resistant ryegrass. Resistance is defined as a sample where more than 20% plant survival was detected in a pot trial. Paddocks surveyed in WA = 500, SA = 700, Vic = 450 and NSW = 600.

Glyphosate resistance in ryegrass has also been detected in grower samples sent to commercial resistance testing laboratories. In most cases, testing requests have been to identify effective herbicides or verify a herbicide failure. Requests to test with glyphosate due to poor performance is common. Figure 2 presents test results from Plant Science Consulting in the last 12 months. It highlights that the level of glyphosate resistance is similar across the southern states and is approximately 10-fold greater than the figures identified in the random weed surveys (Figure 1).

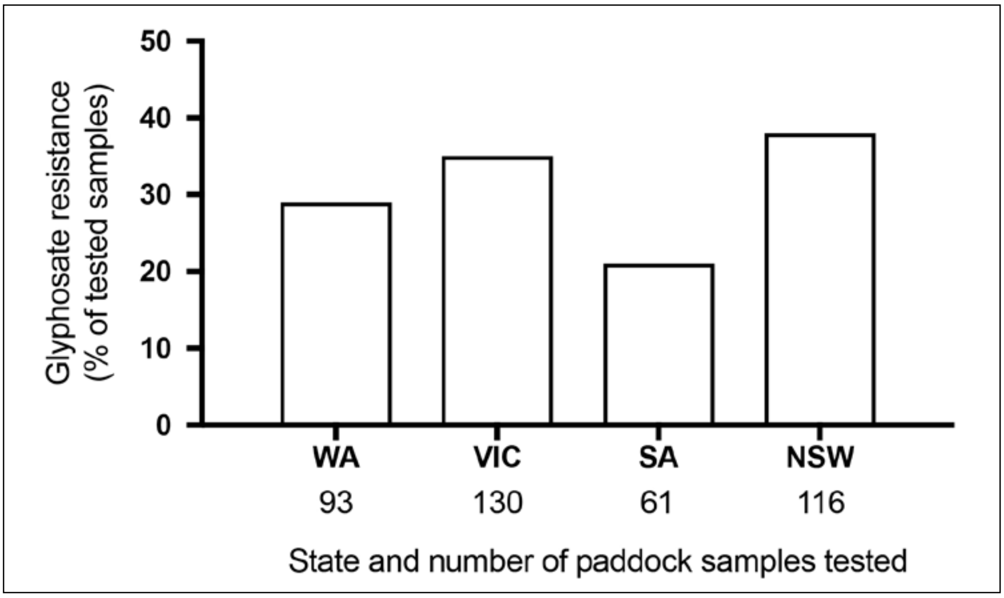

Figure 2. Resistance to 1.5L/ha Glyphosate 540 confirmed in grower ryegrass samples (Seed and Quick-Test) in the past 12 months by Plant Science Consulting.

Differences between glyphosate products

Significant differences between glyphosate products have been identified in outdoor pot trials conducted in winter and summer annual weed species. Three undisclosed registered glyphosate products were compared in initial trials, with significant differences in weed control. Herbicide products Gly 1 and Gly 3 gave consistently greater control than Gly 2 on susceptible and resistant ryegrass (Figure 3). Surfactant differences between glyphosate products is likely to be a major factor determining final control. In the field, using glyphosate products with quality surfactants could be the difference between controlling ryegrass individuals with lower levels of resistance or allowing them to survive, cross-pollinate and increase the levels of glyphosate resistance.

Differences in the level of control between glyphosate products in another key weed species such as glyphosate-resistant milkthistle (sowthistle) from NSW has also been confirmed (Figure 4). This information highlights that significant differences in control between glyphosate formulations occur, not only on glyphosate sensitive, but also on glyphosate resistant individuals.

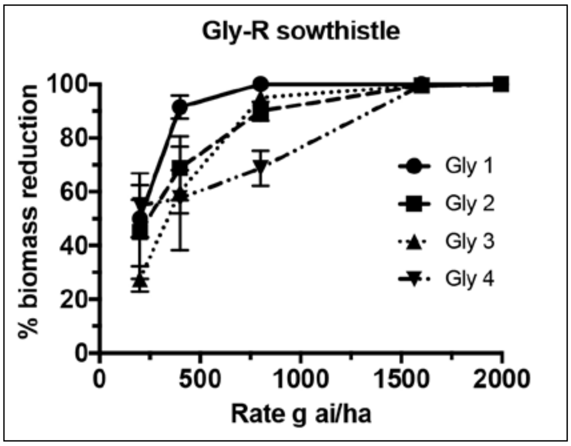

Figure 4. Efficacy of four glyphosate products on control of glyphosate resistant milkthistle as confirmed by outdoor pot trials by Plant Science Consulting.

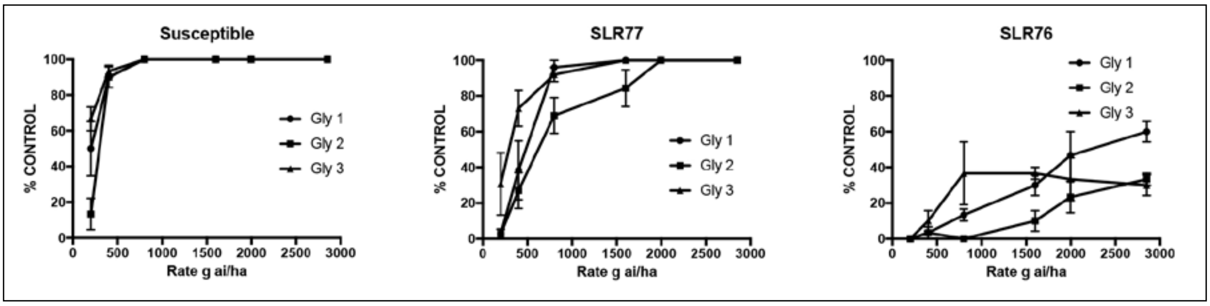

Figure 3: Efficacy of three glyphosate products on susceptible and glyphosate resistant ryegrass populations, SLR77 with weak glyphosate resistance and SLR76 with strong glyphosate resistance.

Growth stage and glyphosate rate

Plant growth stage can play an important role in weed control. Even in resistant populations, improved control can be achieved at younger growth stages. Younger plants tend to have thinner cuticles than older plants, and therefore, herbicide movement into younger plants is generally quicker. The effect of growth stage and glyphosate rate was investigated in a field trial in NSW on a susceptible and two glyphosate resistant sowthistle populations by Tony Cook, DPI Tamworth (Table 1). Increased control of glyphosate resistant sowthistle was observed at younger growth stages.

Weed seed sterilisation

Crop-topping is a procedure aimed at controlling weed seed set at pre-harvest timings with non-selective herbicides. One of the most commonly used practices is applying glyphosate pre-harvest to prevent seed set by flowering ryegrass. Only two glyphosate products (Nufarm Weedmaster DST® and Roundup Ultramax®[Φa]) are registered for this practice in wheat, barley[Φb], canola and some pulse crops. A field trial was conducted in 2016 to investigate the effect of crop-topping a glyphosate resistant ryegrass population with 2.8L/ha and 4.1L/ha of Weedmaster DST at two timings (flowering and milky dough). Additionally, laboratory testing confirmed that this population was not target site resistant, therefore resistance is due most likely to the reduced translocation mechanism. This is the most common glyphosate resistance mechanism identified in ryegrass. Viability testing of the seed after maturation revealed that the reduction in seed germination was between 9% to 22%, indicating that at least 80% of the seed remained viable. Glyphosate was therefore not effective in sterilising glyphosate resistant ryegrass. In addition, glyphosate resistance can increase if susceptible ryegrass is sterilised leaving only resistant individuals to cross-pollinate with each other.

[Φa] Roundup Ultramax is no longer registered but Pintobi Attack has these uses on its label; commercial applicators must use registered products. [Φb] Products listed are not registered for use in barley, their use is for research purposes only.

Effect of temperature

Temperature has been identified as playing a major role in glyphosate efficacy. Significant differences were identified in wild oat control with the same glyphosate product in plants sprayed in outdoor summer or winter pot trials in South Australia (Figure 6). Complete control of a wild oat population was not achieved in summer even at higher than label rates (1600g ai/ha glyphosate) whereas in winter trials 400g ai/ha glyphosate resulted in complete control. These large differences suggest that controlling wild oats in summer fallows can be affected by high temperatures.

Table 1. First cases of confirmed glyphosate resistant sowthistle from Liverpool plains. Data presented as percent biomass reduction at three growth stages. Fallow spray timings from early to late summer. Data courtesy of Tony Cooke, DPI, Tamworth.

Glyphosate rate (g ai/ha)	Growth Stage: Early rosette 10cm	Growth Stage: Early bolting	Growth Stage: Mid-flowering
Susceptible sowthistle- (% biomass reduction)			
360	79	76	0
720	100	81	33
1260	100	100	100
1800	100	100	100
Resistant sowthistle biotype “Yellow” - (% biomass reduction)			
360	55	27	0
720	97	0	0
1260	95	16	0
1800	97	63	4
Resistant sowthistle biotype “CRK” - (% biomass reduction)			
360	64	7	0
720	80	35	5
1260	91	71	58
1800	97	78	100

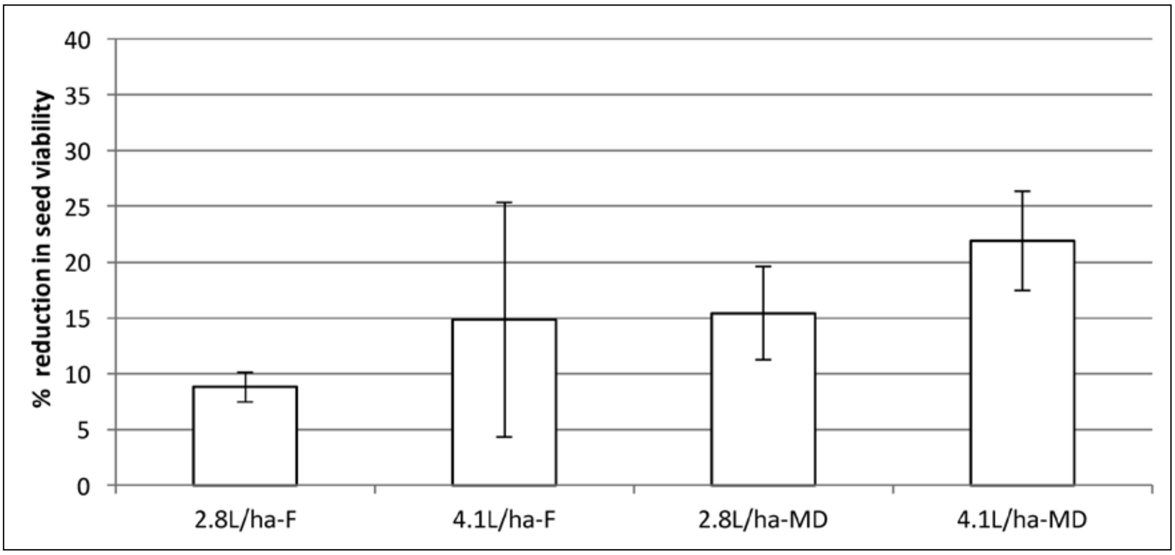

Figure 5. Reduction in viability of ryegrass seed after crop-topping with Weedmaster DST at two timings, F - flowering and MD = milky dough. Trial conducted at Roseworthy SA in 2016.

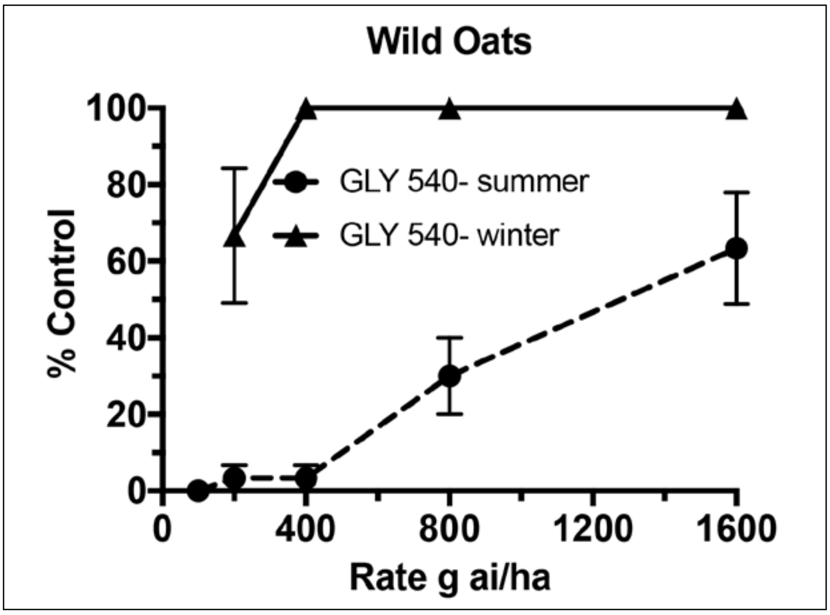

Figure 6. Control of wild oats with the same glyphosate product in outdoor summer and winter pot trials.

A current study is investigating the effect of temperature on control of glyphosate resistant sowthistle from NSW. Initial trials have confirmed greater control with glyphosate at lower temperatures, particularly of resistant biotypes (Table 2). These findings suggest that applying glyphosate at lower temperatures can improve control of glyphosate resistant sowthistle. At lower temperatures glyphosate remains in liquid form on plant surfaces longer leading to greater uptake, particularly at higher humidity. Maximising glyphosate uptake is therefore likely to improve weed control and factors such as lower temperature and higher humidity influence uptake.

Table 2. Effect of temperature in control of four biotypes of sowthistle with Glyphosate 540. Data is LD50= dose required to kill 50% of the population.

Biotypes	Resistance level	LD50 (g a.i/ha)	
		20°C	30°C
Yellow	strong	439	962
Crocket	strong	389	919
White	weak	132	389
GI	susceptible	135	152

Conclusion

In the southern cropping zone glyphosate resistance in ryegrass is becoming increasingly common. Significant differences between registered glyphosate products have been identified on several weed species with some products more effective than others. Differences in the control of glyphosate resistant ryegrass and sowthistle biotypes with different glyphosate products were observed. Products with quality surfactants can be expected to more effective than products with poor quality surfactants, particularly on stressed weeds. Treating younger plants under cooler temperatures using robust rates can improve weed control of susceptible and some glyphosate resistant individuals. These initial findings have identified that there are several factors that influence glyphosate efficacy including product choice. A better understanding of glyphosate formulations could improve weed control and delay glyphosate resistance. Further investigation of glyphosate products is recommended.

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 under project UCS00020. Additional thanks Tony Cook from DPI Tamworth and to Sinochem Australia for permission to use trial data.

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Notes

Harvest weed seed control – growers spoilt for choice

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[1]Grassroots Agronomy; [2]Australian Herbicide Resistance Initiative.

Keywords

- weed seed banks, integrated weed management (IWM), herbicide resistance, annual ryegrass, wild radish, harvest weed seed control (HWSC), narrow windrow burning (NWB), chaff cart, chaff lining, chaff decks, Integrated Harrington Seed Destructor (iHSD).

Take home messages

- Harvest weed seed control (HWSC) comes in many forms — bale, burn, graze, mill or rot.
- Match the HWSC tactic to your farming system, crop types and location.
- Capturing weed seeds in the chaff fraction when chaff lining or using chaff decks requires attention to detail in harvester set-up.
- HWSC cannot be used effectively in isolation — adopt the 'Big six' and top shelf agronomy to drive weed numbers to zero.

Background

Grain producers have become more proficient atHerbicide resistance remains an ongoing challenge for Australian grain growers, but the industry is continually innovating to minimise the risks. Non-chemical tools are becoming mainstream practice so that growers and advisers can deal with herbicide resistance by reducing weed seed banks and protecting chemistry.

One of the most popular weed management tactics being adopted in recent years is harvest weed seed control (HWSC). This process takes advantage of seed retention at maturity by collecting weed seeds as they pass through the harvester. Problematic weeds such as annual ryegrass, brome grass and wild radish retain 77% to 95% of their seed above a harvest cut height of 15cm at maturity, creating an ideal opportunity for seed collection.

Seed retention will change over time with the proportion of retained weed seeds declining the longer harvest is delayed past crop maturity. Therefore, crop and weed maturity will have a significant impact on the success of HWSC. Harvest height is equally important for HWSC, with a 15cm cut height preferred to capture 80% to 90% of the ryegrass seed at maturity — this can be challenging in high yielding cereals or bulky hybrid canola crops.

In the southern cropping region, low harvest height has been a barrier to adoption with growers not wanting to slow harvest down, incurring higher fuel costs and reducing harvester efficiency. Growers and researchers have since been looking at tactics that will enhance the efficacy of HWSC without slowing harvest. One option being adopted is sowing crops at narrower row spacings or higher plant populations. Weeds are then forced to grow taller to compete for light, therefore producing seed higher in the crop canopy. Stripper fronts are also being investigated to gauge any differences with weed seed capture and harvest efficiency, reducing the need to cut low whilst minimising fuel consumption.

HWSC practices

Originally pioneered 30 years ago with chaff carts in Western Australia (WA), HWSC has now been adopted nationally as growers tailor their options to suit different farming systems and locations.

The HWSC options are all slightly different with narrow windrow burning (NWB) and bale direct taking in both straw and chaff for burning or baling. Newer HWSC practices only take in the chaff fraction containing weed seeds for rotting, grazing or destruction through a mill. This includes chaff lining or chaff decks, chaff carts and emerging mill technology using the Integrated Harrington Seed Destructor (iHSD) or Seed Terminator.

Research by Walsh et. al. 2014 (https://ahri.uwa.edu.au/harvest-weed-seed-control-tools-they-all-work/) highlighted that HWSC tactics are equally effective in reducing weed seed production. The use of chaff carts, NWB or iHSD, were compared at 24 sites across Australia with an average reduction in ryegrass of 60% germination the following autumn. This was achieved by removing 70% to 80% of the seed at harvest through either burning or destruction of weed seeds.

Research has recently commenced to gauge the impacts of chaff lining and chaff decks on the rotting of weed seeds under different crop types. Preliminary data suggests poor seed survival under canola or barley chaff because of an allelopathic effect, however, in wheat there was high ryegrass seed survival underneath the chaff row which is unexplained. Michael Walsh from Sydney University and John Broster from Charles Sturt University are currently working to quantify the value of rotting under chaff line and chaff deck systems.

Each HWSC practice has its own benefits and challenges with growers leading the charge, working with a small group of researchers to develop harvester modifications that maximise weed seed control with harvest height and seed retention. For HWSC to be successful at the farm level, the practice needs to be both cost effective and practical to fit in with existing operations.

HWSC cannot be used in isolation for weed management — growers and advisers should implement a range of diverse weed management practices to drive weed numbers down. Defined as the ‘Big six’ (https://weedsmart.org.au/the-big-6/), these management practices include diverse rotations, mix and rotating herbicides, crop competition, double knocks, crop topping/hay to stop seed set and HWSC. The ‘Big six’ complements best practice agronomy such as calendar sowing combined with effective pre-emergent herbicide packages.

HWSC adoption

An online twitter survey was conducted in November 2017 by WeedSmart with 269 growers responding. The results indicated that HWSC practices are changing, with NWB declining at the expense of chaff lining and chaff decks. Thirty two percent of growers were planning to use NWB in 2017, whilst 26% would be chaff lining and 9% using chaff decks. Chaff carts were stable at 13%, mill technology at 3% and 14% would be doing nothing.

The overall trend is positive and reflects the high value growers are increasingly putting on HWSC as a mainstream weed management tool. It does not come easy and looking at each practice in detail (Table 1) highlights what growers and advisers need to be aware of.

Table 1. HWSC options.

HWSC tactic	Indicative cost	Labour required	Crop residue removed	Positives	Negatives	Best fit
NWB	$200	Burning rows	Chaff and straw 40%-100%	Low cost	Nutrient removal, smoke, fire escapes	Low rainfall, canola and pulses
Glenvar Bale Direct	$340,000	Pick up bales	Chaff and straw 40%-50%	Profit from bales	Nutrient removal, cost	Market for bales
Chaff carts	$15,000 to $80,000	Graze, burn heaps	Chaff only 15%	Feed value for sheep	Burning of piles	Mixed growers
Chaff lining	$200 to $4500	Minimal	Chaff only 15%	Low cost, no burning, weed seeds left to rot	Insects and mice in chaff rows	Everywhere except small, windy paddocks. Suits both mixed growers and intensive croppers
Chaff decks	$15,000 to $20,000	Minimal	Chaff only 15%	No dust on tramlines, no burning	Insects and mice in chaff rows, chaff rows driven over	CTF growers, both mixed and intensive croppers
iHSD	$165,000	Minimal	0%	No loss of residue	Still in the development stages, cost	Intensive croppers
Seed Terminator	$100,000	Minimal	0%	No loss of residue	Still in the development stages, cost	Intensive croppers

Narrow windrow burning (NWB)

Developed in the northern WA cropping zone, NWB has been highly effective at reducing annual ryegrass and wild radish seed banks across the nation. A chute is attached to the back of the harvester to concentrate straw and chaff into a 500mm to 600mm narrow windrow — these rows are then burnt the following autumn. The practice is low cost and highly effective with rows burning hotter for longer than a standard stubble burn. Up to 99% of weed seeds are controlled in a well managed hot burn where temperatures reach 400°C to 500°C for at least 10 seconds.

Despite its simplicity and popularity, the practice is now in decline due to several factors. Burning is the major challenge, especially if fire escapes from the rows to burn the whole paddock or trees. Rows becoming wet after summer rains can create challenges waiting for the rows to dry out for the fire to burn hot enough and destroy weed seeds. Nutrient redistribution and ground cover loss are also key issues for growers using NWB, particularly on lighter soil types.

Smoke in built up rural communities has been problematic for NWB, where smoke lingers late into the evening when wind inversions occur. Some growers are actively looking at alternative options to NWB, whilst for those where the process works, it will remain a key tool in their HWSC toolbox.

Glenvar Bale Direct

Chaff and straw are collected during harvest then baled directly using a baler attached to the harvester. There is a moderate level of ground cover removal with straw and chaff removed, whilst weed seed removal is high. A large capacity harvester is needed to operate the baler, but does not slow the harvesting operation down. Growers would require access to markets to utilise the bales for bedding or as a feed source.

Chaff carts

The first HWSC tool was introduced from Canada for the collection of chaff material for feeding to sheep. A cart is towed by the header which collects chaff and weed seeds then dumps it in piles for grazing or burning. The original blower delivery system was improved with a conveyor belt elevator which allows some small straw into the chaff fraction. The increased oxygen levels in the chaff have resulted in a quicker, hotter burn. Burning of chaff piles has created similar issues to NWB with chaff piles smouldering for long periods.

New research is proving the value of chaff dumps, not only for weed seed reduction, but also sheep feed (https://ahri.uwa.edu.au/chaff-carts-good-for-the-crop-and-the-sheep/). Chaff piles can be grazed by sheep directly or baled for sale into feedlots or other associated markets. Ed Riggall is a sheep consultant from WA who has found that sheep grazing chaff piles gained 3kg/head more over three weeks than those without chaff piles. This was despite the sheep taking one week to get used to the chaff piles. Chaff piles are reducing supplementary feeding costs and increasing scanning results while reducing weed seed numbers. Studies have shown that sheep do not spread weed seeds, with only 3% to 6% of seed remaining viable after passing through the rumen. Cattle are less effective at destroying ryegrass seed with 15% to 20% of the seed remaining viable.

Chaff lining

Developed by Esperance grain growers, chaff lining involves separation of the chaff and weed seed fraction from the straw residue, with chaff dropped into a narrow line behind the harvester via a chute attached to the main sieve. The chaff line remains on the soil surface where weed seeds are left to rot, while the straw travels through the rotor to be chopped and spread.

Chaff lining is repeated on the same runs year after year to allow weeds to continually rot in a defined area. There is limited research data to quantify the full impacts of seed rotting, but observations to date indicate the undisturbed chaff row is a hostile environment for weed seeds. Growers do not need to be on a full controlled traffic farming (CTF) system, but ideally the header needs to run on the same lines each year.

Chaff lining is low cost, involves no burning and growers have the option to graze chaff lines with similar feed values as those found with chaff carts. Chaff lines have been successfully grazed in stubble over summer, but also in winter when sown to a dual-purpose grazing crop.

Harvester set-up is critical to maximise weed seed capture with growers adding a separating baffle above the sieves to ensure chaff stays out of the straw and exits via the chute. Grain needs to be threshed hard to remove weed seeds out of the head, with the grates of the harvester opened up to get as much material out of the rotor and onto the sieve for collection.

Growers have built their own chutes and baffles to suit a wide range of harvesters with 2017 being the first season many growers adopted the practice. There were several situations where chaff lining set-ups caused issues at harvest including a build up of excess fine chaff on the air cleaner or blockages at the rear of the baffle in canola. Refinements to chaff lining are ongoing as growers work with each other and industry to achieve continuous improvement with the practice.

Chaff decks

The chaff deck system operates on a similar principle to chaff lining, but the chaff material is directed onto dedicated wheel tracks in a CTF system. Known also as chaff tramlining and developed in the Esperance region of WA, weed seeds exit the harvester off the sieves in the chaff fraction whilst straw is chopped and spread with no loss of harvest efficiency. Weed seeds are exposed to the same rotting effects as in chaff lining, but there is half the material given the split across the two wheel tracks.

Dust generated when summer spraying is minimised due to the presence of the chaff on the tramlines. Conversely, the weed seeds are exposed to a level of disturbance on tramlines which increases their potential to germinate as opposed to continually rotting. This contrasts with chaff lining where the single chaff row is not exposed to any wheel traffic and potentially optimises its rotting potential.

Chaff deck systems have opened new opportunities for alternative forms of weed control not previously thought possible. Weed seed collection has been so effective that very dense populations have emerged in defined rows on the tramlines in crop. Due to the nature of permanent CTF tramlines, growers can use a range of alternative chemistry or cultural practices throughout the season and not affect the main crop. For example, in a 12m CTF system only 8% of the paddock is dedicated to wheel traffic, therefore weeds in the chaff lines can be targeted using non-chemical options such as microwave, baling or crimping as potential forms of site specific weed control.

Agronomy for chaff rows created by chaff decks and chaff lining is a key issue and growers need to be aware of some issues that need to be managed. These include:

- Sow through the chaff rows with either a disc or tyne — unsown rows become too weedy without any competition. Increase the sowing rate on these rows if practical.
- Increase herbicide rates on the chaff rows using higher output nozzles for all passes including knockdown, pre-emergent, post emergent and crop topping.
- Graze with sheep where available to help to reduce the bulk of chaff rows.
- Monitor for pests such as mice, earwigs, millipedes and slaters, which can breed up in chaff rows, especially when sowing canola and consider on-row baiting or insecticide.

Integrated Harrington Seed Destructor (iHSD)

Recognised as the ultimate form of HWSC, the mill technology conceived by Ray Harrington is now reaching commercial reality for growers with investment from GRDC. The iHSD comprises of two hydraulically driven cage mills that are mounted within the back of the harvester (just below the sieves). The mills can destroy 93% to 99% of the weed seeds and then spread the material back out on the paddock without any loss of stubble or nutrients. Suitable for fitting onto all class eight, nine and ten harvesters, the mill has been tested to destroy 96% of annual ryegrass seeds, 99% of wild oat seeds, 99% of wild radish seeds and 98% of brome grass seeds in the chaff.

Seed Terminator

Developed by Nick Berry and his group in South Australia (SA), the Seed Terminator uses a multi stage hammer mill on weed seeds in the chaff fraction. The mill uses a combination of processes to shear, crush, grind and high impact to destroy more than 90% of weed seeds. More research is underway to further quantify this weed seed kill. The mill is mechanically driven with three stages of screen to sort material for size and can be operated at dual speeds of 2800 and 2950 RPM.

Conclusion

Growers now have available a diverse range of HWSC tactics at their disposal depending on their farming system, location and scale. The options are becoming less labour intensive with a shift away from burning of windrows towards chaff lining or mill technology, which leave crop residues and nutrients in place. Although intensive croppers have previously been the major adopters of HWSC, mixed growers can also benefit through grazing chaff dumps or chaff lines while reducing weed seed banks.

HWSC is part of a broader weed management package that includes improved herbicide management as well as crop competition, diverse rotations, double knocking and crop-topping or hay to stop seed set. The implementation of some or all these tactics will ensure growers keep weed seed banks low, but more importantly, remain profitable.

Useful resources

Broster J, et al. (2015). Harvest weed seed control: ryegrass levels in south-eastern Australia wheat crops. 17th Australian Agronomy Conference. http://agronomyaustraliaproceedings.org/images/sampledata/ASA17ConferenceProceedings2015.pdf

Walsh M, et al. (2017). High levels of adoption indicate that harvest weed seed control is now an established weed control practice in Australian cropping. Weed Science Journal of America 31, 341-347.

https://ahri.uwa.edu.au/harvest-weed-seed-control-tools-they-all-work/

https://ahri.uwa.edu.au/chaff-carts-good-for-the-crop-and-the-sheep/

Subscribe to AHRI Insight for short and sharp newsletters relating to more crop, less weeds: www.ahri.uwa.edu.au

Visit WeedSmart for practical information and videos: www.weedsmart.org.au

Acknowledgements

Funding for AHRI is provided through GRDC. 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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Notes

Getting the best out of canola with in-crop agronomy

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GRDC project codes: CSP00187, DAN00213

Keywords

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

Take home messages

- Match varietal phenology with sowing date so that flowering starts at the optimum time for your environment.
- Hybrid varieties respond better than open-pollinated triazine tolerant (OP TT) varieties to high rates (above 100kg/ha) of nitrogen (N) provided flowering date is close to the optimum start of flowering (OSF) date.
- Moderate rates of N (70kg/ha) can generate good returns even in relatively 'risky' environments (Mallee region).
- Canola can recover well from major frost damage especially where frost occurs in the early stages of reproductive development and where there is enough water available for the crop to set new pods.

Introduction

Grain producers have become more proficient at Canola performed well in most regions of Victoria (VIC) in 2017, especially where pre-crop agronomy (rotation, weed control, stubble management) was followed up with prudent in-crop agronomy (sowing date, variety choice, N management) that maximised the amount of N and water available to the crop and ensured that flowering occurred at the optimum time to limit exposure to stresses and to maximise growth. This paper will refer to OSF dates in the context of results from 2017.

What is the optimum start of flowering (OSF) date?

Collaborators (NSW DPI, CSIRO, SARDI and GRDC) in the Optimised Canola Profitability (OCP) project have recently released an eBook with OSF dates for most major canola growing locations from South Australia (SA) to Queensland (QLD) (https://grdc.com.au/__data/assets/pdf_file/0015/291012/Ten-Tips-to-Early-Sown-Canola.pdf). OSF dates are when flowering should be targeted to **start** (defined as when 50% of plants have one open flower). For canola (like most crops), OSF dates are a balance between minimising the stresses of heat, frost, drought and disease, while maximising the crop's ability to grow a high grain yield potential. Growers can target their OSF (Table 1) by selecting slow or mid-slow varieties (e.g. Archer$^{(b}$, ATR WahooA, Pioneer® 45Y91 (Clearfield® (CL)) from early sowing (before mid-April) or fast varieties (e.g. ATR Stingray$^{(b}$, Nuseed Diamond, Hyola® 350TT, Pioneer® 43Y92 (CL)) from traditional (around 25 April) sowing dates.

Table 1. Optimum start of flowering dates (OSF) for key VIC locations plus Lameroo from SA and Wagga Wagga from New South Wales (NSW) (both with relevance for this paper).

Location	OSF
Birchip	13-July
Mildura	14-July
Ouyen	15-July
Lameroo^{1}	17-July
Wagga Wagga^{2}	5-August
Bendigo	7-August
Horsham	7-August
Shepparton	7-August
Inverleigh	9-August
Rutherglen	14-August
Hamilton	14-August

^{1}Lameroo is in the Mallee region of SA and ^{2}Wagga Wagga is in the eastern Riverina region of NSW

2017 research

This paper reports on results from three experimental sites in 2017 (Table 1). While two of the sites (Ganmain, NSW and Lameroo, SA) are not in VIC, their findings are directly relevant for nearby regions.

Each experiment was essentially the same, with the exclusion of Roundup Ready® varieties at Lameroo. Eight varieties (six at Lameroo) were sown at two sowing dates (early and traditional) with two rates of applied N. The actual N rates were different at each site, targeting a decile five and a decile nine yield level. Nitrogen to support decile five yield was applied to all treatments at sowing with the decile nine N treatment applied as topdressed urea in-crop (amount applied equalled the difference between the decile nine and decile five rates).

Longerenong

There was no effect of sowing date (or interactions with sowing date) on grain yields in 2017 as there was a much wider OSF window due to lower disease pressure, little frost (at this site) and likely a clearer winter with higher levels of incoming solar radiation (energy for the crop). There was, however, an interaction between variety and N rate (Table 4). For the five hybrid varieties, Nuseed Diamond, Pioneer® 44Y90 (CL), Pioneer® 45Y25 (RR), Hyola® 600RR and Archer$^{\phi}$, there was an average grain yield increase of 0.7t/ha from increasing the N rate from 20kg to 180 kg/ha, however the yield increase for the OP TT varieties, ATR Stingray$^{\phi}$, ATR Bonito$^{\phi}$ and ATR Wahoo$^{\phi}$, was only (on average) 0.2t/ha.

Table 4. Grain yield of eight canola varieties with two rates of N applied at Longerenong, 2017.

	20kg/ha	180kg/ha
Diamond	3.8	4.4
ATR Stingray$^{\phi}$	3.4	3.7
44Y90 (CL)	3.7	4.4
ATR Bonito$^{\phi}$	3.4	3.6
45Y25 (RR)	3.8	4.4
Hyola® 600RR	3.5	4.4
ATR Wahoo$^{\phi}$	3.5	3.8
Archer$^{\phi}$	3.6	4.0
l.s.d. (var. * N) *P*=0.05	0.27t/ha	

Table 2. Location, fallow rainfall (1 November to 31 March), in-crop rainfall (1 April to 31 October) and soil N at sowing at three canola experimental sites in 2017.

Location	Region	Nov 16-Mar 17 Rainfall	Apr 17-Oct 17 Rainfall	Available N (sowing)
Longerenong	Wimmera	130mm	303mm	77kg/ha
Ganmain	Riverina, NSW	180mm	190mm	123kg/ha
Lameroo	Mallee, SA	132mm	258mm	160kg/ha

Table 3. Location, variety, N rate and sowing date for three experimental sites in 2017.

Location	Varieties#	N Rate (D5 and D9)	Sowing date
Longerenong	Diamond, ATR Stingray$^{\phi}$,	20 and 180kg/ha	8 April and 28 April
Ganmain	44Y90 (CL), ATR Bonito$^{\phi}$, Archer$^{\phi}$, Hyola® 600RR*,	70 and 170kg/ha	21 April and 8 May
Lameroo	45Y25 (RR)*	20 and 70kg/ha	8 April and 26 April

**Hyola® 600RR and 45Y25 (RR) were not sown at Lameroo.*

#ATR Stingray$^{\phi}$, ATR Bonito$^{\phi}$ and ATR Wahoo$^{\phi}$ are OP TT varieties. Nuseed Diamond is a hybrid conventional herbicide variety, Pioneer® 44Y90 (CL) and Archer$^{\phi}$ are hybrid Clearfield® varieties and Hyola® 600RR and Pioneer® 45Y25 (RR) are hybrid Roundup Ready® varieties.

Table 5. Grain yield (t/ha), oil concentration (%) and gross income ($/ha, assuming canola price of $500/tonne) of hybrid (all non-TT) and OP TT at two N rates.

	Grain yield (t/ha)	Oil (%)	Gross income ($/ha)
	20kg/ha N		
Hybrid	3.7	45.2	1939
OP TT	3.4	45	1777
	180kg/ha N		
Hybrid	4.4	42.9	2230
OP TT	3.6	42.7	1819

The high rate of N reduced oil concentration from 45.1% to 42.8% (averaged across all varieties). With only a modest grain yield increase from higher N for the OP TT varieties, there would have been an economic loss (assuming N cost of $1/kg) from increasing N rate from 20kg to 180 kg/ha (gross benefit of $42/ha), however the total gross income benefit for the hybrids was $291/ha (Table 5) which would have made the high N rate profitable. Hybrid seed is more expensive than OP TT but this cost would already have been repaid by higher yields at the low N rate.

Ganmain

There were many severe frost events at Ganmain in 2017 (Figure 1) 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 = 275mm) 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 experiment (2.1t/ha) was still close to average for the region (1.8t to 2t/ha) due to deep stored water from spring rainfall in 2016.

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 2). 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 flowering until early to 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) following frost damage.

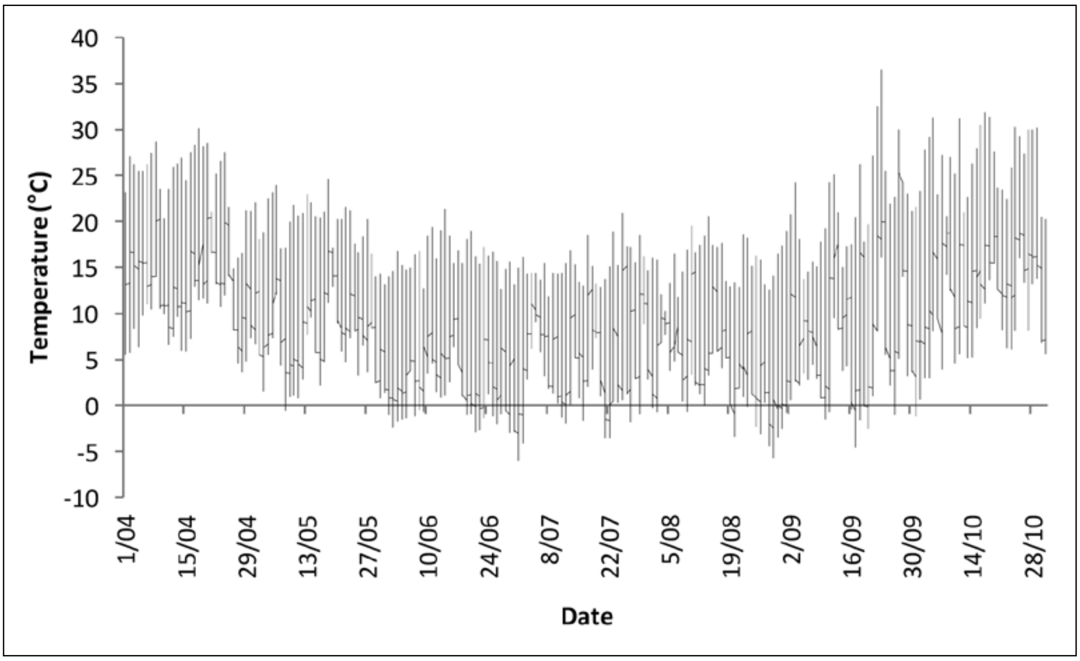

Figure 1. Temperature (°C) from 1 April to 31 October at the Ganmain experimental site.

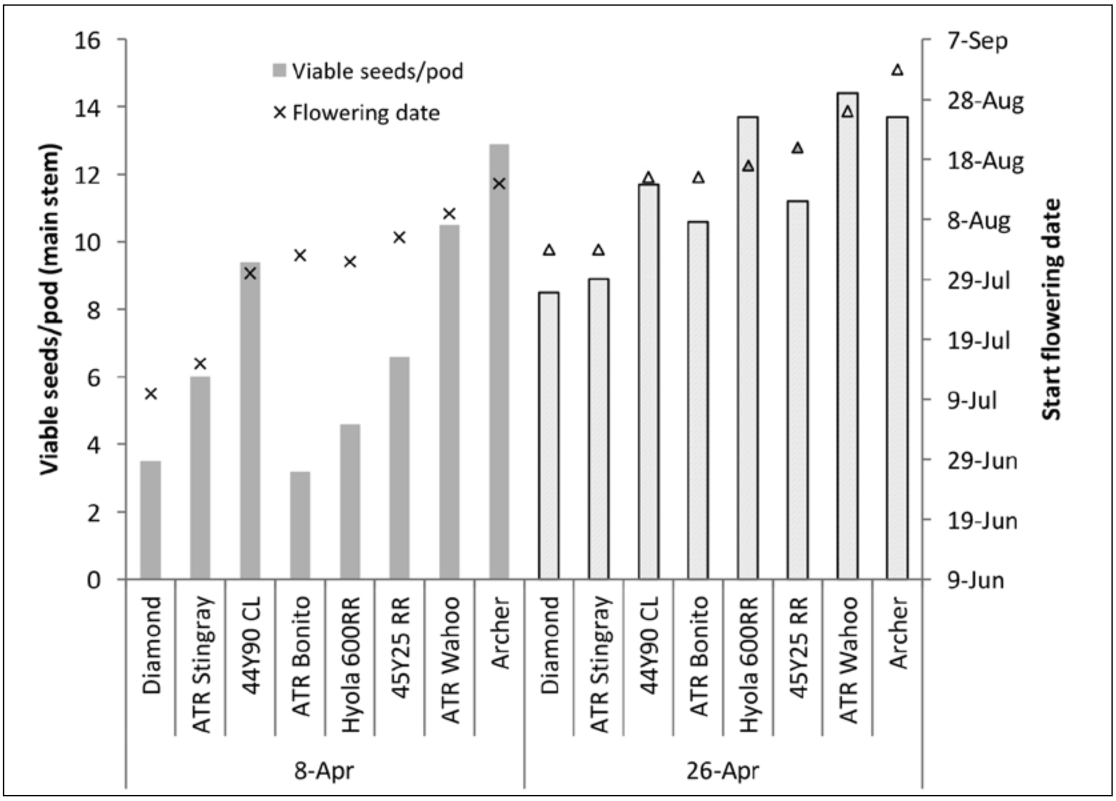

Figure 2. Viable seeds per pod (columns) and flowering date (× and Δ) of eight canola varieties sown at two sowing dates (averaged across N rates) at Ganmain, 2017 (viable seeds/pod l.s.d. $P<0.05 = 2.1$)

In this experiment (Figure 3), increased yield came from sowing varieties in their optimum window to achieve the OSF date (early to mid August) and where they were well fertilised with N. The fast varieties (Nuseed Diamond and ATR Stingray⁽ᐱ⁾) were heavily penalised by frost where they were sown early and flowered early (see flowering dates in Figure 2) and the slower varieties (e.g. Archer⁽ᐱ and ATR Wahoo⁽ᐱ⁾) had reduced yields from later sowing as flowering occurred later (late August) than optimal and pod development was limited by rising spring temperatures. Importantly, the N response increased for varieties sown in their correct window. For example, there was a strong response to N with Archer⁽ᐱ, Pioneer® 45Y25 RR and ATR Wahoo⁽ᐱ 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 N at both sowing dates (Figure 3).

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

Lameroo

Lameroo is considered a relatively ‘risky’ environment for growing canola, however in 2017, there was a grain yield increase from planting hybrid varieties (compared with planting OP TT varieties) and applying a robust rate of N (70kg/ha) for the region (Table 6). Hybrid varieties yielded (on average) 0.2t/ha more than OP TT varieties and the 70kg/ha N rate yielded (on average) 0.4t/ha more than the 20kg/ha N rate. As the cost of hybrid seed was approximately the same as the cost of increasing N rate from 20kg/ha to 70kg/ha in 2017 (approximately $50/ha to $60/ha), the return on investment was greater for increasing N rate. Similar to Longerenong, there was no effect of sowing date on grain yield in 2017.

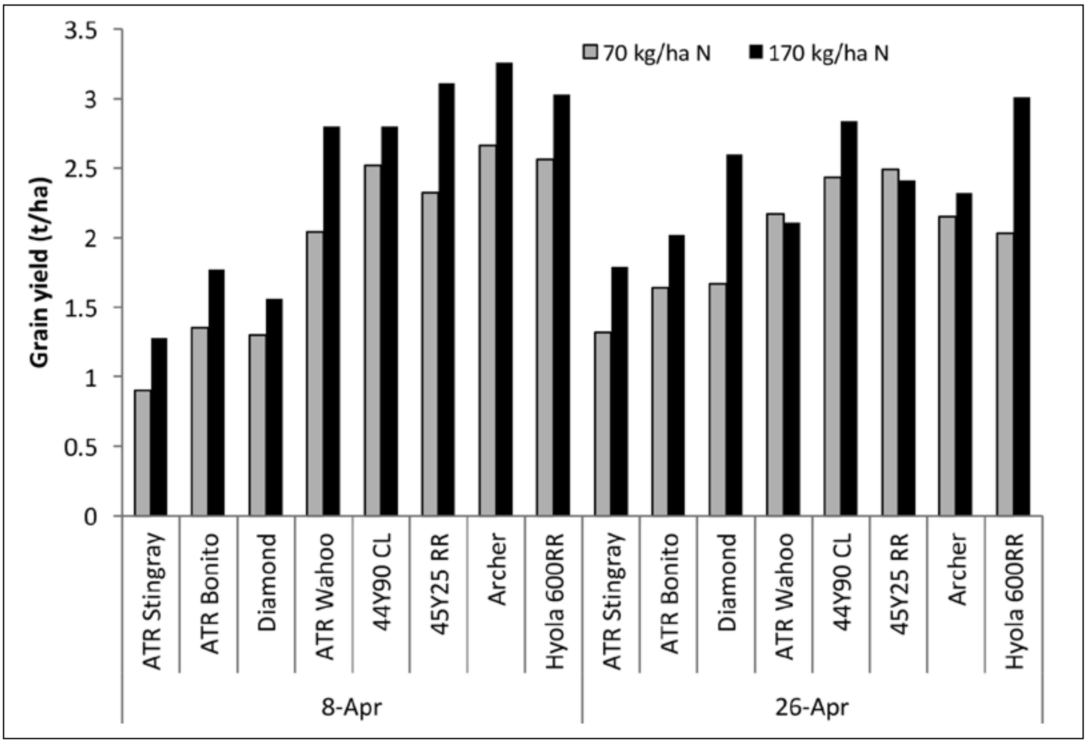

Figure 3. Grain yield of eight canola varieties sown at two sowing dates and fertilised at two N rates at Ganmain, 2017 (l.s.d. $P<0.05$ = 0.38t/ha).

Table 6. Effect of N rate (two) and variety (six) on grain yield (averaged across two sowing dates) at Lameroo, 2017.

	20kg/ha	70kg/ha
Diamond	1.6	2.0
ATR Stingray$^{\Phi}$	1.4	1.9
44Y90 (CL)	1.7	2.1
ATR Bonito$^{\Phi}$	1.3	1.8
ATR Wahoo$^{\Phi}$	1.4	1.8
Archer$^{\Phi}$	1.3	1.7
l.s.d. *P*=0.05 (N)	0.13t/ha	
l.s.d. *P*=0.05 (variety)	0.22t/ha	

Conclusion

To get the best out of canola, 'in-crop' agronomy should focus on ensuring canola flowers close to the OSF date and the crop has access to enough N for its grain yield potential (aim for 80kg/ha available N per tonne of grain yield targeted). In medium to high yield potential situations, hybrids can increase profitability further, however the extra yield from hybrids (compared with OP TT) in lower yield potential sites may not be enough to warrant the extra cost. In seasons with a 'kind' winter and spring, it may only be necessary for two of three of these factors to be in place. Winter and early spring conditions in 2017 were relatively benign (low frost, heat, drought and disease risk combined with high levels of radiation) across VIC and SA, hence there was little relationship between flowering date of canola and grain yield. Grain yield was maximised in experiments at these locations by choosing hybrid varieties and applying enough N to match the grain yield potential.

The experiment at Ganmain in the Riverina region of NSW highlighted the importance of matching sowing date and phenology so that crops flower close to the OSF date. At Ganmain, there was increased yield from applying a high rate of N and selecting hybrid varieties, but this was only observed on treatments that flowered from early to mid-August, on target for the simulated OSF date of 5 August for nearby Wagga Wagga.

Acknowledgements

The projects supporting this research are co-investments from GRDC, NSW DPI, CSIRO and SARDI.

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC. The author would like to thank them for their continued support. Thanks to technical staff for assistance including Danielle Malcolm and Warren Bartlett (NSW DPI), Amanda Pearce and Carolyne Hilton (SARDI).

Further reading

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

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Agricultural machine technology – practical uses now and into the future

Steven Rees.

University of Southern Qld.

Key words

- unmanned aerial vehicles, autonomous machinery, blue-sky research.

Take home messages

- Unmanned aerial vehicles (UAVs) - uses and cans and can't dos.
- Machine vision identification capabilities (for example; spot-spraying weeds in-crop, identification of pests in-crop) and limitations (for example; weather affecting cameras, breeding affects data sets).
- Sensors – machine vision and soil.
- Autonomous machinery (legal, regulatory, insurance, reality versus aspirational – how far away?).
- Blue-sky overview of where technology is heading (artificial intelligence (A.I.)/deep-learning).

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Monitoring mice in Australia

***Steve Henry*[1] *and Peter Brown*[2].**

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GRDC project code: AIC00002

Keywords

- mouse monitoring, crop damage, zinc phosphide.

Take home messages

- Mouse numbers are currently moderate across most regions of southern New South Wales (NSW), South Australia (SA) and northwest Victoria (VIC). There is potential for economic damage at sowing in 2018.
- Current efforts to monitor mice are not sufficient to detect variations in mouse abundance between and within cropping regions. Growers need to stay informed about potential increases in mouse numbers from the mouse monitoring updates that the project publishes at the end of each monitoring session. https://www.feralscan.org.au/mousealert/pagecontent.aspx?page=mouse_news
- Growers should conduct their own monitoring to ensure they know what is happening in their own paddocks in the lead up to sowing each autumn. Growers should follow the recommendations outlined in the GRDC GROWNOTES™, Tips and Tactics, Better Mouse Management page at https://grdc.com.au/resources-and-publications/all-publications/publications/2017/07/tips-and-tactics-better-mouse-management
- Broad-scale application of zinc phosphide bait is the only method available to growers to control mice in their paddocks. Timely application of mouse bait at the prescribed rate is paramount for reducing the impact that mice have on crops at sowing. Strategic use of bait is more effective than frequent use of bait.

Background

'Surveillance and forecasts for mouse outbreaks in Australian cropping systems' is a GRDC-funded study to monitor and model mouse populations across the grainbelt of Australia. The project started in October 2012 as a collaboration between Landcare Research (New Zealand), CSIRO and the Invasive Animals Cooperative Research Centre.

The aim of the project is to monitor mouse populations across the grain growing regions of Australia and develop predictive models to forecast mouse outbreaks. A key element of the project is to publicise the results of the monitoring and predictions to growers and industry through GRDC and other communication networks to enhance awareness of increases in mouse activity.

Mouse populations are monitored in typical grain farming systems in Western Australia (WA), SA, VIC, NSW and Queensland (QLD) at three key times each year, coinciding with important crop stages (e.g. at sowing of winter crops) and critical times in the build-up of mouse populations (e.g. commencement of breeding in spring). The monitoring is used to collect information about the population size, breeding status and overall activity of mice. This information is used in predictive models to determine the probability of changes in mouse abundance. These models were developed at long-term monitoring sites in the northern Adelaide plains in SA, the northwest Mallee in VIC and the Central Darling Downs in southern QLD.

Mouse monitoring

The monitoring of mouse populations occurs at three levels of intensity on 110 transects across 11 sites (Figure 1):

1. **Benchmark sites** in the Adelaide Plains (SA), Northwest VIC, and the Darling Downs (QLD), where long-term trapping has been conducted for more than 20 years and where forecast models have been developed. Live trapping data is collected at three key times per year and the data is used in the models to predict the likelihood of outbreaks for those regions.
2. **Quantitative rapid-assessment sites** in Geraldton and Ravensthorpe (WA), Horsham and Walpeup (VIC), Riverina, Central West and Moree (NSW), Mallala and Yorke Peninsula (SA) and the Darling Downs and Goondiwindi (QLD) where there are two types of monitoring — mouse chew cards set out overnight (10 chew cards at 10m spacing along 100m survey lines), and active burrow counts along 4m x 100m survey lines. Monitoring is conducted three times a year.
3. **Qualitative monitoring networks** in all the areas with rapid-assessment sites where key growers and agronomists are contacted to collect information about mouse activity in the region, as well as any reports of the use of rodenticides.

Issues with monitoring

Current models are performing well and mice are being monitored at a large number of sites across the grain belt, but only a snapshot of what is happening with mouse populations is being gained. Data is not being currently collected from enough locations to deal with the variability in mouse activity between regions, farms or between paddocks on individual farms. In an effort to deal with the lack of data, a mobile phone application, MouseAlert (www.mousealert.org.au) was developed with the idea of having growers and agronomists to supply data about mouse abundance on their farms (Figure 2).

Unfortunately, use of the App has been low and the data collected has been insufficient to use in predictive models. The App still provides growers with the opportunity to enter data and view observations of other growers about the level of mouse activity in their district.

Monitoring outcomes

Over the five years that the monitoring project has been running, mouse numbers have fluctuated at all of the monitoring sites — on one occasion in QLD, mouse numbers were significant and damage was recorded on the Darling Downs.

In the spring of 2016, based on the trapping data at Walpeup and Mallala, the models predicted a high likelihood of an outbreak in autumn 2017

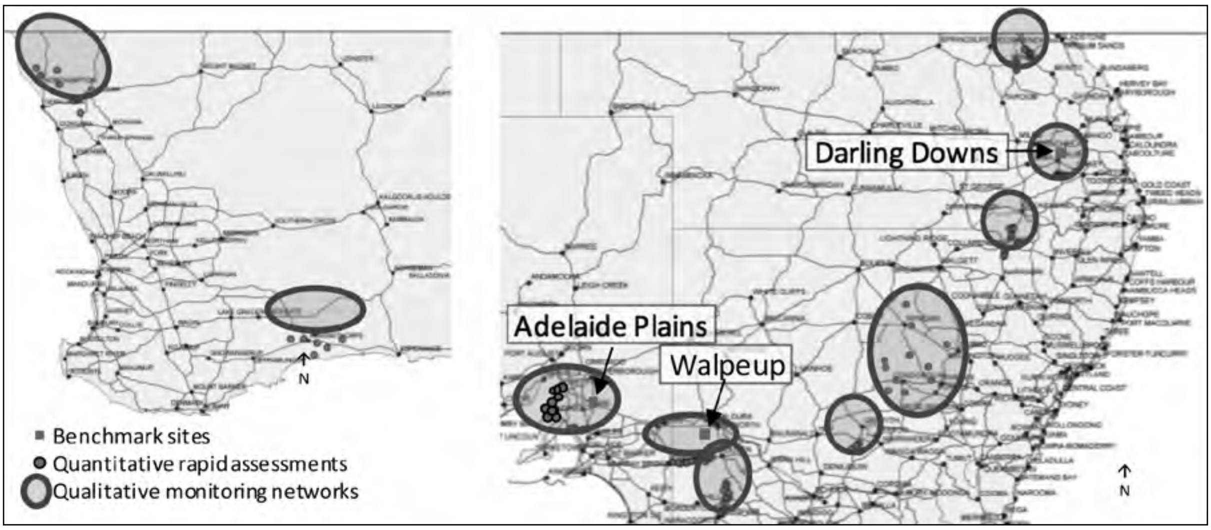

Figure 1. Location of monitoring sites across western, southern and eastern Australia.

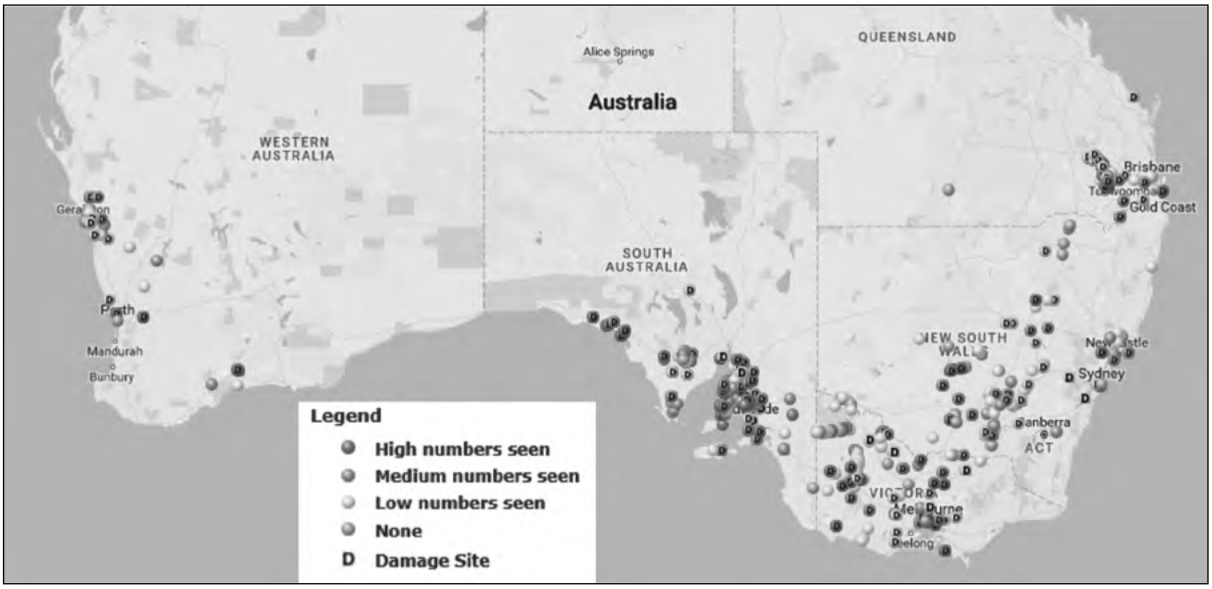

Figure 2. Records of mouse observations in MouseAlert web site/phone app (www.mousealert.org.au) since 2014 (containing > 500 records).

(Figure 3). Through the summer, numbers of mice in southern NSW, central and western VIC and most cropping regions of SA continued to rise and as a result, growers had to undertake significant baiting programs to reduce damage from mice at sowing in 2017. Despite warnings about the potential for significant increases in mouse numbers, many growers were caught unprepared. This was probably the result of high stubble loads after an exceptional 2016 harvest masked the signs of mouse activity.

Mice continued to be a problem throughout the 2017 crop. Monitoring early in the spring showed little or no sign of activity associated with active burrow counts or crop damage, but a significant level of activity was recorded on the chew cards. Adjusted trap success in north western VIC was significantly higher than expected for the spring trapping, indicating that breeding had started early.

Later in the spring, significant amounts of damage were recorded in many of the developing crops. Anecdotal reports of damage to all types of crops continued to be reported right up to harvest and reports of higher than expected numbers of mice through the harvest were not uncommon. Severe weather events during the 2017 crop resulted in significant crop losses in some areas due to dropped grain or frost damage, resulting in a greater than normal supply of food for mice.

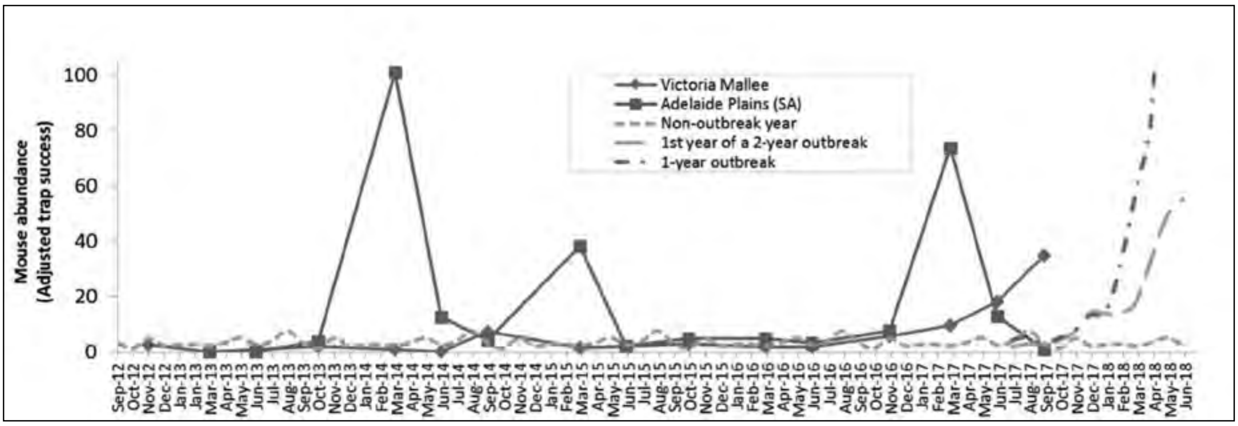

Figure 3. Current mouse population abundance at benchmark sites in VIC and SA compared to outbreaks in the past.

Mouse control issues

More data is needed to make accurate predictions about changes in mouse abundance across cropping regions. One way to achieve this would be to develop a remote monitoring system that could detect changes in mouse activity on a broad scale.

The current approach to bait application is to spread bait on a broad scale across entire paddocks. Our understanding of mouse ecology and behaviour is based on work undertaken in conventional cropping systems. Understanding mouse ecology in zero and no-till cropping systems could lead to more strategic application of bait, potentially reducing the quantity of bait spread or increasing the effectiveness of bait by targeting high activity zones in paddocks. Testing of the palatability of different bait substrates might also result in increased uptake of bait.

Future development of new toxins for mouse control is still some time away and the development of novel biocontrol techniques has potential, but is still in the very early stages of development. In the interim, there is a need to find ways to use the tools that are available to control mice more effectively.

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.

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Rethinking your approach to canola harvesting

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Grain Orana Alliance.

GRDC project code: GOA00002

Keywords

- canola, windrowing, direct heading, desiccation, pod shatter.

Take home messages

- Timing of windrowing of canola can have a huge impact on profitability through its influence on yield and oil%.
- Profit could be reduced by up to $50/day for every day that crops are windrowed before they are ready.
- The window for windrowing on time is relatively small.
- Direct heading of canola is a viable and comparable alternative to well-timed windrowing, but may easily outperform crops that are windrowed before they are ready.
- In contrast, the window for direct heading crops to maximise yield and profit may be much larger than those that are windrowed.
- Desiccation, other than that for weed control, in many cases will not significantly speed up crop maturity.

Background

Windrowing of canola in the central west of NSW has been the traditional approach adopted by most growers. Recent survey data collected in 2017 by Grain Orana Alliance (GOA), a GRDC Grower Solutions Group, indicates that a decade ago, between 65%and 80% of canola growers used windrowing exclusively (GOA, unpublished).

In 2009, GOA was asked to investigate if windrow timing (WRT) was potentially impacting on canola performance, in particular oil % of harvested grain, which can impact on crop profitability. In response, GOA established two trials in 2009 that compared different WRTs. In both trials, early windrowing resulted in significant yield penalties of up to 0.5t/ha, but only low levels of impact on oil% of the grain.

The outcomes from these two trials inspired many subsequent trials undertaken by GOA, not only investigating the impact of WRT, but investigating the fit of direct heading, the use of desiccants, the use of Pod Ceal™, and the impacts of delays in direct heading. More recently, the potential benefits of new canola varieties with increased tolerance to shattering (Bayer's PodGuard™ varieties) were also trialled.

GOA has previously presented and published on these topics. The detailed presentations and papers can be found on either the GRDC or the GOA website. This paper aims to summarise the key findings and to present a case for growers to reconsider how they might approach harvesting canola in the future.

What is the ideal windrowing time?

WRT is the stage of crop maturity when the crop is cut and placed into windrows to be later harvested when the grain has dried down to a deliverable moisture content (DMC) of 8%. The crop stage is identified by the percentage of the seed that is changing colour. For example, the currently accepted recommendation for the timing of canola windrowing is: 'Windrowing should commence when 40% to 60% seed in the middle third of the main stem has changed colour from green to brown, black or red.'(Carmody, 2009).

The recommendation states that it is the seed from the middle third of the main stem. References in this paper to seed colour change (SCC) refer to this section of the crop.

The seed changing colour should be thought of as an indicator of those seeds reaching physiological maturity. At this point, seed has reached its full potential in terms of seed size and oil content. Prior to this point, the seed is still growing (increasing in size) which is contributing to increasing yields and oil content. The recommendation of 40% to 60% colour change infers that only 40% to 60% of the seed in the referenced part of the crop is mature and reached its full size, while the remaining part of the crop is still growing. Any seed not mature at the time of windrowing will have any further growth or accumulation of oil stopped abruptly which will see potential further increases in yield or oil% forgone. The earlier the timing, the more yield and oil% forgone — the later the timing, the greater the potential yield that is realised.

However, what also occurs with increasing levels of crop maturity is that seed pods dry out and become increasingly brittle. Windrowing involves cutting the canola plants off at their stems and moving the plant tops into a 'windrow'. This process can be aggressive and often results in pods impacting other pods and plants or parts of the windrowing machinery. This can break off and/or break open pods releasing the pods/seed onto the ground where they will not be captured by the harvester.

An ideal WRT should be timed to maximise the increasing crop yield, but not too late as to reduce harvestable yield by shattering out canola either before, but more likely during the windrowing process.

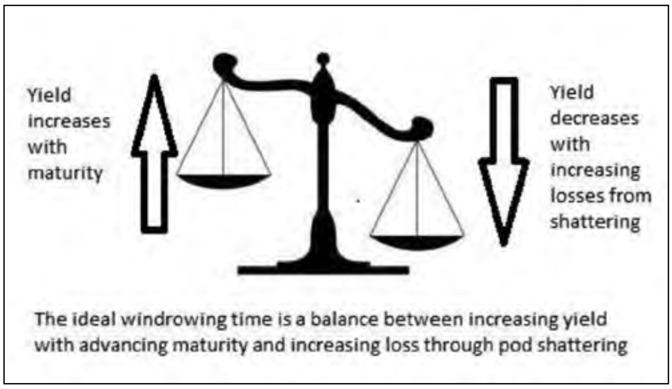

Figure 1. Illustration of the balance needed between increasing yields and increasing potential losses with advancing maturity.

So what did we find?

Large scale, replicated field trials run by GOA over three years showed that WRT could have an impact on oil%, but it was often quite small and not significantly different. The effect of WRT on crop yield, however, was often much larger, not only in magnitude but economic impact. One of the first trials undertaken by GOA at Coonamble in 2009 showed that delaying WRT from 10% SCC to 70% SCC, or eight days, increased yields by 500kg/ha. The increase represented a 30% yield improvement and at current (time of reporting (November 2017)) canola prices ($500 ex farm) would be worth $250/ha excluding GST.

More recently (2015, 2016 and 2017) trials by NSW DPI under the GRDC co-funded 'Optimised Canola Productivity' project have looked more closely at the impact WRT can have on yields and oil%. This work has shown, in some cases, that yield impacts were even greater than those seen in GOA's trials. Yield increases of more than 2t/ha were seen from the earliest WRT, less than 5% SCC, to the latest at 100% SCC at Tamworth in 2016. The influence of WRT on oil% was also much higher in these trials with increases of more than 7% resulting from delays in WRT (Graham et al. 2017).

The consistent message from both GOA and NSW DPI is that WRT earlier than the current recommended timings of 40% to 60% SCC has universally resulted in significant yield penalties. Some of the most stark yield penalties from windrowing too early were seen in the NSW DPI trials at Trangie, Edgeroi and Tamworth in 2016 where reductions of 48%, 55% and 32%, respectively, were seen (Graham et al. 2016). Yield penalties from the larger scale field trials run by GOA which were commercially windrowed at the specific levels of SCC only ranged from 12% to 22% which are still substantial losses.

The trials have also demonstrated the potential to increase yields further by delaying WRT past the recommended timings. The GOA trial at Coonamble showed a further 16% increase in yield (280kg/ha) from only a five day delay in WRT from 50% SCC to 70% SCC (Street, 2014). Delaying WRT at Trangie in 2016 from approximately 60% SCC to the 100% SCC increased yields by approximately 800kg/ha (Graham et al. 2017). A number of other trials also support these findings, where delaying WRT past 60% SCC tends to increase yields. This outcome is not unexpected given that up to 100% SCC, some immature seeds within the crop are still developing and so could contribute to yield. The question remains, however, at what point do the losses from pod or seed shatter negate any further increases in yield?

How late is too late to windrow?

GOA undertook four trials that investigated the effects of delaying WRT past the current recommendations. These trials used commercial windrowers and headers and reported harvested yields. As such, they take into account the potential losses from delayed windrowing. In these trials there was either an increase in yields or trends to increase, but no decline in harvested yields even where WRT was delayed up to 95% SCC. This is not to say that delayed WRT did not result in increased pod shattering, but any losses were compensated by increases in yields from other more immature parts of the plant.

As the NSW DPI trials were assessed by hand cuts from small plots, shattering seed loss from delayed WRT was not taken into account and the reported yields are somewhat theoretical. But given the lack of any measurable downturn in yields in the GOA trials with delays of up to 95% SCC, the yield gains demonstrated in the NSW DPI trials might only be reduced by excessive pod shatter at the very late end of the range of WRT investigated.

This theory was confirmed by a GOA trial in Wellington, NSW, where a measurable downturn in yield of 250kg/ha resulted from a delayed WRT. However, the delay was measured as seven days after 100% SCC and so represented an extreme case of late windrowing.

When should I windrow?

The simple message from this work is that in the very least growers should strive to windrow at the current recommended timings of 40% to 60% SCC as significant yield and oil% penalties will occur by going earlier. However, there is a strong case to suggest growers should work to the later end of this range of SCC or even beyond, if seasonal conditions are supportive of continued seed fill, as in many cases yields have increased further and there has been little evidence that increased pod shattering is resulting in any downturns in harvestable yields.

What is driving the later timing of windrowing?

Plant populations have generally reduced over the years. Street (2014) first suggested that with lower plant populations, proportionally less yield is carried by the main stem where WTR is assessed. Crop maturity on branches is often behind that of the main stem and hence our current approach to assessing SCC on the main stem for windrowing was over-estimating crop maturity as compared to crops with higher plant populations.

NSW DPI's more recent research with its increased precision has shown this to be true. It is also suggesting assessing the whole plant for a measure of maturity rather than just the main stem.

Varieties have also evolved. Variety trials are often not windrowed but desiccated and direct headed. Varieties susceptible to pod shatter would suffer a higher level of yield damage resulting in a yield handicap, reducing the likelihood that any such varieties would progress to commercialisation.

This also means varieties of 20 to 30 years ago would have been more likely to shatter at an earlier level of SCC, tipping the scale towards an earlier windrowing time than it would be with today's varieties.

Where does direct heading fit?

Given that windrowing has the potential to reduce yields because it is done before all seed has matured, does direct heading have potential to capture higher yields? GOA ran four trials which have showed that yields from direct headed situations have generally matched the yields of a **well-timed** windrowing. If compared to that of an ill-timed windrowing, i.e. too early or too late, the direct heading outperformed the windrowed treatment.

GRDC has produced a Direct Heading Factsheet (www.grdc.com.au/GRDC-FS-Direct-Heading-Canola) that examines many of the pros and cons of direct heading. The document suggests that on top of yield advantages, growers should also consider the additional benefits including the elimination of windrowing costs, applicability for heavy lodged crops that cannot be windrowed and for lighter crops where small windrows may be unstable in windy conditions.

How does timing of harvest vary between direct headed or windrowed crops? And will desiccation help alleviate any differences?

One common concern for growers when considering direct heading is the perceived delay in the commencement of harvesting of direct headed crops. It is thought that compared to windrowed crops, ones left for direct heading take longer to dry down to acceptable grain moisture content (GMC) before harvesting can commence.

One option to potentially manage this issue in direct headed crops is to apply a desiccant herbicide to the crop ahead of harvest to speed up the ripening process. Reglone® has been registered for this purpose for some time but its cost, difficulties in application and perceived unreliability often deter many from its use.

More recently, a glyphosate formulation, weedmaster® DST® marketed by Nufarm has been registered for use in canola for pre-harvest application. While the main label claim is for pre-harvest weed control, it is also registered as a 'harvest aid', suggesting that it may also speed up the ripening process.

Over three years GOA has run four trials investigating the relative effectiveness of weedmaster® DST® and Reglone®, in reducing GMC to facilitate earlier harvesting.

The key finding from this work was that Reglone®, when applied as a desiccant to canola, showed some advantage in bringing GMC down quicker

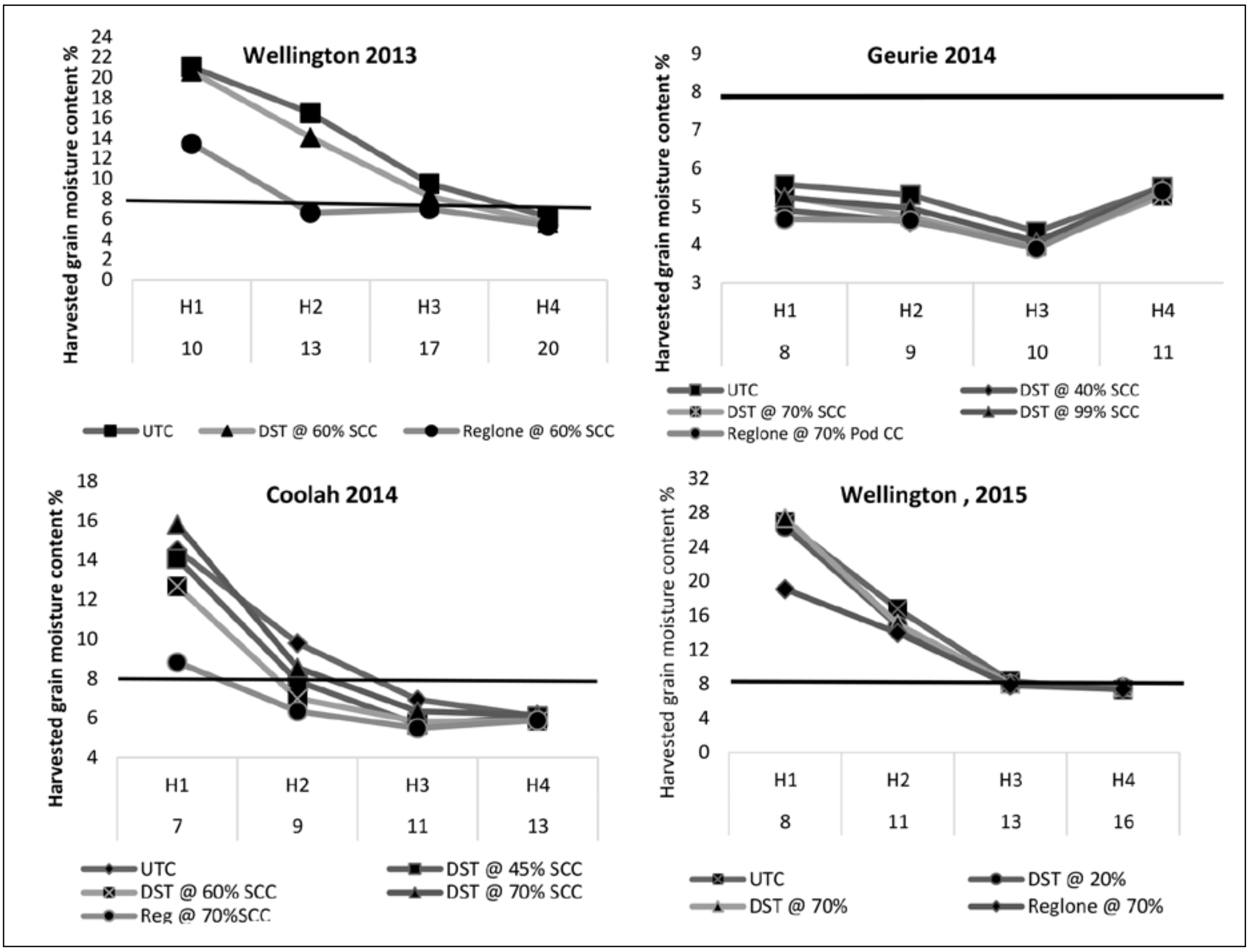

Figure 2. Harvested GMCs in response to application of Reglone® (Reg) or weedmaster® DST® (DST) at differing levels of seed colour change, as assessed at four different harvest timings (H1, H2, H3, H4). Numbers under the harvest timings indicate the number of days since the Reglone® application (approximately 70% SCC).

than natural ripening. At Wellington in 2013, the Reglone® treatment would have allowed harvest to start approximately five days earlier. In the other locations, the GMC of all treatments dropped below 8% within two days, hence the advantage of Reglone® was much less or not even apparent as illustrated in Figure 2.

Weedmaster® DST® applied pre-harvest also showed little practical benefit at bringing harvest forward. Except for one DST treatment at Coolah in 2014, there was no significant difference in GMC at any harvest timing between any DST treatment and the untreated crop.

Further details of the trials can be found at http://www.grainorana.com.au/documents?download=49

An interesting observation in these trials was the rate at which the crops ripened without any desiccation and the relevance this may have to potential time differences between harvesting of a windrowed crop and direct headed one. Reglone® in the trials detailed above was applied at approximately 70% SCC and in light of recent research, this crop stage is arguably an acceptable windrowing time. It can be seen in the graphs above, the time that it takes the untreated crops to dry down the 8% GMC in relation to 70% SCC.

Both Wellington trials took only 13 or 17 days for the untreated to reach 8% moisture but in 2014, Geurie reached 8% moisture in less than eight days and Coolah within 10 days. Past experiences suggest windrows often cure for at least 10-14 days most years and so would suggest the time to harvest a direct headed crop would be within days of one that is windrowed and not weeks as often thought could be the case.

The view of longer delays to this may be brought about through early windrowing. The earlier a crop is windrowed, the sooner it is dry enough to harvest relative to a crop left standing to ripen naturally. It could be suggested that in many cases if growers do experience lengthy delays in commencement of direct heading in comparison to similar ones around, it could indicate windrowing has commenced too early, which we now know could be incurring significant yield penalties.

Windrowing allows me to get started on harvest earlier so as not to interfere with harvesting of my other crops

Many growers argue their preference for windrowing crops as it hastens harvesting, however as it is evidenced above, the difference may not be as large as some think if windrowing at the correct timings. That being said, windrowing may offer a number of days which may be useful, but for many growers this may still not be enough. If growers choose windrowing early to result in more available days to complete harvesting, it should be remembered this could come at a significant cost. Numerous trials have shown that premature windrowing could be costing growers up to $50/ha/day.

Regardless of whether crops are windrowed at the more appropriate later timings or direct harvested, growers should consider changing the traditional harvest order. Canola does not always have to come off first.

Delayed direct heading and pod shattering

One GOA trial has shown that yields in direct headed crops can be relatively stable for a considerable period after the crop is ready to harvest. Results of a trial conducted in 2013, illustrated in Figure 3, demonstrated that the yield did not decline for two weeks after the initial harvest timing. At this point, there was a major weather event that resulted in yield declines, after which the yields plateaued again, and this pattern recurred. This suggests that in this situation, yield decline when harvesting is delayed tends to be stepped rather than linear and that shattering yield losses are most likely a function of weather extremes, which are fortunately infrequent, but unfortunately unpredictable in their nature.

PodGuard™ canola promises of enhanced shatter tolerance

Recently Bayer has bred a unique genetic trait 'PodGuard™' into selected new canola varieties offering increased tolerance to shattering. This trait may allow growers to either delay WRT until later stages of crop maturity to capture higher yields or allow growers to have confidence that crops left to direct head do not shatter before harvesting.

GOA, in conjunction with Bayer, tested shattering tolerance of PodGuard™ against a non PodGuard™ variety in a trial conducted in 2015. A severe shattering event was simulated consisting of dragging a two inch steel pipe twice through the podding zone.

At the first harvest timing (H1) without the simulated shattering, the yields of the two varieties are comparable. However, when the simulated shattering was applied, only the yield of the variety 45Y25 was affected, reducing yields by approx.

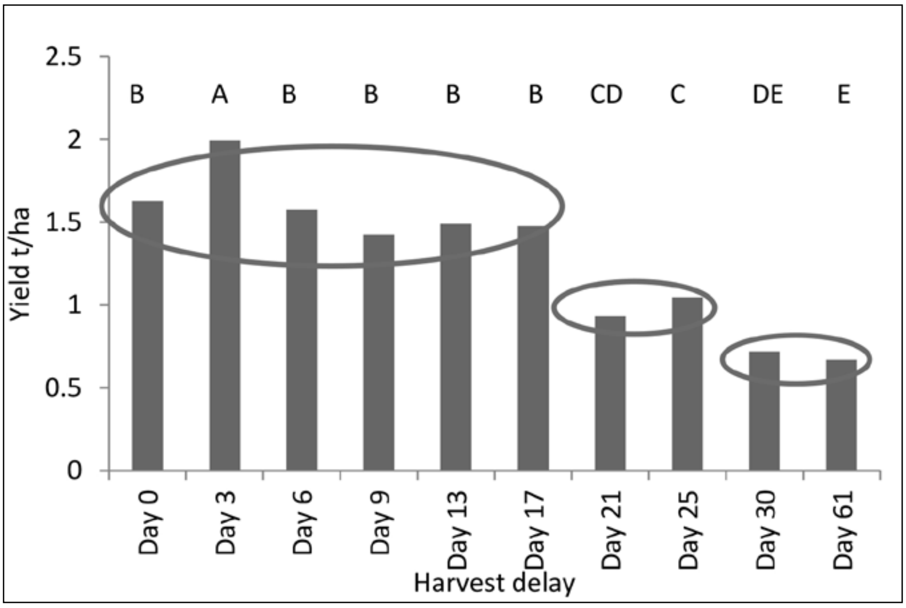

Figure 3. Harvested grain yields in response to delays in direct heading, Wellington 2013.

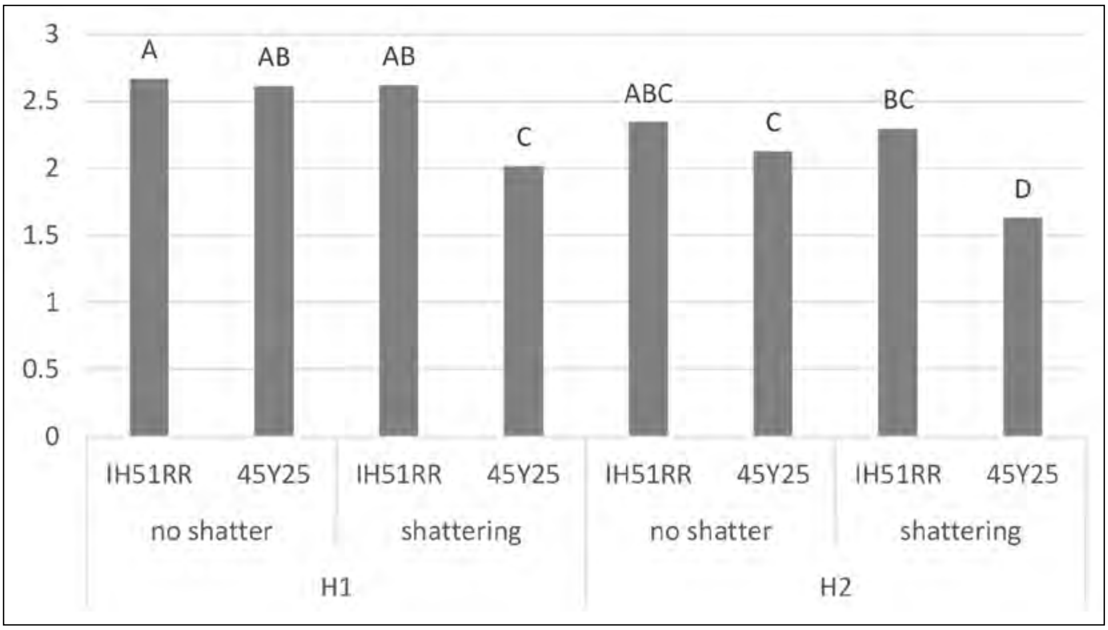

Figure 4. Harvested yield in response to harvest timing and simulated shattering by variety, Wellington 2015.

600kg/ha. Delaying harvest by 14 days (H2) resulted in no statistically significant yield decline in the PodGuard™ variety, however the yield of the 45Y25 was reduced by approx. 500kg/ha. Combining the simulated shattering event with the delay in harvest, the 45Y25 suffered almost a further 500kg/ha yield loss, while the PodGuard™ experienced no loss of yield (Figure 4).

During this trial, measurements were made to quantify the source and timing of the losses encountered. Details of these are covered in the full trial report on the GOA website[5].

In summary, the PodGuard™ variety IH51RR has shown good potential to resist shattering from delays in direct heading or shattering events such as high winds or hail.

Pulling it all together

Windrowing will remain popular with many growers for a number of reasons, however growers should seriously consider windrowing toward the latter end of current recommended timings. There is mounting evidence to suggest that windrowing up to a conservative timing of 70% to 80% SCC can result in even further increases in yields and oils, as pod shattering at this crop stage is likely to be much less than current perceptions. Even if some shattering loss is apparent, it should be remembered that increases in yields from the fuller maturation of the crop will often more than compensate.

Direct heading of canola is a worthy alternative to windrowing crops and much of the negative connotations of the past are not as common as often thought. Direct heading will allow for the whole crop to reach its full potential yield and oil%. Trial work suggests that it will yield as well as a correctly timed windrowed crop. If the alternative is to windrow too early or too late because of weather complications or availability of a windrower, direct heading may be the best.

Concern over rapid yield loss with delay to direct heading has not really been demonstrated in trial work or with commercial experience which has often shown yields to be quite stable post crop maturity. With ever improving varieties or PodGuard™ varieties, concerns could be even further allayed.

Time differences between windrowed and direct headed crops may also not be as different as thought, provided windrowing of crops is done at more appropriate stages. If growers choose to windrow early to finish early, that decision will come at a significant price paid in terms of decreased yield and oil%.

An interesting consideration is that it has been shown that yield impacts from incorrect WRT to amount to losses of up to $50/ha/day, and that the rate of change in SCC can be very rapid. The opportunity to windrow is quite small, maybe as little as one to three days. In contrast, the time to direct head a crop may be much longer.

GOA's trial work on desiccation products has shown little advantage in terms of closing the gap on harvest timing, with Reglone®, while not consistent, performing better than weedmaster® DST®, but overall neither achieving practically useful results.

Useful resources

GRDC Grow Notes- Canola

https://grdc.com.au/resources-and-publications/grownotes

Direct heading factsheet

www.grdc.com.au/GRDC-FS-Direct-Heading-Canola

Factsheet - Stewardship for pre-harvest application of herbicides in winter crops:

https://grdc.com.au/GRDC-FS-PreHarvestHerbicide

http://grainorana.com.au/documents?download=39

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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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Notes

Filling the yield gap – Optimising yield and economic potential of high input cropping systems in the HRZ

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GRDC project code: DAV00141

Keywords

- fertiliser, waterlogging, nitrogen (N), phosphorus (P), potassium (K), sulphur (S), economics, wheat, canola.

Take home messages

- Under-fertilising appears to be a major cause of yield gaps in cropping systems in the high rainfall zone (HRZ).
- Yield gaps need to take into account seasonal risk and relative crop and fertiliser prices.
- Soil test critical values should be higher than commonly used because of the higher yield potential of the HRZ.
- Return on investment in nitrogen (N) fertiliser is maximised if phosphorus (P), potassium (K) and sulphur (S) are non-limiting.
- The project has produced three Excel-based decision support tools to determine the economic optimum application rate of N, P, K and S under a range of conditions.

Background

In the HRZ of southern Australia, commercial wheat and canola yields are well below their water-limited potential (Yield Gap Australia 2018). The yield gap in this case was defined as the difference between actual yields reported by growers to the Australian Bureau of Statistics (ABS), and a potential yield calculated for each region and cropping year using the Agricultural Production Systems sIMulator (APSIM) model supplied with non-limiting nutrients. Since nutrient limitations are one of the most common causes of yield gaps, a plant nutrition component was incorporated into the DAV00141 project. One of the questions posed was whether the soil test interpretation guidelines developed in the low and medium rainfall areas were appropriate to the HRZ with its higher yield potential. The nutrition component comprised field experiments, crop modelling, economics, and the development of three Excel-based decision support tools to assist decision makers choose the most economic application rate of various nutrients for a given season.

Method

Experimentation

To determine which nutrients were responsible for crop responses, a series of nutrient omission experiments were conducted in the 2015 and 2016 growing seasons in the HRZ between Bool Lagoon in South Australia (SA) and Rutherglen in Victoria (VIC). At each site, one treatment was supplied with non-limiting rates of all the nutrients to which responses could be expected (P, K, S, copper (Cu), zinc (Zn)), while in other treatments, one or all of these nutrients was omitted. Nitrogen was applied at a minimal rate — 60% of estimated requirements or 100% of requirements. The experiments were conducted with either wheat (cv. Beaufort$^{(\Phi)}$) or canola (cv. Archer$^{(\Phi)}$) (Table 1). Soil samples were collected prior to sowing to develop yield relationships appropriate to the HRZ. These included soil N and available K to a depth of 1.4m, and Colwell, DGT-P and KCl-40 available S to 10cm. Further details are given by McCaskill et al. (2016) and Pearce et al. (2017).

In the 2017 season, the experimental program was modified to examine a range of application rates for nutrients to determine the economic optimum nutrient application rate. Results are presented here for a canola P response experiment conducted on the Hamilton Long-Term Phosphate Experiment at five starting fertility levels, and sufficient N applied for it to be non-limiting. Background fertility ranged from a Colwell P of 14mg/kg where virtually no P fertiliser had been applied over the previous 40 years, and to a Colwell P of 143mg/kg where the annual application rate had averaged 27kg/ha.

Data presented here have been analysed in Genstat (18th Edition) using the restricted maximum likelihood (REML) and standard curve procedures, and are reported at the 5% significance level. However, as some of the data are from incomplete data sets, the findings must be considered preliminary.

Decision support

Utilising the experimental findings of this and previous projects, a series of Excel-based decision support aids were developed. Firstly, we utilised grain yield response relationships to soil tests for P, K and S from this project and the database of Better Fertiliser Decisions for Cropping in Australia (BFDC). Secondly, these were embedded in the Catchment Analysis Toolkit (CAT) model (Christy et al. 2013) to derive a series of predicted yields for wheat and canola in response to a range of fertiliser application strategies across multiple sites and years. CAT is a biophysical model that operates on a daily time-step, and has a dynamic N model. Scenarios of starting soil conditions and fertiliser application were developed through discussion with commercial agronomists in south-western VIC and southeast SA. Starting soil conditions were based on soil samples collected at the nutrient omission experimental sites. Thirdly, these scenarios were summarised into a series of coefficients for response functions showing diminishing marginal returns and incorporated into Excel look-up tables within the decision support tools. The spreadsheet tools use conventional marginal investment and return economics to calculate the economic optimum application rate of N, P, K and S for a given set of input conditions, grain and fertiliser prices and the user's required benefit/cost ratio or rate of return on the marginal dollar invested in fertiliser. The key risk factor is seasonal outcomes and production functions were determined for four season types — 'very poor', 'poor', 'good' and 'very good'. Three spreadsheet tools were developed from a common base and these address different questions — (i) an **awareness** tool showing likely response to in-crop N based on the initial P, K and S fertility, (ii) a **planning** tool to assist with pre-sowing applications of N, P, K and S and in-crop decisions based on climate forecasts, and (iii) an **evaluation** tool, to check whether the crop was under fertilised or over fertilised, post crop.

Results and discussion

Field experiments

Could full nutrient application close the yield gap?

Grain yields for the 'all' treatments were close to or exceeded the water-limited yield potential in six of the twelve experiments (Table 1). In four experiments, yields below potential were associated with prolonged waterlogging (Bool Lagoon in 2016 and 2017, and Rutherglen in 2016). For example, wheat at Bool Lagoon in 2017 was inundated continuously mid July until mid November, and yielded 2.6t/ha compared with a region-wide yield potential calculated by APSIM of 6.0t/ha for a rainfall decile of 10. In two experiments, yields below potential were associated with an exceptionally dry finish (canola at Francis and Inverleigh in 2015).

Which nutrients were required and what are the critical soil test values?

Statistically significant grain yield responses were found to N, P, K and S, but not to the micronutrients Cu and Zn (Table 1). The magnitude of the P response was related to the Colwell soil test. The data set from this project was supplemented by four previous trials in the HRZ in the BFDC database. An exponential curve described 64% of the variation, with the 90% critical value at a Colwell P of 30mg/kg (±SE 23 to 44mg/kg) (Figure 1). There was no significant difference between wheat and canola (for comparison, 90% critical values from the BFDC database from all trials in Australia are 24mg/kg for wheat and 20mg/kg for canola). Unlike most relationships in the BFDC database, which plateau at 100% of maximal yield, this relationship plateaued at 88% of maximal yield. This is the 'starter P' effect, whereby P banded just below the seed assists early crop establishment.

There were insufficient responses to K and S to derive similar relationships from this project alone. However, from the information collected to date from trials and the experience of crop agronomists, we suggest that the K response relationship for pastures be used for HRZ cropping. The pasture relationship has a 90% critical level at a Colwell

Table 1. Summary of nutrient omission and response experiments conducted under the project, including the decile of growing season rainfall (April to November inclusive), measured grain yield of the all-nutrients treatment, the yield potential estimated by APSIM for seasons of the same rainfall decile from the Yield Gap Australia website, and the relative yield (%) where particular nutrients are omitted (only reported where responses were statistically significant).

Location	Year	Crop	Rainfall decile	Yield of 'all' (t/ha)	Yield potential (t/ha)	Relative yield if a nutrient is omitted
Hamilton	2017	Canola	7	6.3	4.3	P (6%), N (24%)
Bool Lagoon	2017	Wheat	10	2.6	6.0	P (83%)
Hamilton	2016	Canola	10	6.2	3.7	K (83%), N (17%)
Tarrington	2016	Canola	10	5.3	3.7	P (61%)
Inverleigh	2016	Wheat	8	10.9	5.3	
Rutherglen	2016	Canola	10	0.7	2.3	P (78%), N (33%), S (68%)
Bool Lagoon	2016	Wheat	10	4.6	6.0	P (76%), S (78%), N (41%)
Bool Lagoon	2016	Canola	10	1.4	3.4	P (62%), N (59%), S (70%)
Francis	2015	Canola	1	0.9	2.5	N (78%)
Bool Lagoon	2015	Wheat	1	3.6	5.1	
Chatsworth	2015	Wheat	1	4.4	4.6	
Inverleigh	2015	Canola	1	1.8	3.8	P (83%), N (80%)

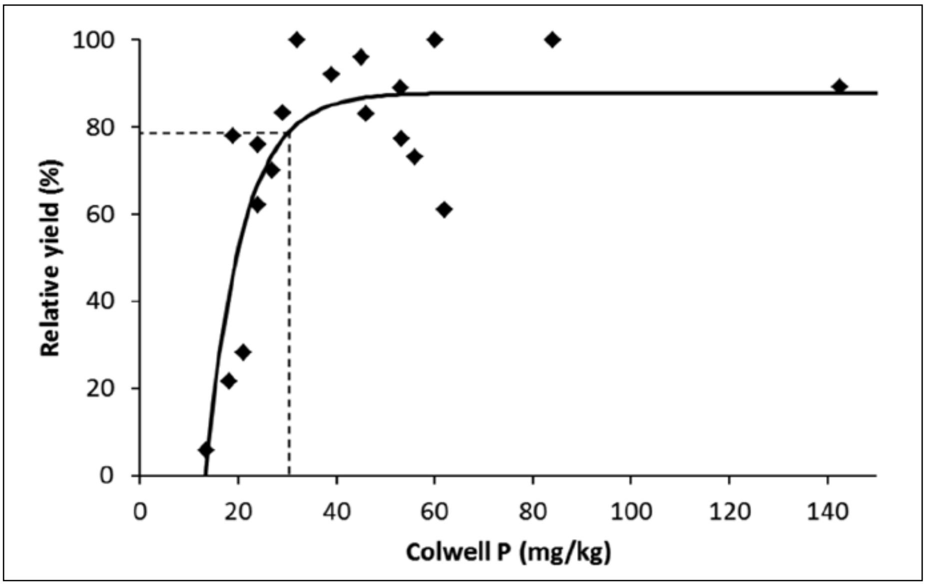


Figure 1. Relative grain yield response to Colwell P in wheat and canola for experiments in the HRZ in this project, and four previous trials in the BFDC database. Vertical line shows where fitted yield is 90% of the maximal value at a Colwell P of 30mg/kg. Note that because the relationship plateaued at 88% of the yield achievable when P is applied at sowing, the critical value is at 90% x 88% = 79%.

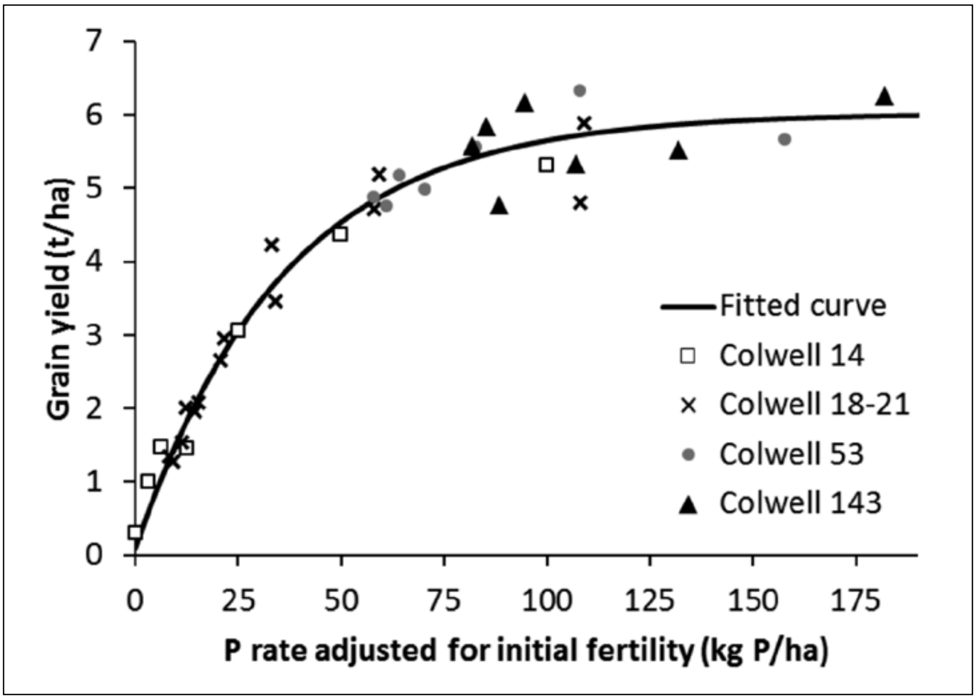


Figure 2. Canola grain yield response to applied P for a starting fertility of 14mg/kg Colwell, on the Hamilton Long-term Phosphate Experiment in 2017. Starting fertility ranged from 14mg/kg to 143mg/kg Colwell P, and P rates are adjusted so they are equivalent to the lowest starting fertility.

K of between 96mg/kg and 109mg/kg Colwell K depending on soil texture (Gourley et al. 2007) (this is much higher than 90% critical values from the BFDC database of 57mg/kg for wheat and 47mg/kg for canola based on trials in drier parts of Australia). For S using the KCl-40 extractant, a preliminary value of 8mg/kg appears to be more appropriate for both than the current BFDC values of 4.5mg/kg for wheat and 6.7mg/kg for canola.

A budgeting approach was used for N to determine application rates for the treatment where we aimed to provide 100% of N requirements. This approach involved calculating plant demand less soil N to a depth of 1m, less an allowance for mineralisation. The approach worked well for wheat but for canola it appeared much of the soil N was unavailable to the crop, despite the crop being highly responsive to fertiliser N. A parallel study (DAV00151 - Understanding how waterlogging affects water and nitrogen use by wheat) has shown that under waterlogged conditions, soil layers below approximately 5cm, become anaerobic. This would limit the capacity of roots to actively take up N and other nutrients, except where the roots have aerenchyma that allow oxygen diffusion. Wheat has aerenchyma in its adventitious roots, whereas canola lacks adventitious roots. This may explain why canola is much more dependent on fertiliser N application under waterlogged conditions than wheat.

How much nutrient was required?

While soil test response relationships describe the magnitude of response to a non-limiting amount of particular nutrient, they do not indicate the economic optimum amount to apply. This needs a fertiliser rate experiment such as that in Figure 2 (or equivalent model output such as from CAT). Here, seven rates of P were applied to fields with starting P fertility ranging from 14mg/kg to 143 mg/kg Colwell P. Canola grain yield followed a common relationship once adjustment was made for the starting fertility. For example, at a background P of 53mg/kg Colwell, yield of the nil P treatment was equivalent to a treatment receiving 58kg P/ha at a starting fertility of 14mg/kg Colwell.

Table 2. Background Colwell P of the response experiments on the Hamilton Long-term Phosphate Experiment, the long-term (40 year) annual P application that has produced the fertility level, the equivalent P application rate of the background P using the combined relationship in Figure 1, and the economic optimum P application rate at a 2:1 benefit cost ratio for canola at each background level.

Starting soil fertility P Colwell (mg/kg)	Economic optimum P application rate (kg P/ha)
14	88
18	79
21	80
53	30
143	6

Agricultural economists calculate the optimum fertiliser application rate as where $1 of extra grain is produced from $1 of extra fertiliser (Figure 3a), which is a 1:1 benefit cost ratio. A 1:1 benefit cost ratio is suitable if there is a high level of confidence in the response relationship, and no cost of capital. However, if there is some doubt whether a fertiliser investment will return sufficient additional yield despite seasonal variation and other possible crop growth constraints, a benefit cost ratio of 1.25:1 or 2:1 may be preferred, but the overall profits will be lower in the long term. In the example of P application to canola at Hamilton, the optimum P application rate at a 2:1 benefit cost ratio was 88kg P/ha less the allowance for background fertility (Table 2). Key factors that favour either high or low optimum application rates are:

Higher optimum fertiliser application rates	**Lower optimum fertiliser application rates**
High yields	Low yields
High crop prices	Low crop prices
Low fertiliser prices	High fertiliser prices
1:1 benefit cost ratio optimum	2:1 benefit cost ratio (or wider
Good seasons	Poor seasons

The yield factor is illustrated in Figure 3(b) by using the same curve as in Figure 2 scaled down to represent lower yield potentials in the Wimmera and Mallee. The 2:1 economic optimum occurs at 92% of yield potential in the HRZ, compared with 83% in the Wimmera and 66% in the Mallee. Soil tests are often interpreted in relation to a critical level at which 90% of maximum yield is achieved, whereas a higher threshold should be used in areas of greater yield potential.

The crop price factor is illustrated in Figure 3(c) by using the wheat price of $224/t in the canola yield response relationship, rather than the $495/t canola price. The economic optimum at a 2:1 benefit cost ratio declines to 55kg P/ha (from 88kg P/ha), less the allowance for background fertility.

It should be noted that this P response relationship was for a soil with a Phosphate Buffering Index (PBI) of 200, whereas the average PBI of commercial samples submitted in 2015 to the Nutrient Advantage laboratory from south-west VIC was only 108 (McCaskill et al. 2016 and unpublished). While a similar relationship would apply to all soils in the HRZ, the economic optimum application rate is likely to be lower than shown here.

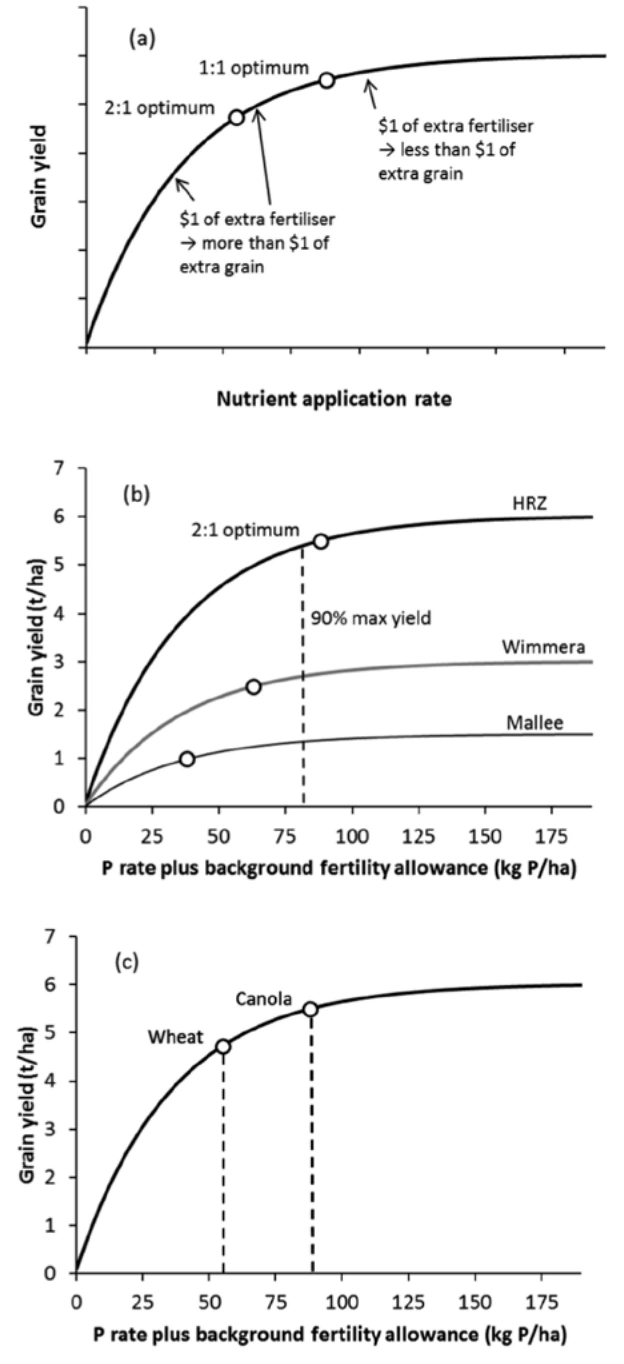


Figure 3. (a) Economic optimum nutrient application for a 1:1 and 2:1 benefit cost ratio; **(b)** economic optimum P application (circles) for a 2:1 benefit cost ratio for yield potentials representative of the HRZ, Wimmera and Mallee using the same curve as in Figure 2, and the fertility required for 90% of yield potential in all three environments; **(c)** economic optimum P application at a 2:1 benefit cost ratio for canola using the same curve as in Figure 2 and current prices, and for wheat if the yield response relationship also applied to wheat.

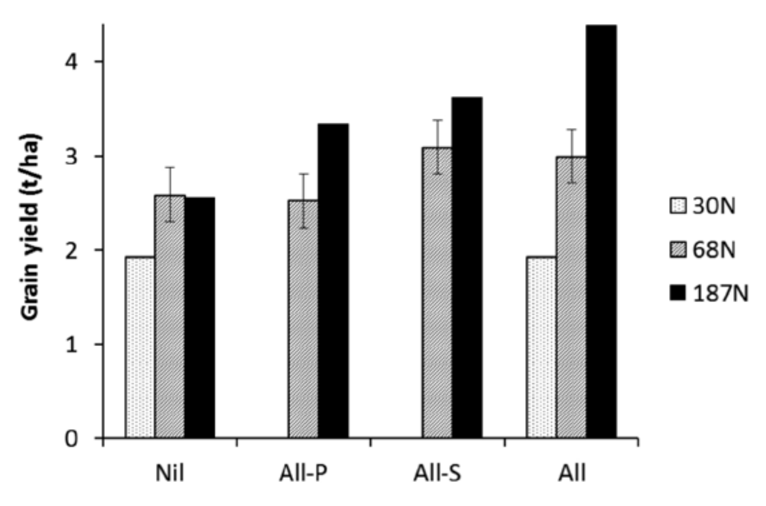
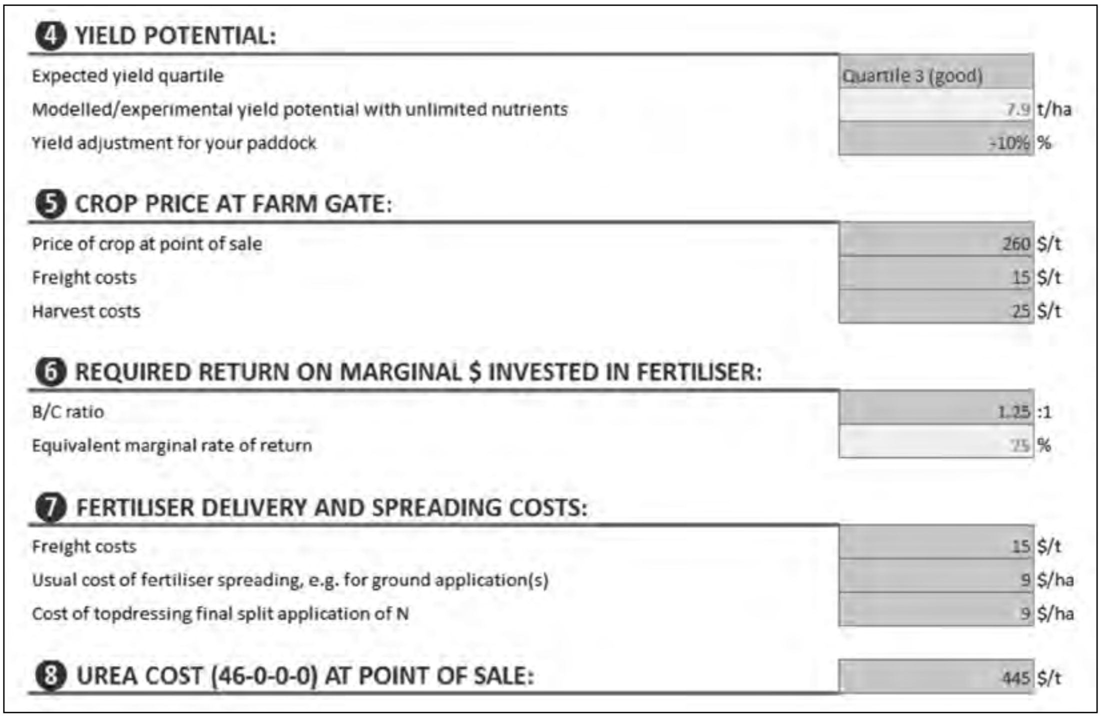


Figure 4. Wheat grain yield response to applied N at Bool Lagoon in 2016 as affected by the omission of all other nutrients at sowing, and the omission of P or S, at N application rates of 30kg, 68kg and 187kg N/ha. Error bars show the 5% least significant difference. Redrawn from Pearce et al. (2017).

What if two or more nutrients are limiting?

In the P rate experiment given above, non-limiting rates of N were applied, and N was not considered in the economic optimisation. In practice, most sites have an interaction between two or more limiting nutrients. This is illustrated from the 2016 wheat omission experiment at Bool Lagoon (Figure 4). There was a strong response to additional N where all the required other nutrients were applied, but there was a weaker response if P or S were omitted. Where both P and S were applied, each additional kilogram of N fertiliser between the mid and high rate of N produced 11.7kg of extra grain, compared with 6.8kg if P was omitted, 4.5kg if S was omitted and no additional yield if both were omitted. Correction of other nutrient limitations is the first step in obtaining a good response to applied N. Conversely, the P and S responses were only statistically significant at the high, but not the mid-rate of N. Similar findings were made from the other omission experiment sites. As cropping in the HRZ adopts varieties with higher potential yields and higher N rates are applied, we can expect more responses to P, K and S unless soil conditions are closely monitored.



❹ YIELD POTENTIAL:

Expected yield quartile	Quartile 3 (good)	
Modelled/experimental yield potential with unlimited nutrients	7.9	t/ha
Yield adjustment for your paddock	-10%	%

❺ CROP PRICE AT FARM GATE:

Price of crop at point of sale	260	$/t
Freight costs	15	$/t
Harvest costs	25	$/t

❻ REQUIRED RETURN ON MARGINAL $ INVESTED IN FERTILISER:

B/C ratio	1.25	:1
Equivalent marginal rate of return	25	%

❼ FERTILISER DELIVERY AND SPREADING COSTS:

Freight costs	15	$/t
Usual cost of fertiliser spreading, e.g. for ground application(s)	9	$/ha
Cost of topdressing final split application of N	9	$/ha

❽ UREA COST (46-0-0-0) AT POINT OF SALE: 445 $/t

Putting it together — decision support

Since the economic optimum changes with input costs and product prices, economic information is better conveyed by calculation tools than static information. The tools combine well established production economics principles with relatively poorly developed (to-date) nutrient response relationships from the HRZ and are available on the eXtensionAUS website. The spreadsheet tools allow users to adjust prices for crops and inputs and reveal optimum nutrient ratios and fertilisation levels for the range of seasonal conditions. For limited capital and/or high risk situations, users are also able to specify their required benefit/cost ratio or rate of return on the marginal dollar invested in fertiliser. Simple graphs and tables were used to illustrate expected outcomes. A screen grab from the awareness tool (Figure 5) shows how limitations of P, K or S affect the optimal application rate of N.

The effect of season variability on the optimal fertiliser strategy is accommodated by a drop-down box of yield quartiles. At sowing, these yield outcomes have equal probability, and possible N, P, K and S fertiliser strategies can be tested under both good and poor seasonal conditions. As the season progresses, the probability of achieving a particular yield outcome becomes more certain because of rainfall received after sowing, and drought influences become apparent such as El Niño or a positive Indian Ocean Dipole (IOD). Much of this information is available in late August and can influence decisions on split N application in late winter and early spring. The planning tool allows users to test how these factors affect the probability of achieving a low or high final yield, and the economic optimum N application rate. We expect to conduct training and feedback sessions with the tools over the next year, leading to improved versions. Eventually the tools may be made available in other forms, through incorporation into existing decision support tools and possibly smartphone apps, but the current Excel form provides a way of prototyping in parallel with gathering more information on nutrient response relationships.

Conclusion

Through a series of nutrient response experiments, we have established that by providing sufficient nutrients, the yield of wheat and canola crops can be equal to or exceed the water-limited potential, except in cases of severe waterlogging or drought. The strongest responses were to P followed by N, S and K. The magnitude of these responses was related to soil tests, but with critical values at which 90% of maximal yield was achieved slightly higher than from previous trials in other parts of Australia. Economic analysis showed that the 90%

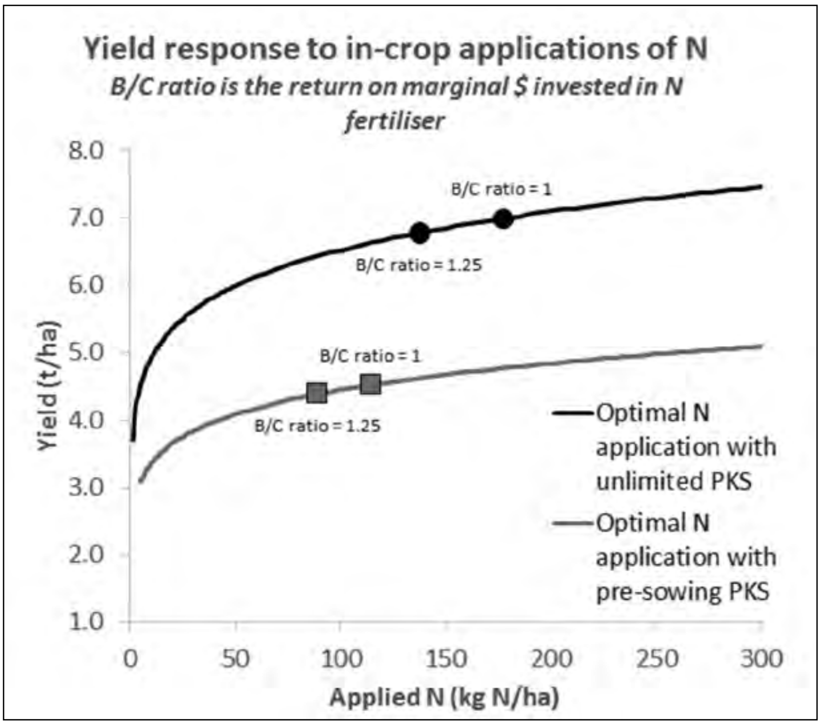


Figure 5. Screen grab from the awareness tool, showing some of the input data required, and a dynamic calculation of the economic optimum N application under conditions of limited P, K or S, and if these nutrients are fully supplied.

critical value underestimated the economic optimum because of the higher yield potential in the HRZ. Since the economic optimum fertiliser application rate is also dependent on input prices, product price and seasonal outlook, we have prepared three spreadsheets to calculate the optimum under a wide range of conditions. The spreadsheets are populated with yield and nutrient response data from a biophysical model, but allow modification to suit individual circumstances.

Useful resources

eXtensionAUS (http://extensionaus.com.au/)

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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. We thank the Victorian Department of Economic Development, Jobs Transport and Resources, and the International Plant Nutrition Institute (IPNI) for co-investing in this project. We also thank the landholders upon whose properties the experiments were conducted, and the technical staff who have contributed to the study.

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AGRICULTURE VICTORIA

The art of communicating science and recognising the ‘snake oil’

Jenni Metcalfe.

Econnect Communication.

Keywords

- science communication, extension, storytelling, science engagement.

Take home messages

- Science communication is effective when it helps to create positive and evidence-based change in peoples’ lives; for grain growers, that means they have the ability to make decisions that increase their profitability and sustainability.
- Science communicators are most effective at creating positive change when they listen to and understand the needs of people, and develop relationships of trust.
- Using simple language and telling engaging stories helps science communicators to build trust in and understanding of the science.

Introduction

“Like most farmers, we look to new grain varieties to help us maximise farm performance.

Over the last 10 years, we have generally shifted to shorter season varieties to improve yields in dry seasons. We have refined this process, and now we’re prepared to change our program depending on summer rainfall and the timing of the break.

We’re aiming to reduce risk and maximise returns.

We’re also starting to plant earlier than we ever have before, to try to get the crops out of the ground when we know there’s going to be a break. We run the risk at the other end of the season with frost. But with a good early break, we will swing back to using longer season varieties to minimise that frost risk, and increase yield if we get spring rains.

Our agronomic strategy is to know exactly where we are at the start of each season before we put the crop in. We’re continually getting smarter about the things we can control - what mix of crops we put in and what nutrients we apply to maximise our productivity (http://www.climatekelpie.com.au/index.php/farmers-managing-risk/climate-champion-program/susan-findlay-tickner)

These are the words of Susan Findlay Tickner who with her husband Simon has two farming properties: one north (2400 ha) and one south (600ha) of Horsham. Susan and Simon grow wheat, lentils, barley, canola, and fodder.

Susan was a participant in the Climate Champion program that was supported by investment from GRDC and the Managing Climate Variability program from 2010 until 2016. Susan and Simon are grain growers who have embraced science in their on-farm decision-making and are typical early adopters of technology. But what role does science communication play in such adoption? And how can we support growers like Susan and Simon to influence other growers to use science in their decision-making?

For me, good science communication is always about achieving some sort of positive change in people’s lives. This paper outlines how science communication can help achieve such positive change. For grain growers this means increasing profitability and sustainability despite changing markets and climate. So first, it is important to consider what science communication is, and how it relates to agricultural ‘extension’.

Extension and science communication — what is the difference?

Creating evidence-based change in on-farm practices requires close participation between researchers, growers, and their advisers — consistent with modern definitions of effective 'extension'.

The Australasia-Pacific Extension Network (APEN) defines extension as 'working with people in a community to facilitate change in an environment that has social, economic and technical complexity'(http://www.apen.org.au/what-is-extension) . It can be achieved by 'helping people gain the knowledge and confidence so they want to change and providing support to ensure it is implemented effectively'. This compares with earlier extension processes, which were far more 'top-down'; that is, a more elitist, one-way transfer of knowledge from scientists to extension officers to growers.

APEN believes that each step in extension is active and participatory. Extension is seen to be an education process (capacity-building). The work with the target audience takes genuine engagement. The responsibility of decision-making is a shared one, to achieve greater personal and group ownership of decisions (empowerment). These elements combine 'to improve the commitment towards reaching common goals'.

However, as already noted, extension hasn't always been inclusive and participatory. Instead, it has changed and evolved from 'old 'training and visit' models' to 'playing the role of broker between different actors'(CGIAR Research Program on Policies, Institutions and Markets, 2013).

Like extension, many people believe science communication has evolved over time, from a one-way model of communication to approaches that include more direct involvement from various people, including growers, in the research. Many elements identified as important for effective extension are echoed in best practice for science communication.

Science communication is defined by some scholars as: 'the use of appropriate skills, media, activities and dialogue to produce one or more of the following responses to science: awareness, enjoyment, interest, opinion-forming, and understanding' (Burns et al. 2003). I would reiterate that, for me, regardless of the objectives or the means, the end goal of all good science communication is about engendering positive change in people's lives.

There are three dominant science communication models postulated by various researchers (Callon, 1999; Irwin, 2008, 2014; Rowe & Frewer, 2005; Trench & Junker, 2001). Until the early 1990s, the 'deficit' model of science communication dominated the process of science communication where all-knowing scientists imparted their knowledge to the public who were seen as 'empty vessels' needing to be filled (Joly & Kaufmann, 2008; Trench 2008). This is similar to the top-down style of traditional agricultural extension. Then, this model was replaced with the 'dialogue' model, where some scientists consulted the public about scientific developments, especially any that they might be concerned about — such as the genetic modification of plants or animals (Irwin, 2008; Trench 2008). This model sought to make science more transparent and open, but many saw it as a way for scientists to legitimise their research without true participation/consultation and, in the process, reinvent the deficit model (Wynne, 2005; Wilsdon & Willis, 2004).

The third model of science communication, the 'participatory' model, seeks to have the public take part in science to jointly review or deliberate about science issues or even to join as equal partners with scientists in co-creating new knowledge or products (Irwin, 2008; Joly & Kaufmann, 2008). In this model, scientific knowledge is just one of the sets of knowledge brought to the engagement process, along with knowledge and experience from various concerned citizens, sectional interests, and non-government organisations. Participatory communication brings about a greater reflection by all those involved about science and its role in society, including for the purposes of decision-making Warner, 2002.

This participatory model of science communication aligns most closely with the latest definitions of extension, which also values the experience and knowledge of growers. I take the view in this paper that to achieve the objective of evidence-based practice change, there needs to be a more participatory approach between researchers, growers, and their advisers.

Unfortunately, the level of public investment in extension (E) has declined over the years, along with decreasing investment in research (R) and development (D) (Sheng, Mullen & Zhao, 2010). This is largely due to state governments reducing their overall investment in RD&E. The traditional role of states in providing free extension services to growers has virtually disappeared; rural research and development corporations (RDCs) and private providers have become more prominent. Most

RDCs see extension as essential to improving rural productivity and sustainability.

Delivering this extension is a set of complex communication and delivery channels, according to the 2010 DAFF Submission to Productivity Commission inquiry into the Australian Government Rural Research and Development Corporations Model. The submission says that, 'while in each industry extension operates differently, extension is now a maze of different providers and access points, through private consultants, agribusiness and input suppliers, local grower groups, and public information obtained through the internet, conferences, demonstrations, workshops and publications'.

Science communicators — whether they are professional communicators, scientists or advisers — can assist the uptake and adoption of evidence-based knowledge by growers by:

- Listening to and understanding the growers' needs.
- Telling gripping stories using simple language.

Listen to and understand growers

The single most important skill of a good science communicator is their ability to listen. Unless you understand people's perceptions, concerns and needs in relation to a science issue then you can never hope to be effective in your communication.

Bill Long, in a paper presented at the 2013 GRDC Grains Research Update (Long, 2013) says that growers often make decisions by 'gut feel', and 'rules of thumb'. Bill explains that for many growers, rational decision-making is often outweighed by lifestyle factors, love of farming, and their values and beliefs.

For example, when looking at how growers make climate- or weather-based decisions, researchers found that growers make decisions in complex environments and that those decisions are not always focused on weather and climate (Risbey et al, 1999). There are also issues of pests, market conditions, terms of trade, soil quality and water availability.

One of the things the Climate Champion program did was to bring researchers directly together with growers at workshops and other events to discuss the latest science as well as grower needs. Such events were deliberately designed to be as interactive as possible. The CliMate App was developed through the input of growers like Susan Findlay Tickner. They told the researchers what climate/weather information they needed, when they needed it, and how they liked to access it. Once the prototype app had been developed, the Climate Champion growers tested it and provided further feedback. Its development has continued to evolve with the inputs and ideas of growers. It has been a joint process.

I would reiterate the importance of listening. And most of us are not very good at it particularly active listening where we genuinely put aside our own concerns and needs to focus on the people we are listening to. Two illustrative quotes from researchers who genuinely listened to the growers, and then benefitted from that listening, were:

- 'Our original list of variables we intended to analyse changed dramatically after speaking with Climate Champions. The way we presented our research results also benefited significantly from communication with Climate Champions'.
- 'A very satisfying experience and more than met my expectations. After I got off the phone [from talking with a climate champion grower] I felt like I'd taken a big step forward with my research'.

Tell gripping stories using simple language

Good stories create conversations and can lead to real actions.

Such storytelling relies on strong narratives that help the reader or listener to identify or empathise with the characters in the story. Good storytelling is all about people. Good storytelling grips people's imagination. It motivates and excites them. I still remember a Melbourne journalist telling a bunch of scientists at a media skills workshop: 'I'm interested in just about any science story you have to throw at me. But don't talk to me about weeds; they're just plain boring'. Clearly our weed stories, which although are very important to growers, are not exciting to them.

The key to telling good stories: they must be about people. Here are my seven tips for telling good stories about science to grain growers:

1. Talk about people's mistakes as well as their successes. Good stories have drama, emotion and conflict.
2. Make stories personal and relevant to those you want to listen to them. Get people to talk in the first person about their own experiences — this includes scientists!

3. Check that stories are relevant to the growers. This might mean finding out about their current perceptions, concerns and motivations regarding the topic. For example, Greiner et al. (2009) found that promoting a set of best management practices for weed control did not engage as many growers as it was thought it might. The reason? Those proposing the best management practices did not understand the personal goals behind how growers made their land management decisions. This could have been overcome by getting growers to share their goals and aspirations for their farms through personal stories.
4. Engage the whole community in telling local stories about grain growing. Let people share their own experiences with others for mutual learning.
5. Use simple, active colloquial language to tell stories. Avoid fluent 'stakeholder speak'. 'Stakeholders' are not real people, and 'implementing agreed weed control frameworks' means nothing to most people. Use conversational rather than bureaucratic language to tell stories.
6. Tell stories in different places and through different media. Try sharing science stories in locations where your listeners feel most comfortable. For example, while 'preaching to the converted' at field days is important, it's even more important to reach those growers who are currently disengaged. This might mean sharing stories at a local sporting event or at the pub.
7. Be visual in your storytelling. Paint pictures with your words that stimulate people's imagination. Illustrate your stories with video, photos and infographics.

Many researchers and advisers are used to traditional media — especially ABC radio — as a means of telling their science stories and communicating their advice, but nothing beats personal face-to-face story telling. Increasingly, people, including researchers and growers are using social media as a way of sharing their stories.

Unfortunately, this is where there's plenty of 'snake oil' for people to beware of. In my experience, growers are very good at sorting out the sources that are trustworthy or not. They're a sceptical bunch, and rightly so. In the past Australian growers put their trust in agricultural research and extension (Vanclay, 2004), but this is no longer the case. In my experience, growers are most likely to trust growers they interact with regularly, which is where the Climate Champion program had particular value.

However, social media means a multiplicity of messages and it's increasingly important for growers to be able to tell the 'snake oil' from the real gold. Here's three tips for sorting 'fake' science news from the real stuff:

- Credibility — is the author from a credible and known organisation? Do they have a history of talking on this subject?
- Content —What kind of content is it? Does it show evidence or is it an opinion piece?
- Connections — Who follows them? Do you know their followers? Are they credible?

Conclusion

Good science communication, like effective agricultural extension, comes down to developing relationships of trust. This works best when the communication is personal and face-to-face. This takes time, a lot of time but the payoff can be enormous. Developing relationships of trust requires those of us who communicate science to:

- Actively listen to those we want to communicate with.
- Understand their perceptions, concerns and needs regarding the science we want to communicate.
- Recognise they have valuable knowledge to share.
- Invest the time in communication that is personal.
- Tell stories about people and their passions.
- Speak directly, distilling the science in a way that people can understand without compromising its integrity.

Susan Findlay Tickner and Simon Tickner are early adopters of science that helps them to make decisions on their farms. This was enhanced through the Climate Champion program when they got to spend significant time over several years conversing with climate scientists, finding out the latest science and sharing their perceptions, concerns and needs. We also supported Andrea and Mark, and the other Climate Champions to develop skills in sharing the science they learnt about by presenting, storytelling through the media and social media, and through their ongoing relationships with other growers in their networks.

There is no hard evidence about whether the Climate Champion program improved adoption of best practices by growers. An independent evaluation of the program by Agtrans Research, commissioned by the GRDC in 2012, found a benefit to cost ratio of 2.89:1 (http://www.managingclimate.gov.au/wp-content/uploads/2014/12/GRDCImpact-Assessment-Climate-Champions-Program-November-2012pdf-1.pdf). However, this evaluation focussed on interviews with the then 33 grower participants in the program, and not the wider farming community.

We conducted a survey with all 45 participants of the program over its lifespan when it concluded in June 2016. Thirty-three responded to the survey:

- 97% said program helpful/very in supporting their communication with other growers.
- 72% said their activity in communicating about climate risk was higher or much higher than it otherwise would have been.
- 94% believed they were able to influence other growers' use of climate risk knowledge and tools to at least a moderate extent.
- 69% thought the program had been able to change practices/behaviours to a high or very high degree.

Kym Fromm was another SA Climate Champion farmer who farms about 5000 acres in tough country near Goyder's Line in Orroroo in the Flinders Ranges. He said: "The Climate Champion program is a really good opportunity for us to get the information that we need, and bring that back to our farmer groups. I think that is really important in the situation and location that we are in: right on the edge of the cropping district. The beauty of this group is that we get cutting-edge, good information. It's the perfect opportunity to get it straight from the scientists to the grass roots, without that normal filtering-down effect that might take two or three years (http://www.climatekelpie.com.au/index.php/farmers-managing-risk/climate-champion-program/kym-fromm)."

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Acknowledgements

I would like to thank GRDC and the Managing Climate Variability Program for funding and supporting the Climate Champion Program from its inception in late 2009 until the end of June 2016. I would also like to thank the Climate Champion growers for their ongoing inspiration to me in my work as a science communicator. Thanks to Sarah Cole for reviewing and editing this paper, and to Madeleine Stirrat for compiling the references for me.

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Notes

Herbicide resistance – where we are, where we are going and what can we do about it

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GRDC project codes: UA00159, UCS00020, USC00020, UCS00024, US00084

Keywords

- herbicide resistance, pre-emergent herbicides, crop competition, weed seed set control.

Take home messages

- Herbicide resistance occurs most commonly in continuously cropped grain production fields.
- Grass weeds with resistance to pre-emergent herbicides (Groups D and J) and broadleaf weeds with resistance to Group I herbicides are emerging problems that will test growers' management skills.
- Attempting to introduce three effective control practices in each crop will enable weed seed banks to be reduced.

Where are we with herbicide resistance?

Currently in Australia there are 50 weed species with resistance to herbicides from 11 modes of action. These include 23 grass species resistant to eight modes of action and 27 broadleaf weed species resistant to seven modes of action. Herbicide resistance is known from all six states of Australia, but some states, notably WA, SA and VIC, tend to have more resistance than other states. Herbicide resistance has occurred in all situations where herbicides are used, but is most common and most widespread in grain cropping. Of the 91 weed species by herbicide modes of action with resistance listed in Table 1, 65 have occurred in grain cropping systems. Herbicide resistance in grass species is typically the most problematic issue in grain production due to the dominance of cereals in cropping rotations.

With investment from GRDC, University of Adelaide and Charles Sturt University weed resistance survey data suggests that most, if not all, grain growers have some herbicide resistance on their farms. Resistance is particularly prominent to Group A and B post-emergent herbicides, but is also present to herbicides from Groups C, D, F, I, J, L, M, and Z. Herbicide resistance can also move between locations on wind, in water, in hay and in machinery. However, this only becomes an issue when growers are using the same weed management practices.

Where are we going?

Data from our (University of Adelaide) weed resistance surveys shows that with annual ryegrass, the number of herbicides that any one grower has resistance is bimodal with approx. 40% of fields having resistance to four to six herbicides and about half having resistance to zero or one herbicide (Figure 1). When we looked back at where these fields were located, those with resistance to four to six herbicides were mostly from areas where continuous cropping was common and those with resistance to zero or one herbicide were from areas where pasture was common in rotations. Having pasture in rotations reduces the risk of herbicide resistance, because most growers use few herbicides in the pasture phase. This shows that the major risk factor for developing herbicide resistance is using herbicides. The more focus on continuous

Table 1. Herbicide resistant weeds in Australia.

Grass Weeds	Groups	States present
Annual ryegrass (*Lolium rigidum*)	A	WA, SA, VIC, TAS, NSW
	B	WA, SA, VIC, TAS, NSW
	C	WA, SA, VIC
	D	WA, SA, VIC, NSW
	J	SA, VIC, NSW
	L	WA, SA
	M	WA, SA, VIC, NSW
	Q*	WA, SA
Winter grass (*Poa annua*)	B*	SA, VIC, NSW
	C*	SA, VIC, NSW
	D*	SA, VIC, NSW
	M*	SA, VIC, NSW
	Z*	SA, NSW
Barley grass (*Hordeum glaucum*)	A	SA
	B	WA, SA, VIC
	L	SA, VIC
	M	SA
Barley grass (*Hordeum leporinum*)	A	SA
	B	SA, VIC
	L	SA, VIC, TAS, NSW
Wild oats (*Avena fatua*)	A	WA, SA, VIC, NSW, QLD
	B	SA, VIC, NSW, QLD
	Z	NSW, QLD
Wild oats (*Avena sterilis*)	A	SA, VIC, NSW, QLD
	B	SA, VIC
	Z	NSW, QLD
Great brome (*Bromus diandrus*)	A	SA, VIC
	B	SA, VIC
	M	SA, VIC
Brome grass (*Bromus rigidus*)	A	SA
	B	WA, SA
Red brome (*Bromus rubens*)	M	WA
Large crabgrass (*Digitaria sanguinalis*)	A*	SA
	B*	SA
Crowsfoot grass (*Eluesine indica*)	A*	QLD
	L*	QLD
Paradoxa grass (*Phalaris paradoxa*)	A	NSW
	B	NSW
Lesser canary grass (*Phalaris minor*)	A	VIC
	B	VIC
Liverseed grass (*Urochloa panicoides*)	C	QLD
	M	NSW
Silver grass (*Vulpia bromoides*)	C*	WA, VIC
	L*	VIC
Awnless barnyard grass (*Echinochloa colona*)	M	WA, NSW, QLD
Barnyard grass (*Echinochloa crus-galli*)	C	NSW
Annual veldtgrass (*Ehrharta longiflora*)	A*	WA
Feathertop Rhodes grass (*Chloris virgata*)	M	SA, NSW, QLD
Windmill grass (*Chloris truncata*)	M	WA, VIC, NSW
Sweet summer grass (*Brachiaria eruciformis*)	M	QLD
Giant Parramatta grass (*Sporobolus fertilis*)	J*	NSW
Serrated tussock (*Nassella trichotoma*)	J*	VIC

** This resistance is not known from grain production systems.*

Table 1 cont. Herbicide resistant weeds in Australia.

Broadleaf weeds	Groups	States present
Wild radish (*Raphanus raphanistrum*)	B	WA, SA, VIC, NSW, QLD
	C	WA
	F	WA, SA
	I	WA, SA, VIC, NSW
	M	WA
Indian hedge mustard (*Sisymbrium orientale*)	B	WA, SA, VIC, NSW
	C	VIC
	F	SA, VIC
	I	SA
African turnip weed (*Sisymbrium thellungii*)	B	QLD
Common sowthistle (*Sonchus oleraceus*)	B	SA, VIC, TAS, NSW, Qld
	I	SA, VIC, NSW
	M	NSW, Qld
Prickly lettuce (*Lactuca serriola*)	B	SA, VIC
	M	VIC
Willow-leaved lettuce (*Lactuca saligna*)	M	WA
Capeweed (*Arctotheca calendula*)	I	SA
	L*	VIC
Fleabane (*Conyza bonariensis*)	B	VIC
	M	SA, VIC, NSW, QLD
Tall fleabane (*Conyza sumatrensis*)	M*	NSW
Arrowhead (*Sagittaria montevidensis*)	B*	NSW
Black bindweed (*Polygonum convolvulus*)	B	QLD
Bedstraw (*Galium tricornutum*)	B	SA
Calomba daisy (*Pentzia suffruticosa*)	B	SA
Charlock (*Sinapis arvensis*)	B	NSW
Dirty Dora (*Cyperus difformis*)	B*	NSW
Iceplant (*Mesembryanthemum crystallinum*)	B	SA
Lincoln weed (*Diplotaxis tenuifolia*)	B	SA
Paterson's curse (*Echium plantagineum*)	B*	WA, SA
Starfruit (*Damasonium minus*)	B*	NSW
Turnip weed (*Rapistrum rugosum*)	B	QLD
Wild turnip (*Brassica tournefortii*)	B	WA, SA
Stinging nettle (*Urtica urens*)	C*	VIC
Dense-flowered fumitory (*Fumaria densiflora*)	D	SA, NSW
Black nightshade (*Solanum nigrum*)	L*	QLD
Pennsylvania cudweed (*Gamochaeta pensylvanica*)	L*	QLD
Small square weed (*Mitracarpus hirtus*)	L*	QLD
Tridax (*Tridax procumbens*)	M*	WA

** This resistance is not known from grain production systems.*

cropping and the more herbicides used, the more likely resistance will occur

As resistance to post-emergent herbicides in grass weeds, particularly in annual ryegrass, has increased, reliance on pre-emergent herbicides has become more common. This has resulted in increasing resistance to pre-emergent herbicides. There has been resistance to trifluralin in SA for many years, however, the extent of resistance has increased in the past 15 years and it is now common in VIC and increasing in NSW. Resistance to trifluralin became widespread in SA by 2005, resulting in early adoption of Boxer Gold® when it was released in 2008. The heavy dependence on Group J herbicides has led to resistance to this mode of action in the past few years. Resistance to Group J herbicides in annual ryegrass has occurred in SA, VIC and NSW. In all cases, the populations also have resistance to trifluralin, suggesting that once trifluralin has failed, selection pressure shifts to other pre-emergent herbicides.

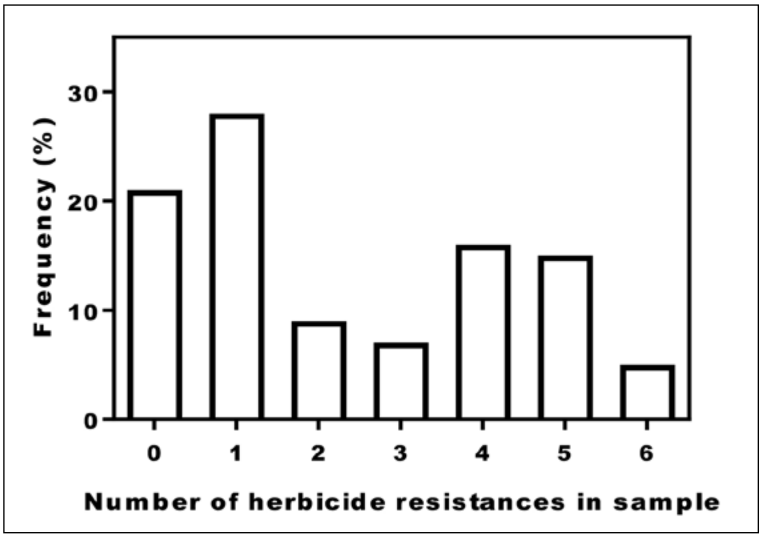

Figure 1. Frequency of randomly collected annual ryegrass samples from SA and VIC with resistance to a suite of six common herbicides.

In one population of annual ryegrass with resistance to Group J herbicides that has been well characterised, resistance occurs across many herbicides of this mode of action (Table 2). This population also has resistance to trifluralin and a reduction in susceptibility to both propyzamide and pyroxasulfone (Sakura®). The current reliance on pre-emergent herbicides for annual ryegrass control could be threatened if more populations like this appear.

Another recent concern is the evolution of resistance to the Group I herbicides in broadleaf weeds. It was once considered to be difficult to develop resistance to Group I herbicides, but the frequency of their use has increased following widespread resistance to Group B herbicides. This has resulted in more important broadleaf weed species with resistance to Group I herbicides (Table 1). These include wild radish, Indian hedge mustard, common sowthistle and capeweed. Perhaps one of the more troubling is common sowthistle, which now has resistance to Group B herbicides, both sulfonylureas (SUs) and imidazolinones (IMIs), glyphosate and all Group I herbicides. This eliminates all the inexpensive options for summer weed control. Given their increasing use in cropping systems, further weeds with resistance to Group I herbicides should be expected.

What can we do about it?

Herbicide management

There are a few strategies involving herbicide management that can be used to reduce herbicide resistance. Rotation of herbicides is one strategy.

Table 2. Concentration of various pre-emergent herbicides required for 50% mortality (LD_{50}) of resistant (R) and susceptible (S) annual ryegrass populations with resistance index (RI).

	Annual ryegrass population			
Herbicide (with Group)	SLR4 (S)	VLR1 (S)	EP162 (R)	RI*
	LD_{50} (g a.i. ha^{-1})			
Triallate (J)	248	181	3188	14.9
Prosulfocarb (J)	311	246	2608	9.4
EPTC (J)	305	288	2867	9.7
Thiobencarb (J)**	370	265	4332	13.6
Trifluralin (D)	39	27	455	13.8
Propyzamide (D)	30	23	74	2.7
Pyroxasulfone (K)	9.5	6.2	64	8.1

**RI = LD_{50} of R population divided by LD_{50} of S populations.*

***Thiobencarb is not registered for annual ryegrass control and is shown for comparison purposes only.*

Rotation of herbicides does not stop resistance from occurring, but can delay resistance. Table 3 is an updated estimate of the number of years of use for different herbicide modes of action. Resistance is more likely to some modes of action than to others, so resistance can be delayed by using high risk modes of action less often.

Table 3. Number of years using a particular herbicide mode of action before herbicide resistance is likely to be a problem.

Herbicide Group	Years of application before resistance is likely
A	6-8
B	4
C	10-15
D	10-15
F	10
I	>20
J	6-8
L	>15

Sometimes, resistance does not occur to all herbicides from a mode of action, allowing use of one or more herbicides from that group to control resistant weeds. For example, clethodim controlled many populations of annual ryegrass that were resistant to other Group A herbicides for many years. However, the same rules do not apply to other grass weed species. Likewise, IMI herbicides can be used to control some broadleaf weeds with resistance to other Group B herbicides. For example, until recently there was very little IMI resistance present in common sowthistle, despite resistance to SU herbicides being widespread. A greater dependence on IMI herbicides for weed control, particularly in lentil production, has seen a rapid selection for IMI resistance in this species. As the extent of resistance within a herbicide mode of action can vary from species to species, the only way to be sure is to test for susceptibility in the resistant population.

Do herbicide rates matter?

The answer to this question is yes and no. Both low rates and high rates of herbicides select for resistance in weeds. Typically, high rates will select for resistance faster, because the selection pressure is stronger. However, low rates can select for weak resistance mechanisms and can result in resistant populations with more complex mixtures of resistance mechanisms. Probably of more significance than worrying about herbicide rates is to ensure herbicides are used to provide as effective weed control as possible.

Non-chemical tactics

Non-chemical tactics are, on their own, not as effective or easy to use as herbicides. This is why growers often opt for herbicides as the first control option. However, non-chemical tactics can help reduce the pressure on herbicides and delay resistance. Employing non-chemical tactics is complex and the correct tactic needs to be chosen for the situation. For example, cultivation is likely to be counter-productive in situations where pre-emergent herbicides are relied on for weed control. Cultivation will distribute the weed seeds through the soil, separating them from the herbicide applied on the soil surface.

The inclusion of non-chemical tactics is likely to be most useful where they help to reduce seed set of weeds. Crop competition is one of these tactics. Increased crop competition can be obtained in numerous ways, including by sowing a more competitive crop, sowing a more competitive variety, increasing crop seeding rates, reducing crop row spacings, grading sowing seed for larger seed, and east-west sowing of cereals in some regions. Recent research in the southern region has shown that early sowing of wheat and sowing hybrid canola instead of open-pollinated canola can both reduce annual ryegrass seed production by up to 50%.

Another set of non-chemical tactics is harvest weed seed destruction. These tactics rely on collecting and destroying weed seed that enters the harvester. There are numerous practices that have been used including chaff carts, narrow windrow burning, chaff lining and the Harrington Seed Destructor (HSD). These practices can reduce weed emergence by approximately 50% in the next season. They do rely on a significant amount of the weed seed being captured in the harvest operation and will not be effective on weed seeds that cannot be harvested.

Crop rotations

Choosing the right crop rotation can help introduce tactics for managing troublesome herbicide resistant weeds. Cereal crops are often the best option for managing herbicide resistant broadleaf weeds, due to the range of tactics that can be included. Likewise, break crops are often the best option for managing herbicide resistant grass weeds. Rotations that have too many cereal crops often become infested with herbicide resistant grass weeds. Likewise, rotations with a high intensity of pulse crops will have problems with herbicide resistant broadleaf weeds.

Achieving better weed management

Our long term weed management trials have emphasised the importance of weed seed set reduction in improving long term management of herbicide resistant weeds. Reducing the number of herbicide resistant weed seeds returning to the soil seed bank needs to be a component of any management program for herbicide resistant weeds. It is also important to maintain yields and reduce the number of weeds competing with the crop. Effective use of pre-emergent herbicides has proved useful in managing herbicide resistant annual ryegrass and wild radish.

The other outcome of these long term trials is that achieving three effective control measures in as many crops in the rotation as possible allows weed seed banks to be reduced. For annual ryegrass, this can be pre-emergent herbicides, crop competition and weed seed set control. For wild radish, crop competition and two herbicide applications or two herbicide applications and seed set control have been required.

Useful resources

https://grdc.com.au/resources-and-publications/iwmhub

https://agwine.adelaide.edu.au/research/farming-systems/weed-science/publications/

https://weedsmart.org.au/case-studies/

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.

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Notes

Notes

GRDC
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CORPORATION

THE 2017-2019 GRDC SOUTHERN REGIONAL PANEL

FEBRUARY 2018

CHAIR - KEITH PENGILLEY

Based at Evandale in the northern Midlands of Tasmania, Keith was previously the general manager of a dryland and irrigated family farming operation at Conara (Tasmania), operating a 7000 hectare mixed-farming operation over three properties. He is a director of Tasmanian Agricultural Producers, a grain accumulation, storage, marketing and export business. Keith is the chair of the GRDC Southern Regional Panel which identifies grower priorities and advises on the GRDC's research, development and extension investments in the southern grains region.

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DEPUTY CHAIR - MIKE MCLAUGHLIN

Mike is a researcher with the University of Adelaide, based at the Waite campus in South Australia. He specialises in soil fertility and crop nutrition, contaminants in fertilisers, wastes, soils and crops. Mike manages the Fertiliser Technology Research Centre at the University of Adelaide and has a wide network of contacts and collaborators nationally and internationally in the fertiliser industry and in soil fertility research.

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JOHN BENNETT

Based at Lawloit, between Nhill and Kaniva in Victoria's West Wimmera, John, his wife Allison and family run a mixed farming operation across diverse soil types. The farming system is 70 to 80 percent cropping, with cereals, oilseeds, legumes and hay grown. John believes in the science-based research, new technologies and opportunities that the GRDC delivers to graingrowers. He wants to see RD&E investments promote resilient and sustainable farming systems that deliver more profit to growers and ultimately make agriculture an exciting career path for young people.

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PETER KUHLMANN

Peter is a farmer at Mudamuckla near Ceduna on South Australia's Western Eyre Peninsula. He uses liquid fertiliser, no-till and variable rate technology to assist in the challenge of dealing with low rainfall and subsoil constraints. Peter has been a board member of and chaired the Eyre Peninsula Agricultural Research Foundation and the South Australian Grain Industry Trust.

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FIONA MARSHALL

Fiona has been farming with her husband Craig for 21 years at Mulwala in the Southern Riverina. They are broadacre, dryland grain producers and also operate a sheep enterprise. Fiona has a background in applied science and education and is currently serving as a committee member of Riverine Plains Inc, an independent farming systems group. She is passionate about improving the profile and profitability of Australian grain growers.

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JON MIDWOOD

Jon has worked in agriculture for the past three decades, both in the UK and in Australia. In 2004 he moved to Geelong, Victoria, and managed Grainsearch, a grower-funded company evaluating European wheat and barley varieties for the high rainfall zone. In 2007, his consultancy managed the commercial contract trials for Southern Farming Systems (SFS). In 2010 he became Chief Executive of SFS, which has five branches covering southern Victoria and Tasmania. In 2012, Jon became a member of the GRDC's HRZ Regional Cropping Solutions Network.

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ROHAN MOTT

A fourth generation grain grower at Turriff in the Victorian Mallee, Rohan has been farming for more than 25 years and is a director of Mott Ag. With significant on-farm storage investment, Mott Ag produces wheat, barley, lupins, field peas, lentils and vetch, including vetch hay. Rohan continually strives to improve productivity and profitability within Mott Ag through broadening his understanding and knowledge of agriculture. Rohan is passionate about agricultural sustainability, has a keen interest in new technology and is always seeking ways to improve on-farm practice.

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RICHARD MURDOCH

Richard along with wife Lee-Anne, son Will and staff, grow wheat, canola, lentils and faba beans on some challenging soil types at Warooka on South Australia's Yorke Peninsula. They also operate a self-replacing Murray Grey cattle herd and Merino sheep flock. Sharing knowledge and strategies with the next generation is important to Richard whose passion for agriculture has extended beyond the farm to include involvement in the Agricultural Bureau of SA, Advisory Board of Agriculture SA, Agribusiness Council of Australia SA, the YP Alkaline Soils Group and grain marketing groups.

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RANDALL WILKSCH

Based at Yeelanna on South Australia's Lower Eyre Peninsula, Randall is a partner in Wilksch Agriculture, a family-owned business growing cereals, pulses, oilseeds and coarse grain for international and domestic markets. Managing highly variable soil types within different rainfall zones, the business has transitioned through direct drill to no-till, and incorporated CTF and VRT. A Nuffield Scholar and founding member of the Lower Eyre Agricultural Development Association (LEADA), Randall's off-farm roles have included working with Kondinin Group's overview committee, the Society of Precision Agriculture in Australia (SPAA) and the Landmark Advisory Council.

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KATE WILSON

Kate is a partner in a large grain producing operation in Victoria's Southern Mallee region. Kate and husband Grant are fourth generation farmers producing wheat, canola, lentils, lupins and field peas. Kate has been an agronomic consultant for more than 20 years, servicing clients throughout the Mallee and northern Wimmera. Having witnessed and implemented much change in farming practices over the past two decades, Kate is passionate about RD&E to bring about positive practice change to growers.

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BRONDWEN MACLEAN

Brondwen MacLean has spent the past 20 years working with the GRDC across a variety of roles and is currently serving as General Manager for the Applied R&D business group. She has primary accountability for managing all aspects of the GRDC's applied RD&E investments and aims to ensure that these investments generate the best possible return for Australian grain growers. Ms MacLean appreciates the issues growers face in their paddocks and businesses. She is committed to finding effective and practical solutions `from the ground-up'.

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2017–2019 SOUTHERN REGIONAL CROPPING SOLUTIONS NETWORK (RCSN)

The RCSN initiative was established to identify priority grains industry issues and desired outcomes and assist the GRDC in the development, delivery and review of targeted RD&E activities, creating enduring profitability for Australian grain growers. The composition and leadership of the RCSNs ensures constraints and opportunities are promptly identified, captured and effectively addressed. The initiative provides a transparent process that will guide the development of targeted investments aimed at delivering the knowledge, tools or technology required by growers now and in the future. Membership of the RCSN network comprises growers, researchers, advisers and agribusiness professionals. The three networks are focused on farming systems within a particular zone – low rainfall, medium rainfall and high rainfall – and comprise 38 RCSN members in total across these zones.

REGIONAL CROPPING SOLUTIONS NETWORK SUPPORT TEAM

SOUTHERN RCSN CO-ORDINATOR: JEN LILLECRAPP

Jen is an experienced extension consultant and partner in a diversified farm business, which includes sheep, cattle, cropping and viticultural enterprises. Based at Struan in South Australia, Jen has a comprehensive knowledge of farming systems and issues affecting the profitability of grains production, especially in the high rainfall zone. In her previous roles as a district agronomist and operations manager, she provided extension services and delivered a range of training programs for local growers. Jen was instrumental in establishing and building the MacKillop Farm Management Group and through validation trials and demonstrations extended the findings to support growers and advisers in adopting best management practices. She has provided facilitation and coordination services for the high and medium rainfall zone RCSNs since the initiative's inception.

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LOW RAINFALL ZONE CO-LEAD: BARRY MUDGE

Barry has been involved in the agricultural sector for more than 30 years. For 12 years he was a rural officer/regional manager in the Commonwealth Development Bank. He then managed a family farming property in the Upper North of SA for 15 years before becoming a consultant with Rural Solutions SA in 2007. He is now a private consultant and continues to run his family property at Port Germein. Barry has expert and applied knowledge and experience in agricultural economics. He believes variability in agriculture provides opportunities as well as challenges and should be harnessed as a driver of profitability within farming systems. Barry was a previous member of the Low Rainfall RCSN and is current chair of the Upper North Farming Systems group.

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LOW RAINFALL ZONE CO-LEAD: JOHN STUCHBERY

John is a highly experienced, business-minded consultant with a track record of converting evidence-based research into practical, profitable solutions for grain growers. Based at Donald in Victoria, John is well regarded as an applied researcher, project reviewer, strategic thinker and experienced facilitator. He is the founder and former owner of JSA Independent (formerly John Stuchbery and Associates) and is a member of the SA and Victorian Independent Consultants group, a former FM500 facilitator, a GRDC Weeds Investment Review Committee member, and technical consultant to BCG-GRDC funded 'Flexible Farming Systems and Water Use Efficiency' projects. He is currently a senior consultant with AGRIvision Consultants.

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HIGH RAINFALL ZONE LEAD: CAM NICHOLSON

Cam is an agricultural consultant and livestock producer on Victoria's Bellarine Peninsula. A consultant for more than 30 years, he has managed several research, development and extension programs for organisations including the GRDC (leading the Grain and Graze Programs), Meat and Livestock Australia and Dairy Australia. Cam specialises in whole-farm analysis and risk management. He is passionate about up-skilling growers and advisers to develop strategies and make better-informed decisions to manage risk – critical to the success of a farm business. Cam is the program manager of the Woady Yaloak Catchment Group and was highly commended in the 2015 Bob Hawke Landcare Awards.

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MEDIUM RAINFALL ZONE LEAD: KATE BURKE

An experienced trainer and facilitator, Kate is highly regarded across the southern region as a consultant, research project manager, public speaker and facilitator. Based at Echuca in Victoria, she is a skilled strategist with natural empathy for rural communities. Having held various roles from research to commercial management during 25 years in the grains sector, Kate is now the managing director of Think Agri Pty Ltd, which combines her expertise in corporate agriculture and family farming. Previously Kate spent 12 years as a cropping consultant with JSA Independent in the Victorian Mallee and Wimmera and three years as a commercial manager at Warakirri Cropping Trust.

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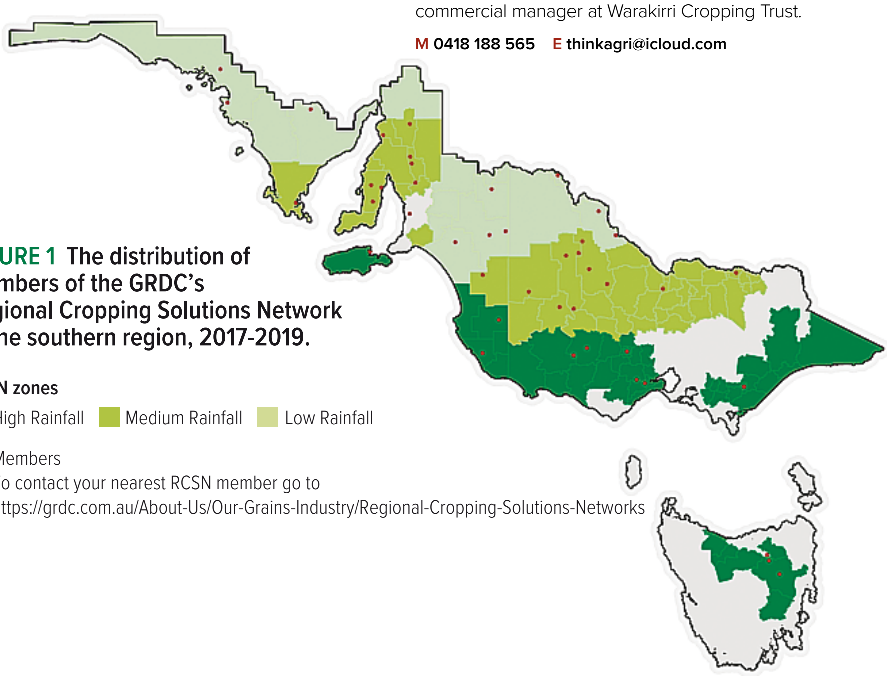

FIGURE 1 The distribution of members of the GRDC's Regional Cropping Solutions Network in the southern region, 2017-2019.

RCSN zones

🟩 High Rainfall 🟩 Medium Rainfall 🟩 Low Rainfall

● Members

To contact your nearest RCSN member go to https://grdc.com.au/About-Us/Our-Grains-Industry/Regional-Cropping-Solutions-Networks

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GRDC Grains Research Update BENDIGO

Acknowledgements

The ORM team would like to thank those who have contributed to the successful staging of the Bendigo GRDC Grains Research Update:

- The state GRDC Grains Research Update planning committee that includes both government and private consultants and the GRDC Southern Regional Panel members (see page 2 for list of contributors).
- Industry supporters that include:

  Adama Australia Pty Ltd
  Australian Grain Technologies (AGT)
  AEXCO
  Alosca Technologies
  Back Paddock Company
  BASF Australia Ltd
  Bayer Crop Science
  CeRDI - Federation Uni
  Decipher AgTech
  Heritage Seed
  Monsanto
  Nuseed Pty Ltd
  NSW DPI - extensionAUS
  Pioneer Seeds
  Seed Force Pty Ltd
  Seednet
  Syngenta Crop Protection Pty Ltd
  Yara Australia

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

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

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

www.surveymonkey.com/r/Bendigo-GRU

Notes

2018 Bendigo GRDC Grains Research Update
Evaluation

1. Name ☐

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

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

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

Your feedback on the presentations

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

DAY 1

3. The pulsating pulse – expansion of high value pulse crops: ***Ron Storey***

Content relevance ☐ /10 Presentation quality ☐ /10

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

☐

4. Collating and analysing small data to make big decisions: Can it improve farm productivity and profitability: ***Terry Griffin***

Content relevance ☐ /10 Presentation quality ☐ /10

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

☐

Concurrent sessions: please circle the session you saw, and review its content relevance and quality

5. 11.00 am	**Are the Russian forces building – what are our spies telling us:** *Maarten van Helden*	**Septoria tritici update and latest developments in powdery mildew:** *Nick Poole*	**Pulses - technical research supporting the expansion of pulse:** *Jason Brand*	**High rainfall wheat and barley review:** *Jon Midwood and Claudia Gebert*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

☐

6. 11.40 am	**Cereal disease update:** *Grant Hollaway*	**Fungicide resistance - recent discoveries pave way to better understanding the resistance mechanisms:** *Fran Lopez-Ruiz*	**Best options for optimal performance from inoculants:** *Matt Denton*	**Weather and seasonal forecasting - science or fiction?** *Dale Grey*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

7. 12.20 pm	**Septoria tritici update and latest developments in powdery mildew:** *Nick Poole*	**'On the couch' session:** *Ron Storey and Terry Griffin*	**Are the Russian forces building – what are our spies telling us:** *Maarten van Helden*	**The effects of stubble on nitrogen tie up and supply:** *Gupta Vadakkatu*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

LUNCH

8. 2.00 pm	**Canola - blackleg management update:** *Steve Marcroft*	**Best options for optimal performance from inoculants:** *Matt Denton*	**Weed warriors - update on brome grass and other emerging problems:** *Sam Kleemann*	**High rainfall wheat and barley review:** *Jon Midwood and Claudia Gebert*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

9. 2.40 pm	**Weather and seasonal forecasting - science or fiction?** *Dale Grey*	**Pulses - technical research supporting the expansion of pulses:** *Jason Brand*	**Cereal disease update:** *Grant Hollaway*	**Improving barley performance in the low rainfall zones:** *Linda Walters*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

10. 3.20 pm	**Fungicide resistance - recent discoveries pave way to better understanding the resistance mechanisms:** *Fran Lopez-Ruiz*	**'On the couch' session:** *Steve Marcroft*	**The effects of stubble on nitrogen tie up and supply:** *Gupta Vadakkatu*	**Weed warriors - update on brome grass and other emerging problems:** *Sam Kleemann*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

11. National variety trials update: ***Rob Wheeler***

Content relevance ☐ /10 Presentation quality ☐ /10

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

12. Long fallows maintain whole-farm profit and reduce risk in the Malleet: ***David Cann, student***

Content relevance ☐ /10 Presentation quality ☐ /10

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

13. Physiological and biochemical responses of lentils to silicon mediated drought tolerance: ***Sajitha Biju, student***

Content relevance ☐ /10 Presentation quality ☐ /10

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

14. Sustainable peak performance for advisers: ***Mark McKeon***

Content relevance ☐ /10 Presentation quality ☐ /10

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

Your next steps

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

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

DAY 2

17. Name

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

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

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

Your feedback on the presentations

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

Concurrent sessions: please circle the session you saw, and review its content relevance and quality

19. 9.00 am	**Canola diseases - sclerotinia in the spotlight:** *Kurt Lindbeck*	**Refining nitrogen placement in cereals - mid row banding:** *Ash Wallace*	**Insects, resistance and control :** *James Maino*	**Glyphosate update:** *Peter Boutsalis*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

20. 9.40 am	**Achieving the best blend of HWSC methods for your situation:** *Greg Condon*	**Critical agronomy management points for optimal canola growth:** *Rohan Brill*	**Agricultural machine technology – practical uses now and into the future:** *Steven Rees*	**Mice - learning from 2017? Looking to 2018:** *Peter Brown*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

21. 10.50 am	**Canola harvest management - new data busts myths:** *Maurie Street*	**Refining nitrogen placement in cereals - mid row banding:** *Ash Wallace*	**Filling the yield gap - Optimising yield and economic potential of high input cropping systems in the high rainfall zone:** *Malcolm McCaskill*	**Canola diseases - sclerotinia in the spotlight:** *Kurt Lindbeck*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

22. 11.30 am	**Critical agronomy management points for optimal canola growth:** *Rohan Brill*	**Mice - learning from 2017? Looking to 2018:** *Peter Brown*	**Insects, resistance and control:** *James Maino*	**Agricultural machine technology – practical uses now and into the future:** *Steven Rees*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

23. 12.10 pm	**Glyphosate update:** *Peter Boutsalis*	**Achieving the best blend of HWSC methods for your situation:** *Greg Condon*	**Canola harvest management - new data busts myths:** *Maurie Street*	**Filling the yield gap - Optimising yield and economic potential of high input cropping systems in the high rainfall zone:** *Malcolm McCaskill*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

PANEL

24. The art of communicating science and recognising the 'snake oil': ***Jenni Metcalfe***

Content relevance ☐ /10 Presentation quality ☐ /10

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

25. Herbicide resistance - where we are, where we are going and what can we do about it:
Chris Preston

Content relevance ☐ /10 Presentation quality ☐ /10

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

Your next steps

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

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

Your feedback on the Update

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

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

Comments

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

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

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

Comments

31. Overall, how did the Update event meet you expectations?

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

Comments

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

Thank you for your feedback.