GRAINS RESEARCH UPDATE

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

Adelaide

Adelaide Convention Centre,
North Terrace, Adelaide

#GRDCUpdates

2021 South Australian GRDC Grains Research Update planning committee

Michael Brougham	*Elders*
Simon Honner	*Honner Agribusiness*
Chris McDonough	*Insight Extension for Agriculture*
Darren Pech	*Elders*
Ashley Pilkington	*Adama*
Kenton Porker	*SARDI*
Richard Prusa	*Barenbrug*
Jake Rademacher	*Growers Supplies*
Steve Richmond	*Nutrien Ag Solutions*
Penny Roberts	*SARDI*
Darryn Schilling	*YP Ag*
Naomi Scholz	*AIR EP*
Mark Stanley	*Ag Excellence Alliance*
Nigel Wilhelm	*SARDI*

GRDC™
GRAINS RESEARCH & DEVELOPMENT CORPORATION

Adelaide GRDC Grains Research Update
convened by ORM Pty Ltd.

Additional copies of the proceedings can be ordered through ORM for $80 (including postage and GST)

ORM
46 Edward Street
PO Box 189
Bendigo VIC 3552

T 03 5441 6176
E admin@orm.com.au
W orm.com.au

CAUTION: RESEARCH ON UNREGISTERED PESTICIDE USE

Any research with unregistered pesticides or of unregistered products reported in this document does not constitute a recommendation for that particular use by the authors, the authors' organisations or the management committee. All pesticide applications must accord with the currently registered label for that particular pesticide, crop, pest and region.

DISCLAIMER - TECHNICAL

GRDC Welcome

GRDC 2021 Adelaide Grains Research Update Welcome

It is sometimes said that rather than procrastinating on making the right decisions, we should instead focus on making informed and timely decisions – and own and learn from the decisions we make.

Countless decisions collectively contribute towards a sustainable and profitable grains enterprise, but have you ever found yourself asking what really drives good decision making? Our decisions are informed by numerous and often complex factors (insert psychology and behavioural sciences disclaimer here) but key to sound decision making is access to relevant information and knowledge, supported by credible, trusted advice.

At the GRDC we pride ourselves in helping to inform the key profit driving decisions confronting grain growers and their advisers through investment in world-class science. Real impact, however, does not come from excellence in research alone but requires a focus upon awareness, extension and adoption of relevant solutions that demonstrate a clear value proposition. Success is highly dependent upon proper interpretation and excellence in implementation of new knowledge, practices and technologies by people like you. The GRDC Grains Research Updates provide a platform for this journey to begin or perhaps continue.

Whilst the past year has been extremely challenging for all Australians, the grains industry has demonstrated an outstanding ability to respond and work through the circumstances that have come with a global pandemic and associated challenges to trade, travel, access to labour and farm inputs. Perhaps this should not come as a surprise based on the ongoing resilience of grain growers in dealing with the unexpected through a requirement to anticipate, plan and respond to seasonal variability and risks that have become the 'new normal'.

While COVID-19 has also necessitated changes to the traditional Grains Research and Farm Business Updates series over the past year, this has brought with it opportunities to try new formats and methods of delivery. One of the changes for this year's Adelaide Update is the live streaming of presentations delivered from the main hall to ensure the information is available to all who need it regardless of personal circumstance and no matter where they are located.

The 2021 Grains Research Update program is once again jam-packed with high quality, locally relevant information to inform your decision making now and in the future.

The scene will be set on day one when we hear from Australian Export Grains Innovation Centre chief executive Richard Simonaitis, chief executive of the recently established Grains Australia Ltd Jonathan Wilson, and the GRDC's new Managing Director Anthony Williams – who will look at the big picture for Australian grains and the opportunities for growth through innovation and differentiation.

Continued innovation will be critical if Australia is to win against strong global competition. New and divergent thinking, approaches and partnerships will be required to access and deploy better solutions, faster. A number of GRDC Agtech Innovation initiatives are examples of this and, as part of the GRDC's

broader innovation strategy, aim to support the ag-tech start-up innovation ecosystem. This includes programs such as Growers as Innovators, Accelerator Program and Grain Innovate. You will learn more about some exciting developments in this space from various ag-tech start-ups through the GrainInnovate fund, established by GRDC and Artesian, as part of the 2021 program.

Each year, the Adelaide Update presents the very latest from the world of grains research and development. And despite the limitations imposed in 2020, an abundance of new technology, insights and results has been delivered over the past 12 months to ensure growers have at their disposal additional means to make a difference in their farming systems.

For example, you will be provided with the first results to emerge from the GRDC's National Phenology Initiative which will enhance understanding of crop phenology and the implications for varietal selection and management of risks around spring radiation frost and terminal heat stress.

The two-day program is loaded with the latest knowledge on all aspects of grain production – from management of weeds, pests and diseases through to soil and crop nutrition, agronomy and farming systems research.

To ensure the RD&E investments made by the GRDC on behalf of growers answer the most pressing profitability and productivity questions from the paddock, we continue to work closely with growers, advisers, agribusiness and others to understand and respond to deliver greatest impact. Through regionally based staff, a dedicated Regional Panel and broad regional networks, we are now more closely linked and better connected to industry than ever. So, if you have concerns, questions or feedback regarding the program or more generally, please contact the Southern team directly on 08 8198 8400 or email southern@grdc.com.au.

Craig Ruchs
Senior Regional Manager South

GRDC™
GRAINS RESEARCH & DEVELOPMENT CORPORATION

Connect with us

Keep in touch with us to find out about the latest RD&E, news and events.

Newsletter subscription

Twitter @GRDC

Facebook @GRDC

Instagram thegrdc

LinkedIn GRDC

GRDC™

PODCAST

GET THE LATEST INFO ON THE GO

The GRDC's podcast series features some of the grain sector's most pre-eminent researchers, growers, advisers and industry stakeholders sharing everything from the latest seasonal issues, to ground-breaking research and trial results with on-farm application.

https://grdc.com.au/news-and-media/audio

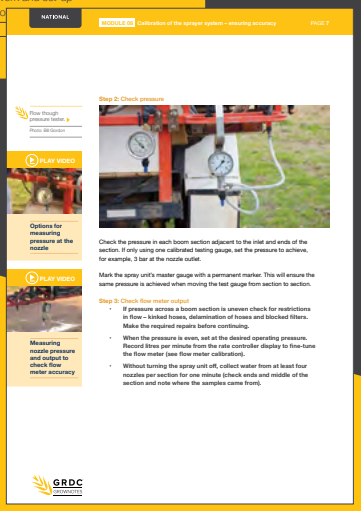
To subscribe to receive newsletters and publications and keep your details up-to-date visit the GRDC subscription centre:
www.grdc.com.au/subscribe

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

P Level 4 | 4 National Circuit, Barton ACT 2600 | PO Box 5367, Kingston ACT 2604 **T** +61 2 6166 4500 **F** +61 2 6166 4599
E grdc@grdc.com.au @theGRDC

GRDC™
GROWNOTES

SPRAY APPLICATION GROWNOTES™ MANUAL



SPRAY APPLICATION MANUAL FOR GRAIN GROWERS

The Spray Application GrowNotes™ Manual is a comprehensive digital publication containing all the information a spray operator needs to know when it comes to using spray application technology.

It explains how various spraying systems and components work, along with those factors that the operator should consider to ensure the sprayer is operating to its full potential.

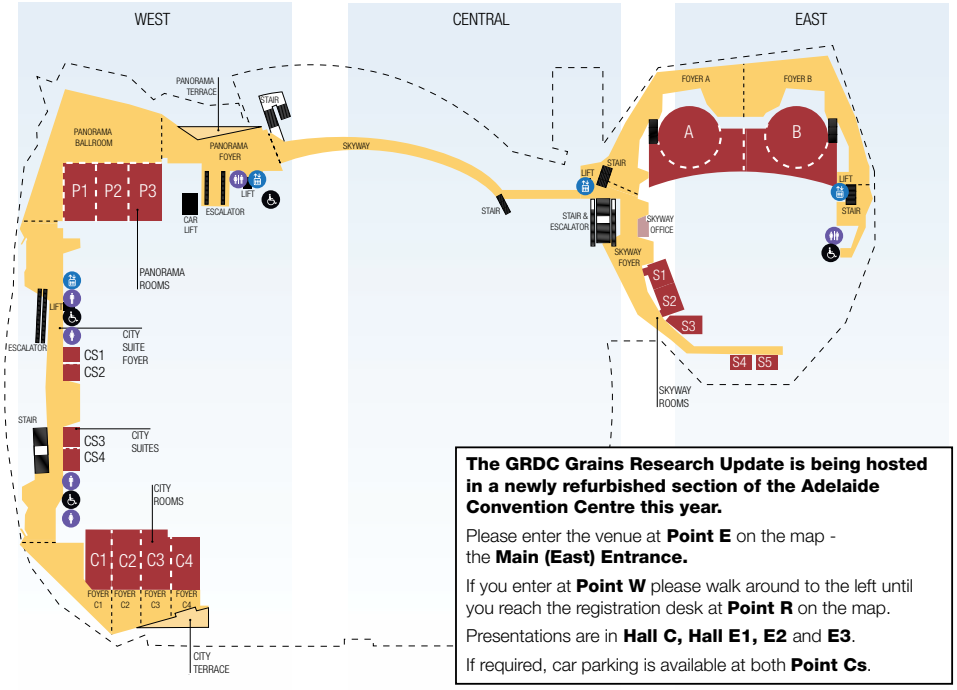
This new manual focuses on issues that will assist in maintaining the accuracy of the sprayer output while improving the efficiency and safety of spraying operations. It contains many useful tips for growers and spray operators and includes practical information – backed by science – on sprayer set-up, including self-propelled sprayers, new tools for determining sprayer outputs, advice for assessing spray coverage in the field, improving droplet capture by the target, drift-reducing equipment and techniques, the effects of adjuvant and nozzle type on drift potential, and surface temperature inversion research.

It comprises 23 modules accompanied by a series of videos which deliver 'how-to' advice to growers and spray operators in a visual easy-to-digest manner. Lead author and editor is Bill Gordon and other contributors include key industry players from Australia and overseas.

Spray Application GrowNotes™ Manual – go to: https://grdc.com.au/Resources/GrowNotes-technical Also go to https://grdc.com.au/Resources/GrowNotes and check out the latest versions of the Regional Agronomy Crop GrowNotes™ titles.

GRDC™
GRAINS RESEARCH & DEVELOPMENT CORPORATION

UPPER LEVEL



The GRDC Grains Research Update is being hosted in a newly refurbished section of the Adelaide Convention Centre this year.

Please enter the venue at **Point E** on the map - the **Main (East) Entrance.**

If you enter at **Point W** please walk around to the left until you reach the registration desk at **Point R** on the map.

Presentations are in **Hall C, Hall E1, E2** and **E3**.

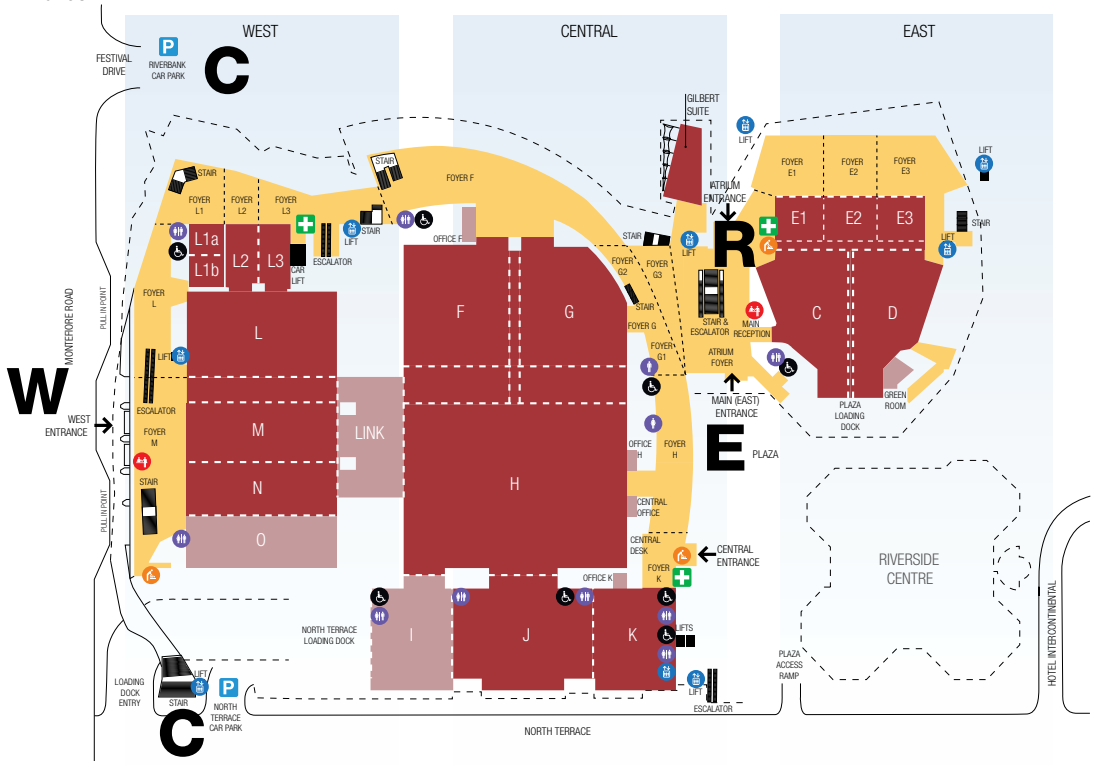
If required, car parking is available at both **Point Cs**.

ADELAIDE CONVENTION CENTRE

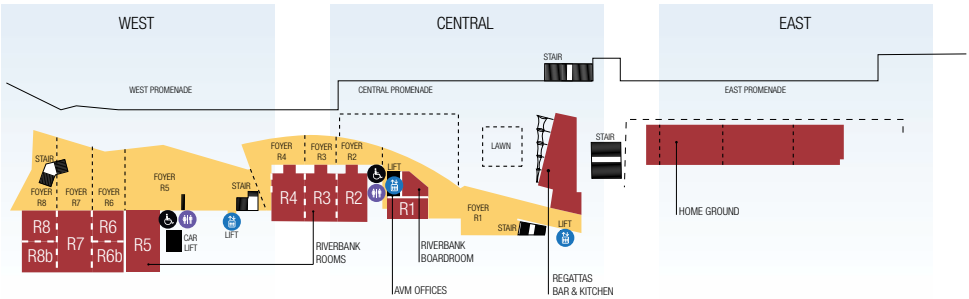
For more information visit www.adelaidecc.com.au

- RECEPTION
- LIFT
- TOILET
- ACCESS TOILET
- PARKING
- FIRST AID ROOM
- PARENT ROOM
- STAIRS & ESCALATORS
- FOYER
- FUNCTION AREA

GROUND LEVEL



LOWER LEVEL



N

0 5 10 20 30 40 50
SCALE

Aug 2018

Contents — DAY 1

OPENING SESSION

CONCURRENT SESSION

FINAL SESSION

Contents — DAY 2

EARLY RISERS SESSION

CONCURRENT SESSION

FINAL SESSION

FURTHER INFORMATION

PROGRAM DAY 1 - FEBRUARY 9th

8.55 am	**Announcements**	
9.05 am	**Extending the impact**	***Anthony Williams,*** *GRDC*
9.25 am	**Consolidating grains industry services and functions**	***Jonathan Wilson,*** *Grains Australia Ltd*
9.45 am	**Current market drivers and opportunities for Australian grain** - P15	***Richard Simonaitis,*** *AEGIC*
10.30 am	**Morning tea**	

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

	Hall C	Room E1	Room E2	Room E3
11.05 am	**The rise of glyphosate resistance (R)** - P 19 ***Peter Boutsalis,*** *University of Adelaide; Plant Science Consulting*	**Insecticide resistance – lessons to be learnt (R)** - P 27 ***Paul Umina,*** *cesar*	**Targeted amelioration in sandy soils to maximise crop water use (R)** - P37 ***Lynne Macdonald,*** *CSIRO*	**Know the new 'lingo' from the National Phenology Initiative** - P45 ***Corinne Celestina,*** *La Trobe University*
11.45 am	**Blackleg infection of canola – latest developments and yield impacts from foliar fungicide use (R)** - P 51 ***Steve Marcroft,*** *Marcroft Grains Pathology*	**Measuring impact of inoculation with a new rhizobia testing tool (R)** - P 57 ***Ross Ballard,*** *SARDI*	**The agronomic value of precision planting technologies** - 65 ***Glenn McDonald,*** *University of Adelaide*	**Maximising benefits from vetch in our farming systems (R)** - P 77 & 83 ***Stuart Nagel,*** *SARDI*
12.25 pm	**Wins and tribulations of chaff lining as a weed reduction tool (R)** - P89 ***Chris Davey,*** *WeedSmart*	**Revised critical soil test values for key nutrients across different soil & break crop types** - P93 ***Nigel Wilhelm,*** *SARDI*	**Insecticide resistance – lessons to be learnt** - P 27 ***Paul Umina,*** *cesar*	**Improving lentil performance on sandy soils (R)** - P 99 ***Sam Trengove,*** *Trengove Consulting*

1.00 pm **LUNCH**

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

	Hall C	Room E1	Room E2	Room E3
2.00 pm	**Targeted amelioration in sandy soils to maximise crop water use** - P 37 ***Lynne Macdonald,*** *CSIRO*	**Nitrogen fertiliser use efficiency rules of thumb put to the test (R)** - P 109 ***Roger Armstrong,*** *Agriculture Victoria*	**Drivers of insect pressure and new management tools for troublesome insects (R)** - P 119 ***Rebecca Hamdorf,*** *SARDI*	**Wins and tribulations of chaff lining as a weed reduction tool** - P 89 ***Chris Davey,*** *WeedSmart*
2.40 pm	**Latest knowledge on treatment of soil acidification** - P 127 ***Brian Hughes,*** *PIRSA*	**Improving lentil performance on sandy soils** - P 99 ***Sam Trengove,*** *Trengove Consulting*	**Maximising benefits from vetch in our farming systems** - P 77 & 83 ***Stuart Nagel,*** *SARDI*	**Blackleg infection of canola – latest developments and yield impacts from foliar fungicide use** - P 51 ***Steve Marcroft,*** *Marcroft Grains Pathology*
3.20 pm	**Nitrogen fertiliser use efficiency rules of thumb put to the test** - P 109 ***Roger Armstrong,*** *Agriculture Victoria*	**Drivers of insect pressure and new management tools for troublesome insects** - P 119 ***Rebecca Hamdorf,*** *SARDI*	**Measuring impact of inoculation with a new rhizobia testing tool** - P 57 ***Ross Ballard,*** *SARDI*	**The rise of glyphosate resistance** - P 19 ***Peter Boutsalis,*** *University of Adelaide; Plant Science Consulting*

3.55 pm **AFTERNOON TEA**

4.25 pm **GrainInnovate - innovation through disruption** - P 139, 141 & 143

Fernando Felquer, *GRDC*; ***Rob Williams,*** *Artesian*; ***Andrew Bate,*** *SwarmFarm*; ***Marcus Kennedy,*** *Telesense Aust and* ***Marie Marion,*** *FluroSat*

5.25 pm **COMPLIMENTARY DRINKS & FOOD IN TRADE DISPLAY AREA**

On Twitter? Follow **@GRDCSouth** and use the hashtag **#GRDCUpdates** to share key messages

PROGRAM DAY 2 - FEBRUARY 10th

8.15 am **EARLY RISERS: Enabling technologies** - P 151 ***Tom Giles,*** *GRDC and* ***Tom Bishop,*** *University of Sydney*

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

	Hall C	Room E1	Room E2	Room E3
9.00 am	**Achieving the big yields** - P 165 ***Eric Watson,*** *Ashburton, NZ wheat grower &* ***Nick Poole,*** *FAR Australia*	**The health report - pulse disease update (R)** - P 173 & 183 ***Sara Blake*** *&* ***Blake Gontar,*** *SARDI*	**Phosphorus application recommendations based on soil characterised zones and testing - does it pay? (R)** - P 193 ***Sean Mason,*** *Agronomy Solutions*	**Reducing input costs without compromising pulse production potential (R)** - P 199 ***Sarah Day,*** *SARDI*
9.40 am		**To spray or not to spray – what does the Russian Wheat Aphid threshold calculator advise? (R)** - P 207 ***Maarten Van Helden,*** *SARDI*	**Frost mapping – a future management tool** - P 215 ***Uday Nidumolu,*** *CSIRO*	**Cereal disease wrap up (R)** - P 217 & 223 ***Tara Garrard,*** *SARDI &* ***Sam Trengove,*** *Trengove Consulting*
10.20 am	**MORNING TEA**			
10.50 am	**Novel agronomy strategies for improving yield (R)** - P 231 & 237 ***Kenton Porker,*** *SARDI*	**Integration of non-chemical tactics to improve brome grass management (R)** - P 245 ***Gurjeet Gill,*** *The University of Adelaide*	**Latest management tactics for snail control** - P 251 ***Kym Perry,*** *SARDI*	**Reducing input costs without compromising pulse production potential** - P 199 ***Sarah Day,*** *SARDI*
11.30 am	**GM technology - farming system learnings from WA** - P 257 ***Geoff Fosbery,*** *Farm Focus Consultants*	**Phosphorus application recommendations based on soil characterised zones and testing - does it pay?** - P 193 ***Sean Mason,*** *Agronomy Solutions*	**The health report - pulse disease update** - P 173 & 183 ***Sara Blake*** *&* ***Blake Gontar,*** *SARDI*	**Cereal disease wrap up** - P 217 & 223 ***Tara Garrard,*** *SARDI &* ***Sam Trengove,*** *Trengove Consulting*

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

	Hall C	Room E1	Room E2	Room E3
12.10 pm	**To spray or not to spray – what does the Russian Wheat Aphid threshold calculator advise?** - P 207 ***Maarten Van Helden,*** *SARDI*	**Integration of non-chemical tactics to improve brome grass management** - P 245 ***Gurjeet Gill,*** *The University of Adelaide*	**Use of chemicals and residues arising - impact, understanding and potential trade issues** - P 263 ***Gerard McMullen,*** *National Working Party on Grain Protection*	**Novel agronomy strategies for improving yield** - P 231 & 237 ***Kenton Porker,*** *SARDI*

12.50 pm **LUNCH**

1.30 pm **Keeping the glyphosate option - the state of play** - P 269 & 273 — ***Katie Asplin,*** *CropLife Australia*

2.10 pm **Herbicide forum - experiences fitting the new chemistries into the farming system** - P 277 — ***Chris Preston,*** *The University of Adelaide;* ***George Pedler,*** *George Pedler AG;* ***Jeff Braun,*** *The Agronomist P/L and* ***Scott Hutchings,*** *Cox Rural Keith*

2.50 pm **CLOSE AND EVALUATION**

On Twitter? Follow **@GRDCSouth** and use the hashtag **#GRDCUpdates** to share key messages

LOOK AROUND YOU.

1 in 5 people in rural Australia are currently experiencing mental health issues.

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

The GRDC supports the mental wellbeing of Australian grain growers and their communities. Are you ok? If you or someone you know is experiencing mental health issues call *beyondblue* or Lifeline for 24/7 crisis support.

beyondblue
1300 22 46 36
www.beyondblue.org.au

beyondblue
Depression. Anxiety.

Lifeline
13 11 14
www.lifeline.org.au

Lifeline
13 11 14

Looking for information on mental wellbeing? Information and support resources are available through:

www.ifarmwell.com.au An online toolkit specifically tailored to help growers cope with challenges, particularly things beyond their control (such as weather), and get the most out of every day.

www.blackdoginstitute.org.au The Black Dog Institute is a medical research institute that focuses on the identification, prevention and treatment of mental illness. Its website aims to lead you through the logical steps in seeking help for mood disorders, such as depression and bipolar disorder, and to provide you with information, resources and assessment tools.

www.crrmh.com.au The Centre for Rural & Remote Mental Health (CRRMH) provides leadership in rural and remote mental-health research, working closely with rural communities and partners to provide evidence-based service design, delivery and education.

Glove Box Guide to Mental Health
The *Glove Box Guide to Mental Health* includes stories, tips, and information about services to help connect rural communities and encourage conversations about mental health. Available online from CRRMH.

www.rrmh.com.au Rural & Remote Mental Health run workshops and training through its Rural Minds program, which is designed to raise mental health awareness and confidence, grow understanding and ensure information is embedded into agricultural and farming communities.

www.cores.org.au CORES™ (Community Response to Eliminating Suicide) is a community-based program that educates members of a local community on how to intervene when they encounter a person they believe may be suicidal.

www.headsup.org.au Heads Up is all about giving individuals and businesses tools to create more mentally healthy workplaces. Heads Up provides a wide range of resources, information and advice for individuals and organisations – designed to offer simple, practical and, importantly, achievable guidance. You can also create an action plan that is tailored for your business.

www.farmerhealth.org.au The National Centre for Farmer Health provides leadership to improve the health, wellbeing and safety of farm workers, their families and communities across Australia and serves to increase knowledge transfer between farmers, medical professionals, academics and students.

www.ruralhealth.org.au The National Rural Health Alliance produces a range of communication materials, including fact sheets and infographics, media releases and its flagship magazine *Partyline*.

ifarmwell growing farmers' wellbeing

Black Dog Institute

Centre for Rural & Remote Mental Health

CORES™

Rural & Remote Mental Health

Heads up
Better mental health in the workplace

NATIONAL CENTRE FOR FARMER HEALTH

NATIONAL RURAL HEALTH ALLIANCE LTD

P Level 4 | 4 National Circuit, Barton ACT 2600 | PO Box 5367, Kingston ACT 2604 **T** +61 2 6166 4500 **F** +61 2 6166 4599 **E** grdc@grdc.com.au

Global opportunities for Australian grains

Richard Simonaitis.

Australian Export Grains Innovation Centre (AEGIC).

Keywords

- markets, opportunities, domestic, export.

Take home messages

- Domestic and export grain markets are dynamic and evolving.
- What are the market signals and drivers shaping the future of the grains industry.
- There are specific opportunities globally for Australian grains.
- AEGIC works to increase value in the Australian grains industry and this work informs the industry in how to participate in these opportunities.

Grain markets, both domestic and export are driven by macro drivers and more aspirational drivers. As markets evolve, populations transition and consumer preferences change, it is important that the Australian grains industry understands the threats and opportunities that this presents us with.

Market signals from customers and drivers from consumers are measurable and to some degree predictable into the future. How can we understand these things and work together as an industry to make the most of opportunities that are available and can be developed, to anticipate threats and to position ourselves for the future demands of our markets?

AEGIC shares its market insights to help inform the industry of the factors shaping current and future market opportunities for Australian grains.

Acknowledgements

AEGIC is an initiative of the Grains Research and Development Corporation and the Department of Primary Industries and Regional Development in Western Australia. The research undertaken by AEGIC 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.

Contact details

Richard Simonaitis
richard.simonaitis@aegic.org.au

Return to contents

Notes

GRDC™

GRAINS RESEARCH
& DEVELOPMENT
CORPORATION

Concurrent session
Day 1

NEW BOOK FOR LOW RAINFALL GROWERS IN AUSTRALIA

IS CTF WORTHWHILE IN THE LRZ?

This new publication addresses common questions about CTF in the LRZ, such as:

- » DO LRZ SOILS SELF-REPAIR OR IS AMELIORATION WORK NEEDED?
- » IS CTF FEASIBLE IN LOW INTENSITY SYSTEMS WITH VERY WIDE MACHINES?
- » DOES CTF REDUCE POWER AND FUEL USE IN LIGHT LRZ SOILS?
- » IS CTF COMPATIBLE WITH LIVESTOCK IN THE SYSTEM?

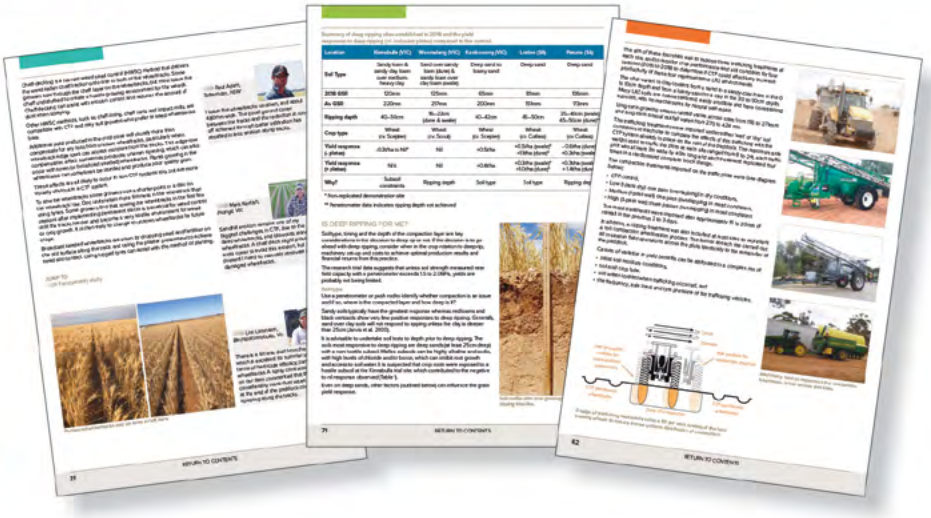
DOWNLOAD YOUR COPY OF THIS NEW RESOURCE FROM grdc.com.au or actfa.net

http://bit.ly/LRZ-CTF

YOU'LL FIND:

- » Practical guides
- » Grower experience
- » Research findings
- » Study investigations

all relevant to the implementation of Controlled Traffic Farming in Low Rainfall Zones



Glyphosate resistant annual ryegrass update - 2020 season

Peter Boutsalis[1,2], Sam Kleemann[2] and Christopher Preston[1].

[1]School of Agriculture, Food & Wine, University of Adelaide; [2]Plant Science Consulting P/L.

GRDC project code: UCS00020

Keywords

- glyphosate resistance, annual ryegrass, optimising control, testing, random weed survey, double knock.

Take home messages

- Glyphosate resistance in annual ryegrass continues to increase.
- There are ways to optimise glyphosate efficacy.
- Partner glyphosate with other herbicides to improve weed control.

Incidence of glyphosate resistance

The GRDC continues to support random weed surveys in cropping regions to monitor for changes in resistance levels in key weed species. The methodology involves collecting weed seeds from paddocks chosen randomly at pre-determined distances. Plants are tested in outdoor pot trials during the growing season. Resistance is defined as a sample where ≥20% plant survival was detected in a pot trial. The incidence of glyphosate resistance identified in paddocks in different cropping regions across South Australia (SA) and Victoria (Vic) from random weed surveys is presented in Figure 1.

Additionally, Bayer CropScience provides access to a significant database (Resistance tracker, https://www.crop.bayer.com.au/tools/mix-it-up/resistance-tracker) which contains data from commercial testing companies. This tool searches herbicide resistance for numerous weed species by postcode and year, with data collated over the past 15 to 20 years.

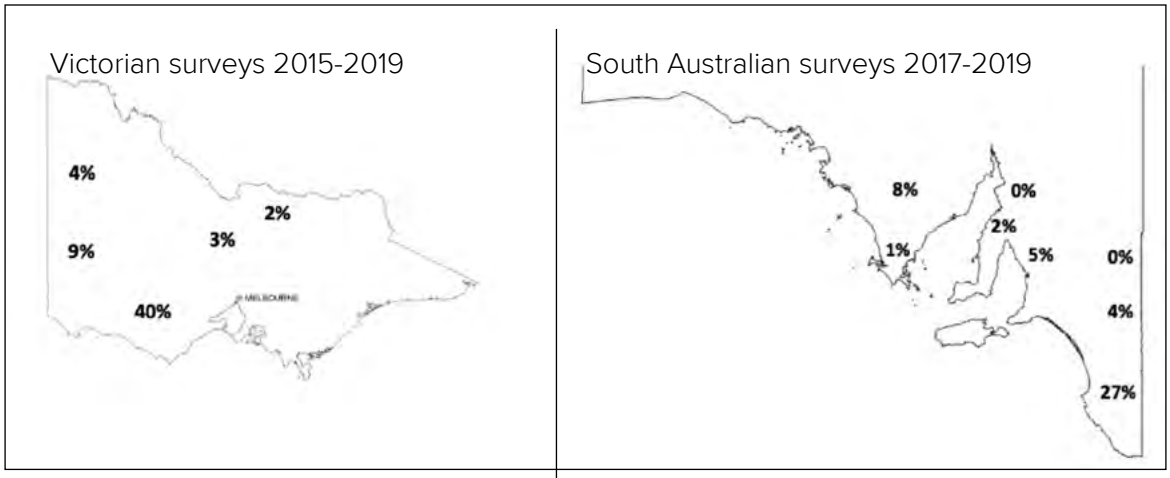


Figure 1. Incidence of paddocks containing glyphosate resistant ryegrass. Resistance is defined as a sample where ≥20% plant survival was detected in a pot trial.

2020 season

The early break in 2020 across most southern cropping regions resulted in an opportunity for knockdown weed control. Multiple applications of glyphosate and paraquat were possible targeting multiple flushes of weeds, in particular ryegrass from early autumn prior to sowing. Plants surviving following glyphosate application from Western Australia (WA), SA, Vic and New South Wales (NSW) were sent to Plant Science Consulting for testing using the Quick-Test method to verify whether herbicide resistance had contributed to survival in the field. The data presented in Figure 2 indicates that 43%, 70% and 79% of ryegrass samples sent from SA, Vic and NSW in 2020 respectively, were confirmed resistant to glyphosate. This highlights that in most cases, glyphosate resistance has contributed to reduced control in the paddock.

Discrepancy between resistance testing and paddock failures to glyphosate

In some cases, plants that have survived glyphosate application in the paddock are not resistant. Reasons for the discrepancy between paddock observations and a resistance test result can include poor application, application onto stressed plants, incorrect timing, sampling plants that were not exposed to glyphosate or a combination of the above.

Evolution of glyphosate resistance

Glyphosate was first registered in the 1970s and rapidly became the benchmark herbicide for non-selective weed control. Resistance was not detected until 1996 in annual ryegrass in an orchard in southern NSW (Powles *et al.* 1998). Only a few cases of resistance were detected in the following decade (refer to Bayer Resistance Tracker). The fact that it required decades of repeated use before resistance was confirmed indicated that the natural frequency of glyphosate resistance was initially very low. At the current time there are over a dozen species that have developed resistance to glyphosate in Australia (https://www.croplife.org.au/resources/programs/resistance-management/herbicide-resistant-weeds-list-draft-3/). The most important species are ryegrass, sowthistle, barnyard grass and feathertop Rhodes grass. Ryegrass and sowthistle will be discussed further within this paper.

There are several contributing factors for the increasing glyphosate resistance in ryegrass with generally more than one factor responsible. Reducing rates can increase the development of resistance particularly in an obligate outcrossing species such as ryegrass resulting in the accumulation of weak resistance mechanisms to create individuals capable of surviving higher rates. This has been confirmed by Dr Chris Preston where ryegrass hybrids possessing multiple resistance mechanisms were generated by crossing parent plants with different resistance mechanisms.

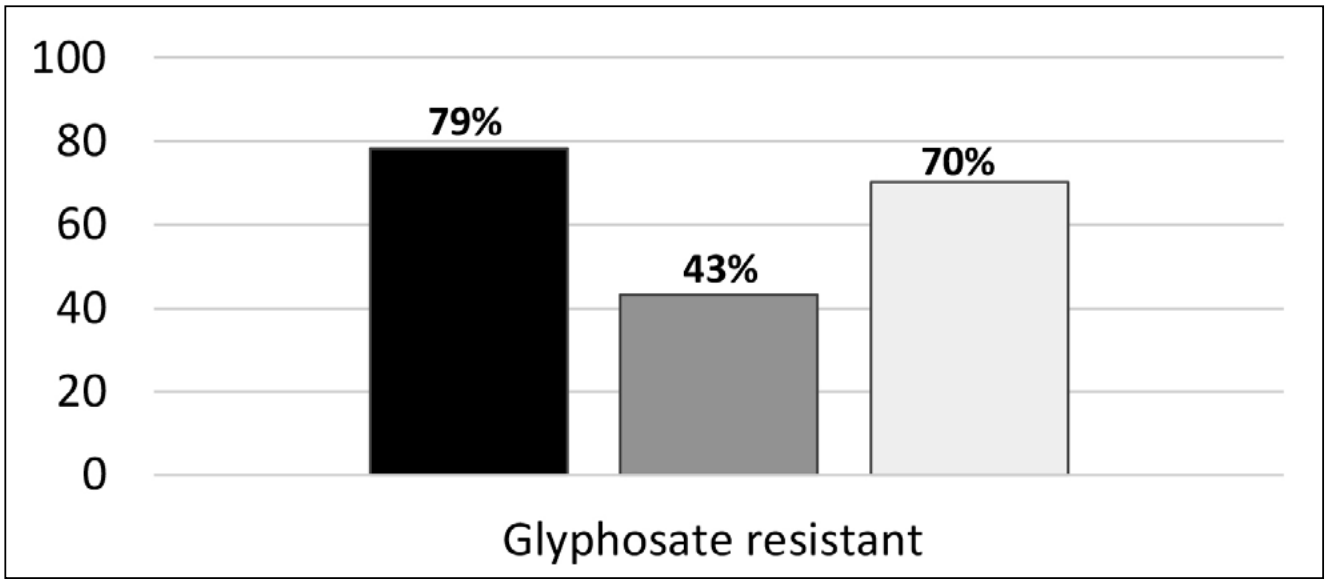


Figure 2. Percent (%) resistance to glyphosate confirmed in farmer ryegrass samples originating from 83 New South Wales, 37 South Australian and 74 Victorian cropping paddocks treated with glyphosate in autumn 2020. Testing conducted by Plant Science Consulting using the Quick-Test.

Other factors that can select for glyphosate resistance by reducing efficacy include:

1. Using low quality glyphosate products and surfactants.
2. Mixing glyphosate with too many other active ingredients resulting in antagonism, particularly in low water volumes.
3. Using low quality water, particularly hard water. Glyphosate is a weak acid, and therefore, binds to positive cations (e.g., magnesium, calcium and bicarbonate) that are in high concentration in hard water (i.e., >200 ppm),
4. Applying glyphosate during periods of high temperature and low humidity, resulting in the rapid loss of glyphosate in solution from leaf surfaces, thereby reducing absorption.
5. Applying glyphosate onto stressed plants can reduce translocation. Maximising glyphosate efficacy relies on translocation to the root and shoot tips. While this occurs readily in small seedlings, in larger plants, glyphosate is required to translocate further to the root and shoot tips to provide high levels of control.
6. Shading effects that reduce leaf coverage resulting in sub-lethal effects.
7. As glyphosate strongly binds to soil particles, application of glyphosate onto dust covered leaves can reduce efficacy.
8. Application factors such as speed, nozzle selection and boom height can reduce the amount of glyphosate coverage.
9. A combination of the above factors can reduce control, thereby increasing the selection for resistance.

Optimising glyphosate performance

The selection of glyphosate resistance can be reduced by considering the points mentioned previously. Additionally, there are a number of important pathways to follow to improve glyphosate performance including:

1. Avoid applying glyphosate under hot conditions. A trial spraying ryegrass during the end of a hot period and following a cool change was conducted in October 2019. Ryegrass growing in pots was sprayed at 8am, 1pm and 8pm with temperature and Delta T recorded prior to each application. Control of well hydrated plants ranged between 0% and 40% when glyphosate was applied during hot weather (30 to 32.5°C) and high Delta T (14 to 16.7) with the lowest control achieved when glyphosate was applied at midday (Figure 3). In contrast, glyphosate applied under cool conditions just after a hot spell resulted in significantly greater control (65%-80%), indicating that plants can rapidly recover from temperature stress provided moisture is not limiting, e.g., after rainfall.

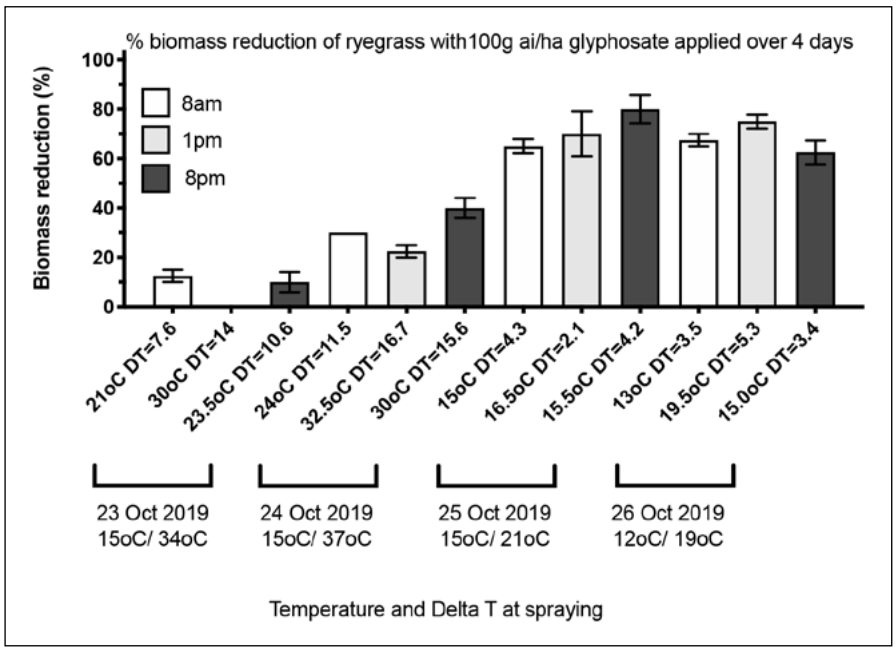


Figure 3. Effect of temperature and Delta T on glyphosate for ryegrass control.

2. Improving water quality and glyphosate activity by using ammonium sulfate (AMS). The addition of AMS has several functions. One is to soften water by combining to positively charged ions such as magnesium and calcium common in hard water. The negative charged sulphate ions combine with the positive cations preventing them from interacting with glyphosate and reducing its solubility and leaf penetration. Additionally, AMS has been shown to independently improve glyphosate performance, as the ammonium ions can work with glyphosate to increase leaf uptake. In a pot trial conducted with soft water, AMS was shown to significantly improve control of ryegrass with 222ml/ha (100g ai/ha) of glyphosate 450 (Figure 4). As a general rule, growers using rainwater (soft) should consider 1% AMS, if using hardwater (i.e., bore, dam water), 2% AMS is recommended. The addition of a wetter resulted in a further improvement in control.

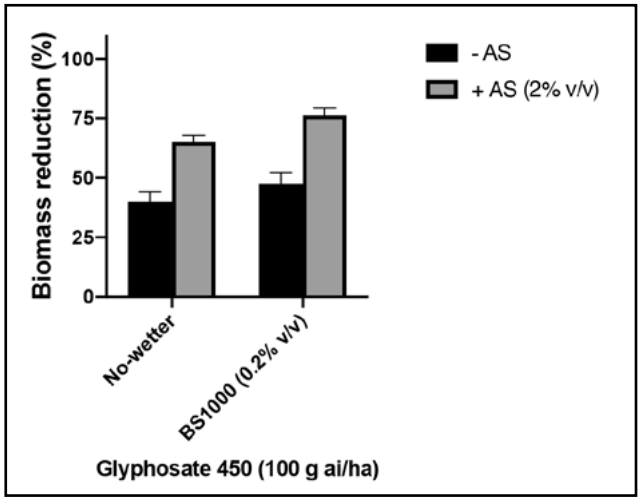


Figure 4. Effect of ammonium sulfate(AS) and wetter (BS1000) on glyphosate performance for ryegrass control.

3. Herbicide activity can vary at different growth stages. In a pot trial investigating the effect of glyphosate at four ryegrass growth stages (1-leaf to 4-tiller), good control was achieved at the three older growth stages but not on 1-leaf ryegrass (Figure 5). Most glyphosate labels do not recommend application of glyphosate on 1-leaf ryegrass seedlings because they are still relying on seed reserves for growth. Consequently, very little glyphosate moves towards the roots.

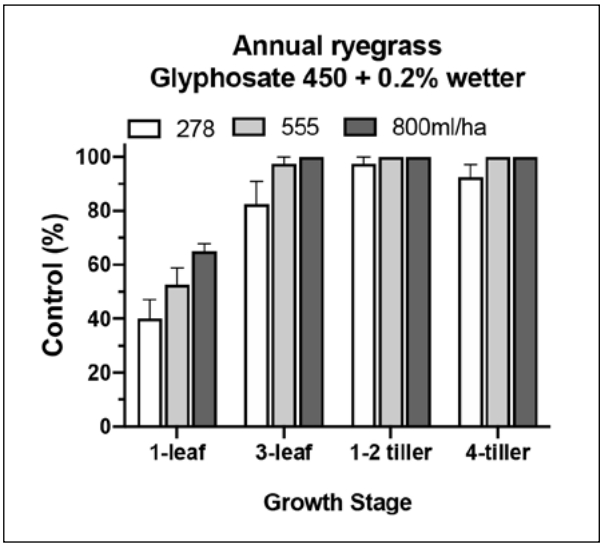


Figure 5. Effect of ryegrass growth stage on glyphosate activity.

A double knock strategy is defined as the sequential application of two weed control tactics to combat the same weed population. The most common double knock strategy is glyphosate followed by paraquat. It has been widely adopted to prevent or combat glyphosate resistance, particularly in ryegrass. The first 'knock' with glyphosate is aimed to control most of the population with the second 'knock' (paraquat) intended to kill any individuals that have survived glyphosate. In the presence of glyphosate resistance, paraquat applied one to five days following glyphosate was shown to provide optimum control in trial work conducted by Dr Christopher Preston (Figure 6). The timing depends on weed size and growing conditions, with three to five days required to maximise glyphosate activity. After a week (depending on environmental conditions) glyphosate resistant plants treated with glyphosate can stress, resulting in the absorption of less paraquat, reducing control with the second tactic. If growing conditions are poor or plants large, the stress imposed by glyphosate maybe further delayed.

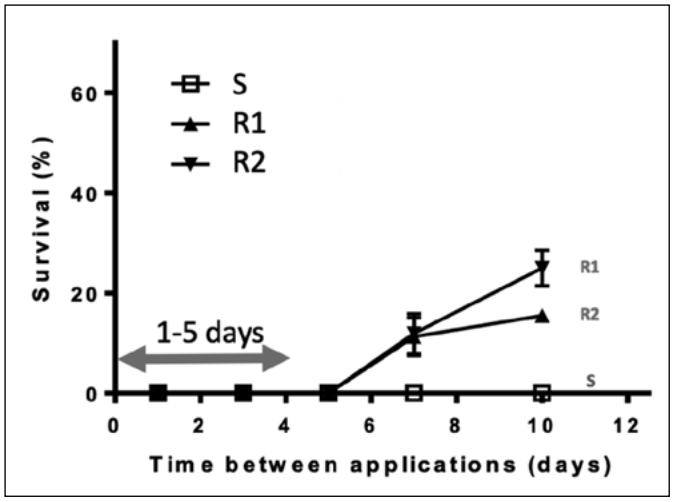


Figure 6. Double knock timing and its effect on ryegrass survival rate. Glyphosate applied onto a susceptible (S) and two glyphosate resistant ryegrass biotypes (R1 and R2) followed by paraquat 1, 3, 5, 7 and 10 days after application (DAA). (Source: Trial work conducted by Dr Christopher Preston (The University of Adelaide)).

Summary

In the southern cropping zone, glyphosate resistance in ryegrass continues to increase as indicated by random weed surveys across the region and the Bayer Resistance Tracker database. The early break in autumn 2020 resulted in the targeted testing of about 200 ryegrass populations prior to sowing with over half confirmed resistant to glyphosate. Although it took about 20 years after the registration of glyphosate for the first case of resistance to be confirmed, in the past 10 years there has been an exponential rise in the number of confirmed cases. Decades of strong selection pressure resulting from repeated use, coupled with application under suboptimum conditions has played a major role in the exponential rise. More efficient use of glyphosate combined with effective integrated weed management (IWM) strategies is required to reduce further increases in resistance.

Acknowledgements

The information for the random weed surveys was undertaken as part of GRDC project UCS00020, and therefore, is made possible by the significant contributions of growers through the support of the GRDC, the author would like to thank them for their continued support.

Contact details

Peter Boutsalis
Plant Science Consulting P/L
www.plantscienceconsulting.com.au
@PBoutsalis

Peter Boutsalis
University of Adelaide, Waite Campus,
Glen Osmond SA 5064
peter.boutsalis@adelaide.edu.au

Return to contents

Notes

Notes

Notes

Pesticide resistance in Australian grain regions – lessons to be learnt

Leo McGrane[1], Francesca Noakes[1], Paul A. Umina[1,2], James Maino[1], Jessica Lye[1] and Aston Arthur[1].

[1]cesar Australia; [2]University of Melbourne.

GRDC project codes: CES00003, UM00057, CES2001-001RTX, CES2001, CES2010-001RTX

Keywords

- redlegged earth mite, green peach aphid, pesticide resistance, resistance management strategy, integrated pest management.

Take home messages

- An over-reliance on broad-spectrum pesticides, and a limited number of registered chemicals available, creates strong selection pressure for resistance in grain pests.
- The redlegged earth mite (*Halotydeus destructor*; RLEM) and the green peach aphid (*Myzus persicae*; GPA) are two important grain pests that have evolved resistance to multiple pesticide groups in Australia. Surveillance demonstrates that resistance is expanding, highlighting the need for a reassessment of management approaches.
- Taking an integrated approach to pest management limits the need for prophylactic pesticide applications by utilising biological and cultural control options, thereby reducing the likelihood of further pesticide resistance evolution.
- Adoption of resistance management strategies (RMSs), and principles described in recently developed best management practice guides (BMPGs), will reduce selection for resistance and prolong the long-term viability of chemical control.

Background

Within the Australian grains industry, increasing cases of pesticide resistance and diminishing chemical options available to growers is necessitating a renewed focus on pest management practices. Several important invertebrate pests of grain crops have evolved pesticide resistance in Australia. These include *Helicoverpa armigera* (cotton bollworm), *Plutella xylostella* (diamondback moth), *Myzus persicae* (green peach aphid, GPA) and *Halotydeus destructor* (redlegged earth mite, RLEM) (for overview, see Umina *et al.* 2019). Most of these species have evolved resistance to multiple chemical classes both in Australia and overseas. Recent forecasting, described in McDonald *et al.* (2019), has further identified several important grains pests at high risk of evolving resistance in the future (including *Bryobia* mite and Lucerne flea) which currently have no known resistances to pesticides in Australia.

This paper focuses on the evolution of pesticide resistance in RLEM and GPA in Australia, describing current research and reporting on recent resistance detection work. Also presented is the research examining the responses of *Bryobia* mite species to different pesticides. Finally, integrated approaches to pest management that could limit prophylactic pesticide applications are discussed.

Pesticide trends

A key driver of increased pesticide resistance in Australian grain regions is the over-reliance on a limited number of chemical Mode of Action groups; Group 1 (carbamates 1A and organophosphates),

Group 3A (pyrethroids) and Group 4A (neonicotinoids) (Umina *et al.* 2019). This over-reliance is underpinned by a number of factors. The large, mechanised nature of Australian grain farms and a zero-tolerance stance for live invertebrates in grain exports has led to the necessity of controlling pest outbreaks on farms. Furthermore, the climatic variability of many Australian grain growing regions makes it difficult to judge the risk of pest outbreaks, often leading to the application of 'insurance sprays'.

In recent years, costs associated with developing a new pesticide have increased exponentially, while the rate of successful development of new pesticides has decreased (Figure 1). A lack of new chemical actives being registered to the Australia market has intensified the use of existing options for RLEM and GPA.

Resistance in the redlegged earth mite

The RLEM is one of the most destructive and economically important pests of winter grain crops and pastures in southern Australia. It is particularly damaging at the establishment phase of plants in autumn (Ridsdill-Smith *et al.* 2008; Umina and Hoffmann 2004). Resistance to synthetic pyrethroids in RLEM was first detected in Western Australia (WA) in 2006, followed by the detection of organophosphate resistance in 2014 (Maino *et al.* 2018; Umina 2007; Umina *et al.* 2012; Umina *et al.* 2017). The continued detection of resistant populations in new regions, such as South Australia (SA) and Victoria (Vic), has resulted in a reassessment of management approaches for this pest.

Control of RLEM currently relies heavily on the application of pesticides through contact sprays or seed treatments (Ridsdill-Smith *et al.* 2008; Umina *et al.* 2017). There are currently five chemical Mode of Action groups registered for control of RLEM in Australia; organophosphates (Group 1B), fiproles (Group 2B), synthetic pyrethroids (Group 3A), neonicotinoids (Group 4A) and diafenthiuron (Group 12A) (APVMA, 2020). Of these, growers rely heavily on three; organophosphates, synthetic pyrethroids and neonicotinoids (Umina *et al.* 2019) (Figure 2).

Redlegged earth mite resistance surveillance and mapping

Since the first detection of pyrethroid resistance in RLEM in 2006, resistance surveillance, supported by GRDC investment, has been undertaken on a yearly basis. This has resulted in 1029 populations being tested over the last 13 years. One hundred and ninety-five RLEM populations have now been detected with pyrethroid resistance, 59 populations have been detected with organophosphate resistance and 24 populations with resistance to both chemical groups (Table 1). Surveillance has covered a wide geographical range throughout Western and eastern Australia, covering a large portion of the entire known Australian distribution of RLEM (Figure 3).

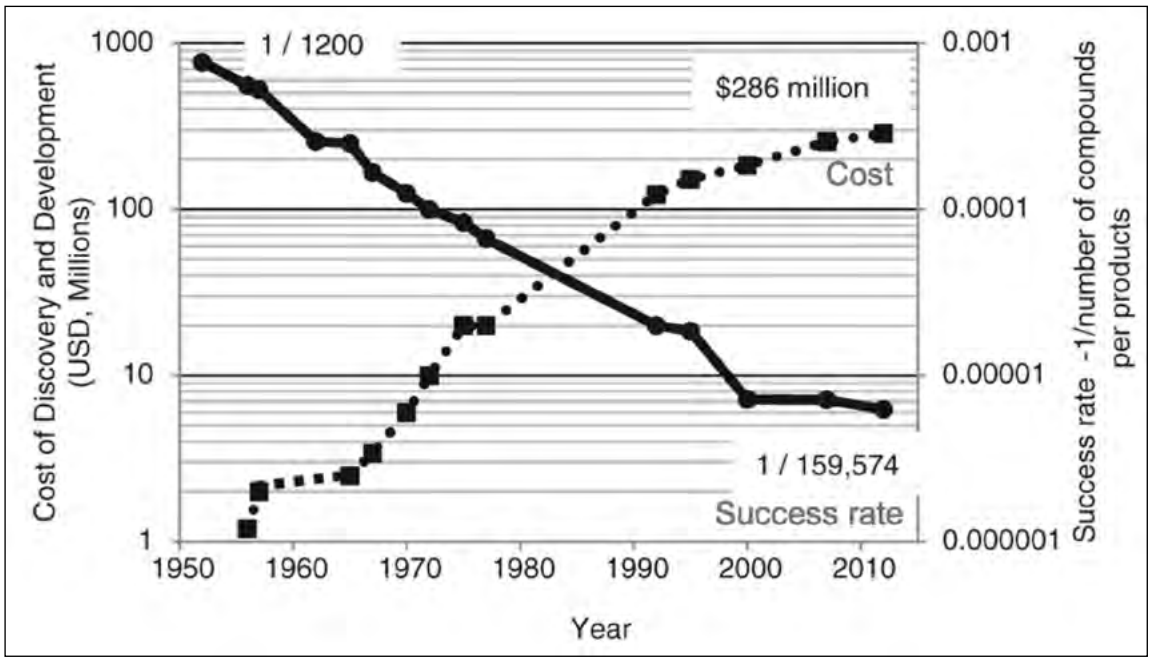


Figure 1. Log scale of pesticide development cost (dotted line) vs pesticide development success rate (solid line) (Image credit: Sparks 2017).

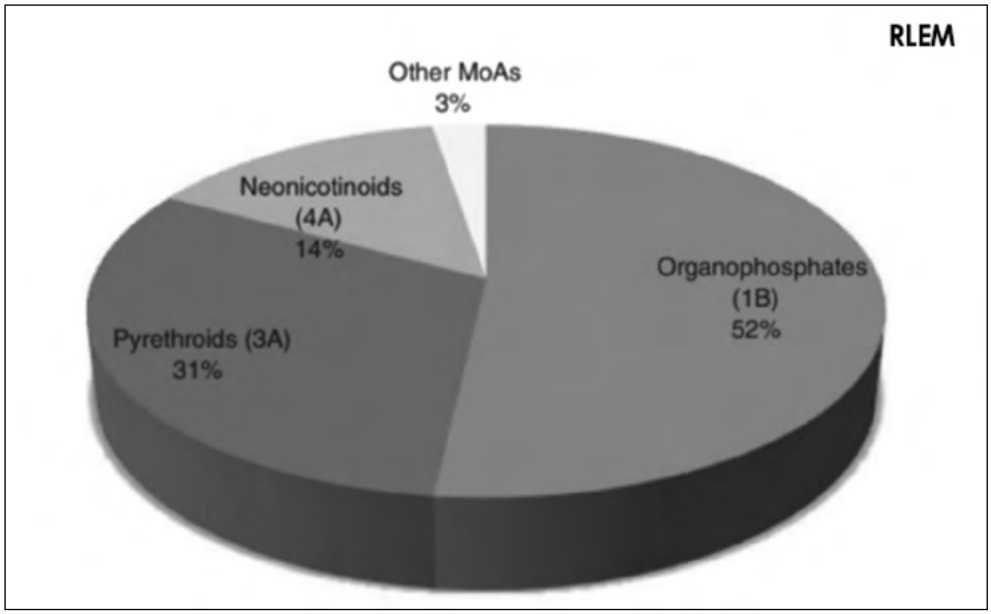


Figure 2. Percentage of pesticides used in Australia against the redlegged earth mite. (Image credit: Umina *et al.* 2019).

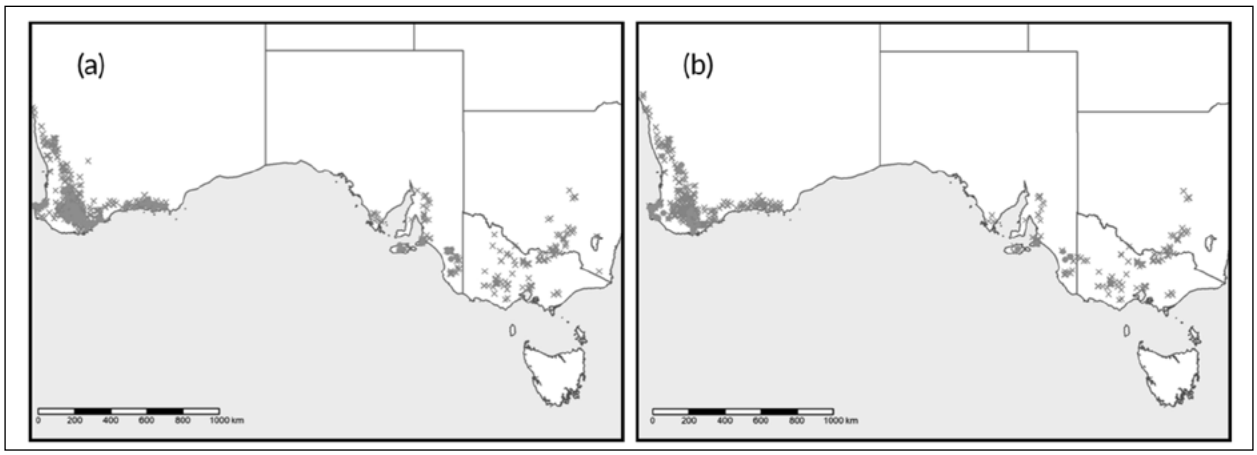


Figure 3. The distribution of RLEM populations screened for (a) pyrethroid and (b) organophosphate resistance across Australia as of 2019. Closed circles represent populations with resistance, and grey crosses indicate populations that are susceptible to pesticides. (Image credit: Arthur *et al.* 2020 (Unpublished)).

A new GRDC investment (CES2010-001RXT) led by cesar Australia, in collaboration with the University of Melbourne and the WA Department of Primary Industries and Regional Development, will continue extensive resistance surveillance of RLEM across Australia utilising improved resistant monitoring tools such as the molecular pyrethroid resistance screening test (Edwards *et al.* 2018) and modelling that has been used to predict 'at risk' areas (Maino *et al.* 2018). This project will also investigate new chemical and biological options to control RLEM, as well as tools to increase confidence in seasonal RLEM risks and management options.

The role of recessive genes in managing RLEM

Resistance to pyrethroids in Australian populations of RLEM has recently been shown to be a recessive trait. In the case of recessive genetic traits, the resistant allele (allele = a version of a gene) must be carried by both parents and both copies passed on for mite offspring to exhibit resistance. If only one copy is passed on (e.g., through the maternal but not the paternal line), the offspring will remain susceptible to pyrethroids. This creates an opportunity to revert largely resistant populations to a susceptible state through management practices

Table 1. Number of *H. destructor* populations collected between 2006 and 2019 from Western and eastern Australia screened for resistance to organophosphates and synthetic pyrethroids.

Year	Populations from Western Australia				Populations from eastern Australia			
	Sampled	With SP resistance	With OP resistance	Dual resistance	Sampled	With SP resistance	With OP resistance	Dual resistance
2006	1	1	0	0	1	0	0	0
2007	33	12	0	0	5	0	0	0
2008	7	0	0	0	-	-	-	-
2009	46	12	0	0	3	0	0	0
2010	44	12	0	0	34	0	0	0
2011	108	14	0	0	19	0	0	0
2012	7	7	0	0	-	-	-	-
2013	8	6	0	0	-	-	-	-
2014	127	28	12	1	39	0	0	0
2015	95	10	6	0	24	0	0	0
2016	28	10	0	0	7	1	1	1
2017	119	22	8	4	47	6	1	1
2018	26	5	1	1	19	3	4	2
2019	117	37	17	10	65	9	9	4

that allow susceptible mites (and their genes) to remain within the population. Other research by cesar Australia has shown that populations of RLEM resistant to synthetic pyrethroids have reduced fitness in comparison to susceptible populations. This is a useful insight, as the fitness cost imposed on resistant mites may help to maintain susceptible populations of RLEM (if managed correctly) as susceptible mites have a higher chance of surviving and passing on their genetic material in the absence of pyrethroid usage. Therefore, thinking about management on a genetic level is required. A strategy that involves maintaining refuges for susceptible mites is one option for maintaining a pool of susceptible alleles in a population.

Cesar Australia has investigated the possibility of strip spraying to maintain refuges of susceptible RLEM populations. Through analysis of pest migration rates and survival from pesticide applications, a simulation approach was used to design a refuge and treatment strategy to maintain field susceptibility to pyrethroids in populations with resistance. It was found that certain field configurations (e.g., treatment strip width of 50m and refuge spacing of 10m) maintained very low levels of resistance across a 30-year time horizon. This could be a successful strategy to manage RLEM as part of an integrated pest management (IPM) program. However, this novel approach will require further field validation in a variety of cropping contexts. Growers interested in trialling such novel strategies are encouraged to contact cesar Australia.

Resistance in green peach aphid

Green peach aphid is a worldwide agricultural pest that attacks a wide range of grain and horticultural crops from over 40 plant families. It is an important vector of over 100 plant viruses. This polyphagous aphid is of particular concern for canola growers in Australia due to its high transmission rate for Turnip yellows virus (TuYV) (formerly known as Beet western yellows virus). Infection of canola plants by this virus prior to stem elongation can cause yield losses of up to 50% (DPIRD, 2020). Feeding damage from high aphid densities can lead to reduced or stunted growth, while the secretion of honeydew can contribute to secondary fungal infections (Blackman and Eastop 2000; Anstead *et al.* 2007).

In Australian grain growing regions, control of GPA largely relies on pesticide applications and seed treatments. There are five pesticide groups currently registered for use against GPA in Australian grains: carbamates (Group 1A), organophosphates (Group 1B), synthetic pyrethroids (Group 3A), neonicotinoids (Group 4A) and sulfoximine (Group 4C) (Figure 4). Paraffinic spray oils are also registered for suppression of GPA. These chemicals are often applied prophylactically as a safeguard against infestations of this pest. This has created strong selection pressures against this pest and has contributed to the evolution of resistance in multiple Mode of Action pesticide groups (including carbamates, organophosphates, synthetic pyrethroids and neonicotinoids) in Australia.

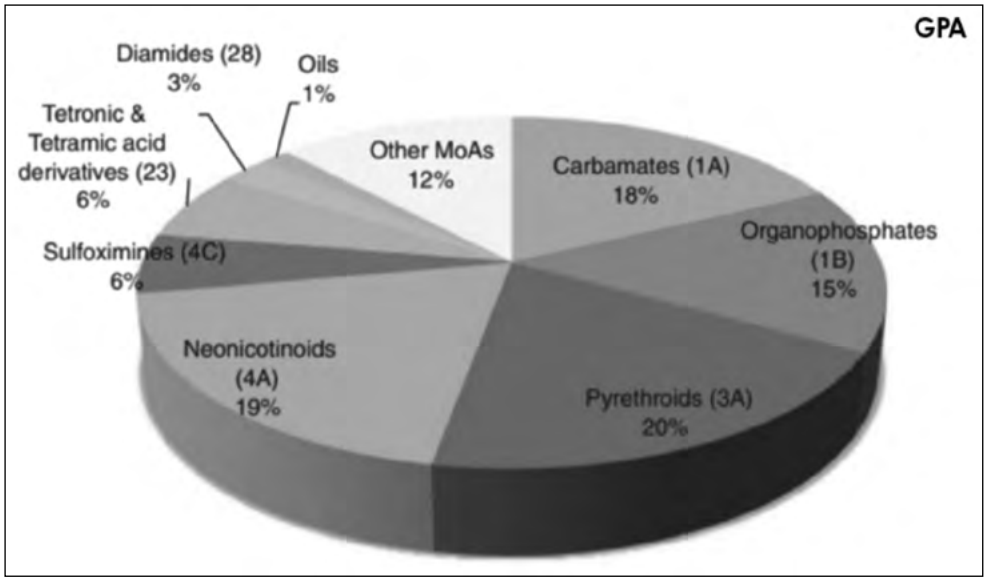


Figure 4. The percentage of pesticides used in Australia against the green peach aphid. (Image credit: Umina *et al.* 2019).

Resistance testing of GPA populations

Asexual reproduction in Australian GPA populations limits genetic variation. However, there are genetic differences between GPA populations. Populations that maintain enough genetic distinctiveness are termed a 'clone'.

Recent work undertaken by cesar Australia and CSIRO as part of a GRDC investment (CES00003) has involved development of a clone database that includes information on resistance-conferring mutations. This enables researchers to track the evolution and spread of resistance across populations by identifying the genetic lineage of an aphid sample, reducing the time and costs related to resistance testing.

Within Australia, green peach aphid populations are dominated by three clones across all seasons in broadacre and horticulture cropping regions in Queensland (Qld), New South Wales (NSW), Vic, SA, WA and Tasmania (Tas). Importantly, all three clones exhibit some level of resistance to synthetic pyrethroids, carbamates, organophosphates and neonicotinoids.

Between 2015-2019, 473 GPA populations were genetically screened against known pesticide resistance conferring alleles for carbamates, organophosphates, synthetic pyrethroids and neonicotinoids. For neonicotinoid resistance testing, a subset of populations was also screened using phenotypic laboratory bioassays (Figure 5 shows maps of the populations screened for resistance to different chemical groups). This testing work identified target site resistance in almost all screened populations to carbamates and synthetic pyrethroids rendering these chemicals ineffective as a control option for GPA. The testing also detected resistance to organophosphates and neonicotinoids in GPA populations.

Resistance to organophosphates was found to be moderate in many populations and a result of metabolic resistance. With metabolic resistance, insects use enzymes to break down and detoxify pesticides, reducing their overall efficacy. As a consequence, organophosphate will provide control in some situations, but less or no control in others. Furthermore, continued use of organophosphates on such populations would likely increase their overall resistance to chemicals from this group.

Resistance to neonicotinoids in GPA is determined by an overexpression of the P450 monooxygenase CYP6CY3 detoxifying gene. This gene was only found to be expressed at low levels in the GPA populations screened, and therefore, complete chemical field failures are unlikely to occur in GPA populations with the levels of neonicotinoid resistance currently observed.

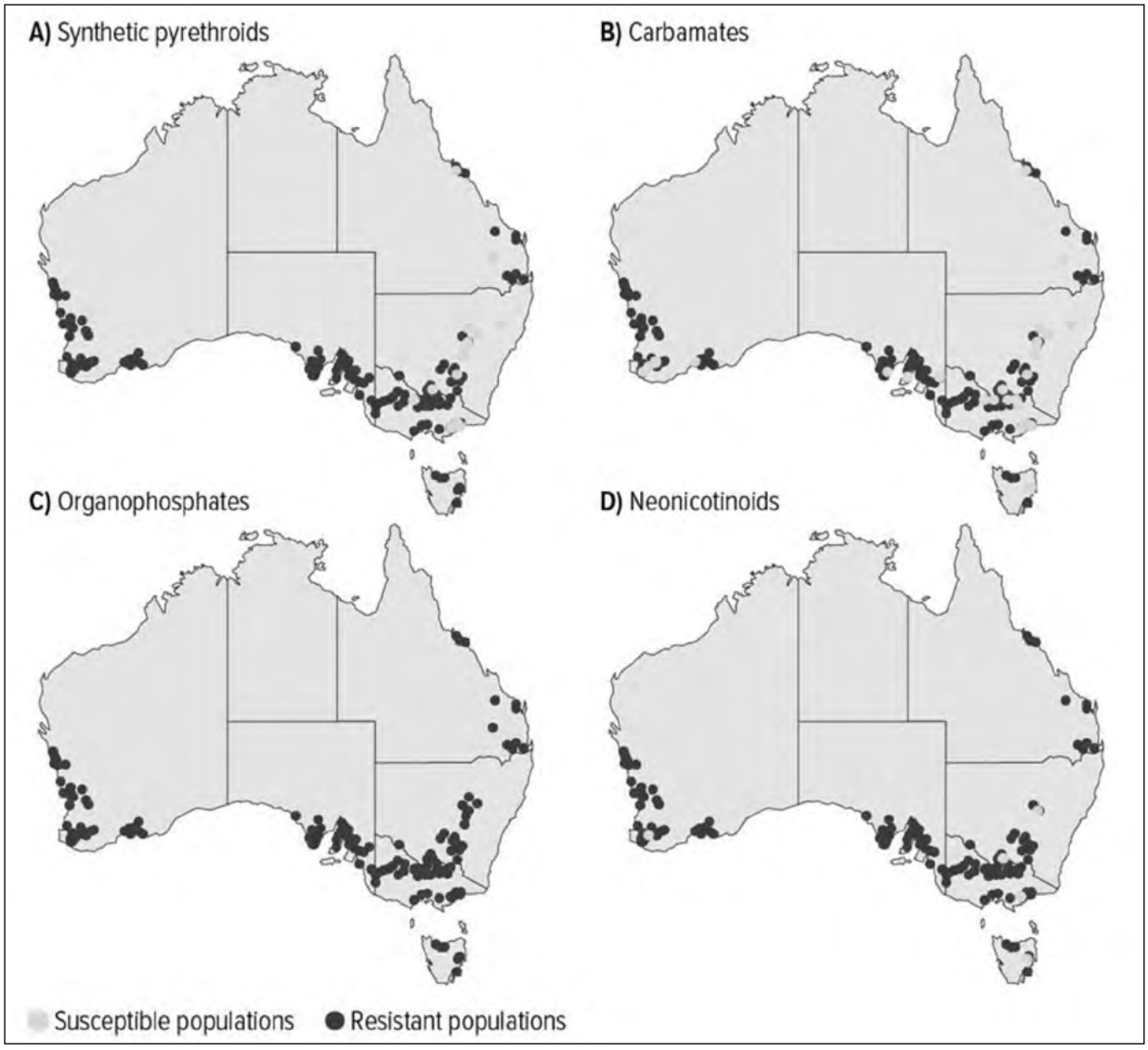


Figure 5. Resistance status of populations tested for resistance to synthetic pyrethroids, carbamates, organophosphates and neonicotinoids. The darker coloured dots represent resistant populations while the lighter coloured represent susceptible populations. (Image credit: Noakes 2020).

Screening for the exotic mutation; R81T in GPA populations

As part of the project, researchers also tested 181 GPA samples taken from a network of sticky traps around Australia for the gene mutation 'R81T'. The R81T mutation has been found in GPA populations overseas and confers near total resistance to neonicotinoids when present. While the mutation was not detected in any of the tested samples, there is ongoing risk of this mutation being found in Australia either through *in situ* resistance evolution or importation from abroad. A risk analysis has been undertaken to identify possible incursion entry points and agricultural regions of high selection pressure.

Sensitivity shift to sulfoximines discovered in GPA populations

A sensitivity shift to sulfoximines in four different GPA populations collected around the Esperance region of WA was identified following a reported control failure in 2019. Figure 6 shows the results of bioassay testing on these populations compared with a susceptible control population. While the recorded sensitivity shifts are currently small, the possibility of GPA populations evolving further resistance to sulfoximines in the future is concerning given the small number of viable chemical options currently registered for use against GPA.

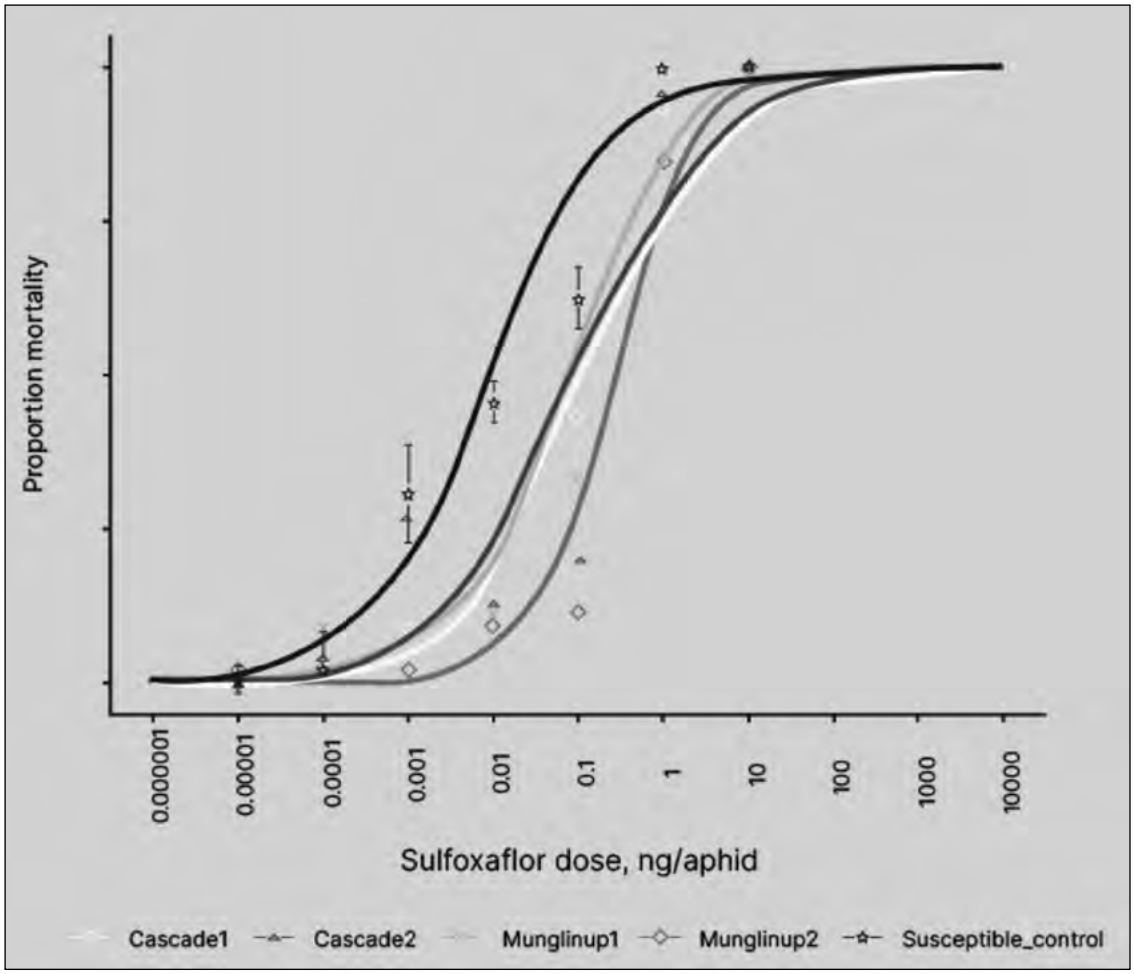


Figure 6. Dose response of sulfoxaflor for four GPA populations and the susceptible control. The populations are named according to their collection location.

Further resistance testing and novel management strategies for GPA is continuing within a GRDC investment, 'CES2001-001RTX: Pesticide resistance in the green peach aphid: national surveillance, preparedness and implications for virus management'. This project is examining resistance trends, dispersal patterns and non-crop hosts for GPAs and associated virus risks and is developing baseline sensitivity data for new chemicals.

Bryobia mites - response to pesticides

Bryobia mites (*Bryobia* spp.) are important pests of winter crops and pastures. There have been growing concerns around control difficulties in the field. Management of *Bryobia* mites is complicated by the fact that they consist of a complex of pest species, with at least seven cryptic species present in Australian broadacre agriculture. Recent research led by cesar Australia, as part of a GRDC investment (UM00057), established baseline sensitivity data for *Bryobia* mites against omethoate (organophosphate) and bifenthrin (synthetic pyrethroid), two common pesticides used in the field to control this mite. Baseline sensitivity data was generated for the first time across multiple Bryobia mite populations from geographically distinct regions in Australia. The responses to bifenthrin were relatively similar across the *Bryobia* populations screened, however, considerable differences were evident between populations in response to omethoate. This variation appears to be linked to different *Bryobia* species, indicating that pesticides used against one species may not be effective against another. Unfortunately, it is impossible to differentiate species in the field. The distribution of species across Australia is currently being mapped in order to better understand the risks posed by *Bryobia* mites.

Conclusion

The continued spread of resistance in RLEM populations across Australia's grain growing regions, as outlined within this paper, has led to the investigation into new ways to manage this pest, such as the role of recessive genes in maintaining susceptible RLEM populations. Furthermore, the continued spread of resistance has highlighted

the importance of the resistance surveillance work for this pest, as well as the need for new chemical and biological control options, both of which will be investigated in a newly commenced GRDC investment (CES2010-001RXT).

Resistance to carbamates and synthetic pyrethroids in GPA is widespread in Australia. The recent discovery of a sensitivity shift in sulfoximines in four GPA populations in the Esperance region of WA has highlighted the need for more integrated methods of control for this pest, methods that do not rely so heavily on the limited registered chemicals available. National resistance surveillance work for GPA will continue under a newly commenced GRDC investment (CES2001-001RTX), which will also develop baseline sensitivity data to new chemicals and investigate seasonal TuYV risks.

Pesticides will continue to play an important role in RLEM and GPA control, However, the increasing spread and evolution of resistance raises concerns for the long-term viability of chemical control. Future control of these pests should be in the form of an IPM approach that aims to reduce chemical usage to limit selection pressures and decrease the risk of further resistance development. Resistant management strategies (RMS) for RLEM and GPA are important resources that help maintain the effectiveness of existing chemistries.

Pesticide RMS have been developed by the National Insecticide Resistance Management (NIRM) working group for the four major resistant invertebrate pests in grains. The RLEM and GPA RMSs provide recommendations regarding effective pest management practices. In addition, a recent GRDC investment (BWD1805-006) has helped develop best management practice guides (BPMG) for RLEM and GPA, published in 2020 (Useful Resources). Growers and advisers are encouraged to become familiar with these guides and the RMSs – all freely available to download from the GRDC website.

General RMS include the following principles:

- Monitoring crops for pest and beneficial insect presence.
- Accurate pest identification to determine the appropriate control strategy.
- Utilising non-chemical control options that suppress pest populations.
- Using economic spray thresholds to guide chemical applications.
- If applying multiple pesticides within a season, rotating the chemical mode of action.
- Using selective chemicals, where possible, in place of broad-spectrum options.
- Considering the secondary impacts of chemicals to non-target pests and beneficials.
- Complying with all directions for use on product labels including using full recommended rates and good coverage of the target area to ensure the best possible chance of contact and subsequent control of the pest.

Acknowledgements

The research undertaken as part of these projects 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.

For the green peach aphid research we also thank Corteva Agriscience, BASF, ISK, CropLife Australia, and Bayer Cropsciences for their support and acknowledge our project collaborators, CSIRO and the WA Department of Primary Industries and Regional Development (DPIRD).

For the redlegged earth mite research we would like to acknowledge our project collaborators, The University of Melbourne, WA Department of Primary Industries and Regional Development (DPIRD) and CSIRO

Useful resources

Resistance management strategy for the green peach paid in Australia grains (www.grdc.com.au/GPAResistanceStrategy)

Resistance management strategy for the redlegged earth mite in Australia grains and pastures (https://grdc.com.au/FS-RLEM-Resistance-strategy)

Green peach aphid best management practice guide – southern (https://grdc.com.au/green-peach-aphid-best-management-practice-guide-southern/)

Redlegged earth mite best management practice guide – southern (https://grdc.com.au/redlegged-earth-mite-best-management-practice-guide-southern/)

PestFacts south-eastern (http://cesaraustralia.com/sustainable-agriculture/pestfacts-south-eastern/)

Insecticide resistance in the southern region: current status, future risk and best management practices (https://grdc.com.au/insecticide-resistance-in-the-southern-region)

Green peach aphid identification. PestBites by cesar (GPA Identification Video - https://www.youtube.com/watch?v=THFHGSvZUN4)

Mite identification. PestBites by cesar (Mite Identification Video - https://www.youtube.com/watch?v=y02DKvGfOkQ&t=6s)

References

Anstead, J. A., Mallet, J. and Denholm, I. (2007). Temporal and spatial incidence of alleles conferring knockdown resistance to pyrethroids in the peach-potato aphid, Myzus persicae (Hemiptera: Aphididae), and their association with other insecticide resistance mechanisms. *Bull. Entomol. Res.* 97: 243-252.

Blackman, R. L., and V. F. Eastop. (2000). *Aphids on the world's crops, an identification and information guide.* Wiley Ltd., Chichester, United Kingdom.

DPIRD. (2020). Managing turnip yellows virus in canola. *Department of Primary Industries and Regional Development* [website content]. Available: https://www.agric.wa.gov.au/canola/managing-turnip-yellows-virus-canola

Maino, J.L., Binns, M. and Umina, P. (2018). No longer a west-side story - Pesticide resistance discovered in the eastern range of a major Australian crop pest, Halotydeus destructor (Acari: Penthaleidae). Crop and Pasture Science, 69, p 216–221.

McDonald, G., Umina, P., Lye, J., Maino, J, Perry, K. and Baker, G. (2019). *Insecticide resistance in the southern region: current status, future risk and best management practices.* Grains Research and Development Corporation. Canberra, Australia.

Noakes, F. (2020, 23 October). Pest detectives tracking the green peach aphid. *GroundCover* [Supplement – Invertebrate pest management: new frontiers], GRDC. https://groundcover.grdc.com.au/weeds-pests-diseases/pests/pest-detectives-tracking-the-green-peach-aphid.

Ridsdill-Smith, T.J., Hoffmann, A.A., Mangano, G.P., Gower, J.M., Pavri, C.C. and Umina, P.A. (2008). Strategies for control of the redlegged earth mite in Australia. Australian Journal of Experimental Agriculture, 48, p 1506–1513.Sparks, T.C., Hahn, D.R. and Garizi, N.V. (2017). Natural products, their derivatives, mimics and synthetic equivalents: role in agrochemical discovery. *Pest. Manag. Sci*., 73: 700-715.

Umina, P.A. (2007). Pyrethroid resistance discovered in a major agricultural pest in southern Australia: the redlegged earth mite Halotydeus destructor (Acari: Penthaleidae). Pest Management Science, 63, p 1185–1190.

Umina, P.A. and Hoffmann, A.A. (2004). Plant host associations of Penthaleus species and Halotydeus destructor (Acari: Penthaleidae) and implications for integrated pest management. Experimental and Applied Acarology, 33, p 1–20.

Umina, P.A., Lord, A., Micic, S. and Edwards, O. (2017). Discovery and characterisation of field resistance to organophosphorus chemicals in a major mite pest, Halotydeus destructor. Pest Management Science, 73, p 1719–1724.

Umina, P.A., McDonald, G., Maino, J., Edwards, O. and Hoffmann, A.A. (2019). Escalating insecticide resistance in Australian grain pests: contributing factors, industry trends and management opportunities. *Pest. Manag. Sci.*, 75: 1494-1506

Umina, P.A., Weeks, A.R., Roberts, J., Jenkins, S., Mangano, G.P., Lord, A. & Micic, S. (2012) The current status of pesticide resistance in Australian populations of the redlegged earth mite (Halotydeus destructor). Pest Management Science, 68, 889–896.

Contact details

Leo McGrane
lmcgrane@cesaraustralia.com

Paul Umina
pumina@cesaraustralia.com

Return to contents

Notes

Targeted amelioration in Mallee sands to maximise crop water use

Lynne Macdonald[1], Nigel Wilhelm[2], Melisa Fraser[3], Michael Moodie[4], Sam Trengove[5], Jack Desbiolles[6], Chris Saunders[6], Rachael Whitworth[7], Rodrigo da Silva[1,8], Rick Llewellyn[1] and Therese McBeath[1].

[1]CSIRO Agriculture & Food, Locked Bag 2, Glen Osmond, SA; [2]Primary Industries and Regions South Australia (PIRSA), Adelaide, SA; [3]Primary Industries and Regions South Australia (PIRSA), 74 Struan House Rd, Naracoorte, SA; [4]Frontier Farming Systems, Mildura, Victoria; [5] rengove Consulting, Bute, SA; [6]University of South Australia, Mawson Lakes, SA; [7]AgGrow Agronomy and Research, Yoogali NSW; [8]The University of Adelaide, Waite Campus, Glen Osmond, SA.

GRDC project codes: CSP00203, GRDC00432

Keywords

- soil constraints, compaction, water repellence, ripping, spading, crop water use

Take home messages

- Across the Southern region research trials which target physical constraints (without significant repellence or subsoil toxicities) have demonstrated positive first-year responses to deep ripping ranging from 0.2t/ha to 1.2t/ha, with an average gain of 0.6t/ha.
- While most trials demonstrate multiple years benefit from ripping, yield penalties have been evident following consecutive drought years in 2018 and 2019, which appear to be greater in soils ripped deeper (60cm versus 30cm).
- Across project trials with water repellence and where subsoil toxicities are not present, spading treatments show an average annual yield response of +0.8t/ha.
- Although spading remains the more effective amelioration approach on repellent sands, inclusion-ripping has shown smaller benefits that persist over multiple years.
- Reliable and effective inclusion of topsoil is strongly influenced by operating conditions (e.g., moisture, operating depth and speed), but enhancements to design alongside and operation set-up could improve inclusion-ripping outcomes.
- When considering amelioration of sandy soils in low rainfall environments, it is useful to estimate the yield gap and evaluate seasonal risks that could limit the size and longevity of benefits.

Background

Grain producers have become more proficient at Uptake of amelioration practices to improve the productivity of sandy soils in the Southern region has gained strong momentum in recent years. These practices include deep ripping which aims to shatter hard or compacted layers, and deep ploughing and spading which aim to mix and dilute repellent or hostile layers, and/or incorporate topsoil into bleached deeper layers. Additionally, inclusion-ripping, deep ploughing and spading practices offer opportunities to incorporate amendments or fertilisers into the profile to improve soil condition or nutrient supply. Amelioration practices invariably incur an upfront cost ranging from around $60/ha (e.g. shallow ripping) to several hundred dollars depending on the machinery running costs, work rate, depth of operation, and amendments applied. First year responses are often positive but return

on investment can require benefits over multiple seasons. Multi-year benefits can be challenging in a water limited environment with high seasonal variability, or where amelioration effects may be short-lived. The impact of the quality of soil and amendment mixing and/or inclusion is often not considered.

Building on previous amelioration trials (PIRSA New Horizons est. 2014, Trengove *et al.* 2015), CSP00203 research aims to improve the diagnosis and management of primary soil constraints across deep sandy soil in the Southern region's low-medium rainfall environment. Including 10 research trials (5 years) and 18 validation trials (3 years) the research project is working to define which sandy environments and amelioration treatments are more likely to provide strong return on investment, and where environmental risks or short-lived effects are likely to limit potential benefits.

CSP00203 research and validation trial overview

A range of research experiments have been established across the Southern region low to medium rainfall environment with estimated yield gaps of between 1.9 - 5.2t/ha, or greater in higher rainfall environments (Table 1). Sites are categorised according to the primary soil constraints identified. Research experiments were established between 2014 and 2019 and include a range of deep ripping and/or ploughing approaches, with/without additional amendments (fertiliser, N-rich hay, chicken manure, clay). Research experiments are supported by validation trials established in 2019-2020 which aim to evaluate responses more broadly across sandy environments. All trials monitored the impact of amelioration on crop growth and yield. Research trials include more intensive measurements to understand the impact of amelioration on crop water use and soil constraints over time.

This paper discusses findings relating to deep tillage practices (ripping, spading) alone, without including responses to incorporation of amendments. Findings report the range of yield responses to deep tillage for: a) sands without water repellence issues where physical constraints have been targeted through ripping-based practices; b) water-repellent sands where approaches have focused on spading and/or inclusion ripping to disrupt repellent layers and physical constraints. All sandy sites are considered to have inherently low biological fertility with topsoil (0-10 cm) organic carbon contents of between 0.3% and 0.7%.

Results and discussion

Ripping deep sands with physical constraints - shattering to maximise root exploration

Yield responses to ripping across seven research trials (2017-2020) and two validation trials with physical constraints are summarised in Figure 1. Except for one non-responsive site, all sites demonstrated a positive response to ripping in the first year (Figure 1b). Yield gains ranged from 0.2t/ha to 1.2t/ha, with an average gain of 0.59t/ha. These responses are similar to those reported

Table 1. Summary of research and validation sites targeting a range of different constraints including the long-term growing season rainfall (mm), an estimated yield gap (t/ha, based on water limited potential minus current attainable yields), an indication of the target soil constraints, and an overview of the deep tillage practices and amendment treatments.

Research Site_Yr Established		GS Rain (mm)	Yield Gap (t/ha)	Amelioration (focus treatments for this analysis)	Validation Trials (est 2019, 2020)
Physical constraints and low inherent nutrition (*plus acidity)					
Bute 2015	Yorke Pen.	298	3.0	Deep ripping approaches including depths between 30 - 60 cm aiming to overcome physical constraints through shattering.	Telopea Downs, Kooloonong, Buckleboo Karkoo, Walpeup, Monia Gap.
Bute 2018		298	3.0		
Yenda* 2017	NSW	252	3.3		
Lowaldie 2019	SA Mallee	235	3.5		
Ouyen 2017	VIC Mallee	213	3.0		
Carwarp 2018		174	2.5		
Waikerie_2018	SA Mallee	157	1.9		
Water repellency, physical constraints and low inherent nutrition (*plus acidity)					
Cadgee* 2014	Upper SE	410	6.2	Mixing (spading) and inclusion ripping (Murlong) aiming to disrupt repellent layers and physical constraints.	Warnertown, Kybunga, Tempy, Karoonda, Mt. Damper, Younghusband, Sherwood, Malinong.
Brimpton 2014	Eyre Pen.	377	5.3		
Murlong 2018		251	3.7		
Karoonda 2014	SA Mallee	235	3.5		

by Dzoma *et al.* (2020) across five site x years at Loxton, Peebinga and Buckleboo. The non-responsive example is the only project site with severe subsoil acidity (Yenda, NSW) which has shown larger responses to nutrition compared to physical interventions (ripping 30cm, deep sweep tine) over four years of monitoring. Seasonal conditions at Yenda have been unfavourable including consecutive drought years and frequent frost events.

Across the remaining trial sites responses in years after the ripping treatments demonstrate an average yield gain of 0.3t/ha, but also include a higher incidence of yield penalties of up to -0.6t/ha. All observed yield penalties relate to the 2019 season and represent a consecutive year of dry seasonal conditions. Ripping responses in the more favourable 2020 season show benefits ranging between 0.3t/ha and 0.9t/ha at responsive sites, including those that suffered penalties in 2019.

Cumulative yield responses across seven multi-year research trials are summarised in Figure 2. Three sites (Bute'15, Lowaldie, and Ouyen) demonstrated cumulative gains over multiple seasons, while three did not (Bute'18, Carwarp, Waikerie). Response variability highlights the importance of understanding where responses are driven by seasonal risks and where soil constraints have not been adequately ameliorated for long-term effect. At two lower rainfall sites established in 2018, small positive responses to ripping in the first year (decile 1) were negated by yield penalties in the second year (decile 1). Second year penalties were larger in deeper ripped treatments (60cm compared to 30cm) despite physical constraints extending beyond 30cm depth. After three years, there was no cumulative yield benefit which highlights risks in environments where consecutive drought years can limit profile re-charge. While the ripping effects at these low rainfall sites (Carwarp, Waikerie) have had small positive gains in two seasons out of three, it will require positive responses in the 4th year to achieve an overall positive return on investment. In these Mallee environments, early positive responses in a particular season are often, but not always, a guide to future cost:benefit performance.

Despite being geographically close, cumulative yield gains from ripping at Bute'18 (a bleached grey sand) have been limited compared to responses at the Bute'15 trial (a red sand, Trengove *et al.* 2018). Comparison of these two trial sites under a similar rainfall environment emphasises the driving role of sand type and the nature and severity of constraints. Soil characterisation indicates contrasting physical constraints and subsoil properties (e.g. presence of kaolinite clay, calcite, silica, and iron). Physical constraints in sandy soils can result from physical processes alone (e.g. tight packing of particles to give a high bulk density) or from chemical processes which bind or cement particles together as the profile dries. Further research is underway to identify the causes and behaviour of subsoil settling and/or cementing in these sandy environments and its potential role in limiting long-term effects of amelioration.

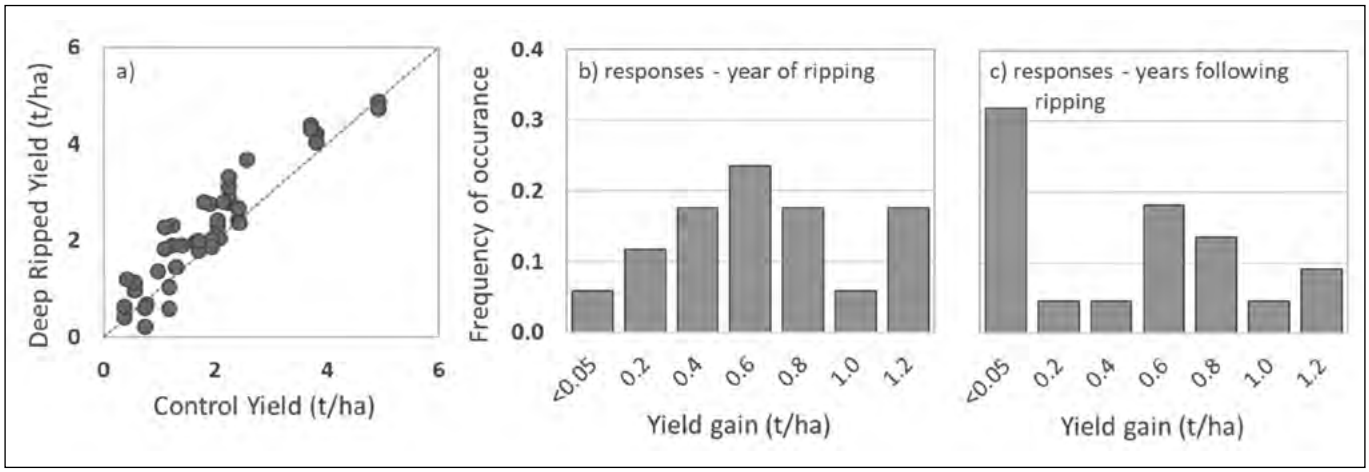


Figure 1. Annual crop yield (t/ha) responses to deep ripping in sands where physical issues are considered dominant including: a) biplot demonstrating unmodified control yields against deep ripped yields; and frequency distributions of yield gains (ripped yield – control yield) in the year of ripping (b) and subsequent years following ripping (c) across CSP00203 trial sites. Data represent treatment averages from seven research trials (multiple years, n=4) and two validation trials (single year, n=3) with a total of 40 response years.

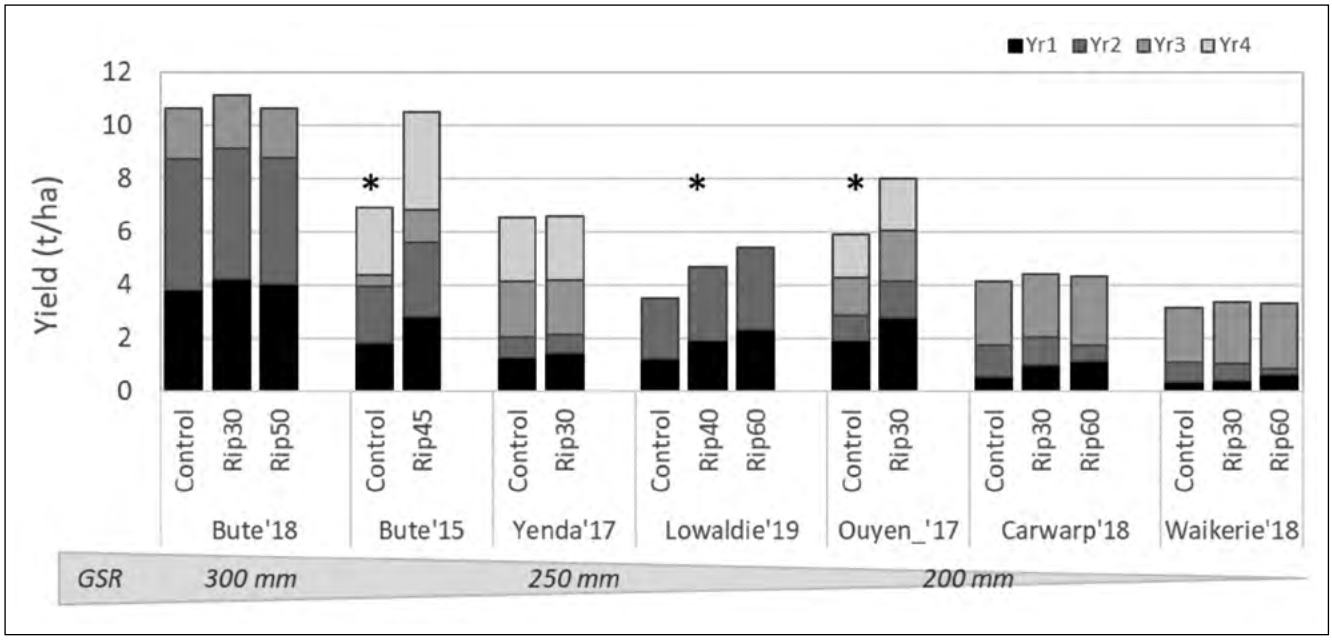


Figure 2. Cumulative yield responses (t/ha) across seven research sites (site & year of establishment) in unmodified (control) and ripped treatments (rip depth cm). Data are averages of four field replicates, with * indicating significant (P<0.05) cumulative gains. Sites are ordered according to longer-term average annual rainfall. All sites have inherently low fertility and physical constraints.

Water repellent sands – mixing to maximise water capture and root exploration

Early research trials led by PIRSA (New Horizons 2014-2018) demonstrated that spading can have long-term yield impact on water repellent sands with physical constraints, providing subsoil chemical toxicities are not present. Five years of monitoring two research sites (Karoonda, Brimpton Lake) showed ongoing establishment, biomass, and/or yield gains. At Cadgee, where physical constraints were less evident but severe subsurface acidity was present, detrimental effects to spading continued for multiple years. Amelioration strategies of acidic soils is reported by Hughes at Adelaide GRDC Grains Research Update 2021.

Within the current project a fourth research site at Murlong and seven validation trials continue to improve our understanding of amelioration responses in repellent sands (Figure 3a), including comparing spading and alternative deep tillage practices (Figure 3b). Where subsoil toxicities are not present, these trials report an average annual yield response of +0.8t/ha, including examples of substantial gains (+1.8t/ha), as well as neutral responses in some seasons (Figure 3a).

Spading offers long-term benefits on repellent sands, but practical challenges include trafficking and managing seed depth for successful crop establisment, and erosion risk. One-pass operations to simultaneously spade and seed, when conducted into a moist profile, can have advantages including minimising erosion risks, securing uniform crop establishment and increasing flexibility of when spading might be implemented within the crop rotation.

While spading is the most effective approach to mix and dilute repellent layers, alternative deep tillage practices can offer some benefit by disrupting water repellent layers, or by overcoming co-occuring physical constraints to root growth. Comparison of spading to inclusion ripping at a severely repellent sand at Murlong demonstrate intermediate benefits from inclusion ripping (Figure 3b). A cumulative three-year benefit of 2.9t/ha was achieved from spading under a wheat (+1.4t/ha), barley (+0.9t/ha), and vetch (+0.6t/ha) rotation. Inclusion ripping provided cumulative gains of +1.4t/ha and 2.2t/ha at 30cm and 40cm depths, respectively.

Although inclusion ripping may appear an attractive option, topsoil inclusion and crop response variability alongside elevated running costs pose challenges for reliable return on investment. Trials on sandy soils in Western Australia and South Australia showed higher draft requirements (+24% to +40%), reduced workrate (-24%), and extra fuel use (+3.7L/ha) with baseline inclusion ripping compared to ripping alone (Parker *et al.* 2019). Engineering research using simulation modelling indicates opportunities to optimise the design of inclusion plates which may improve reliability. Field validation

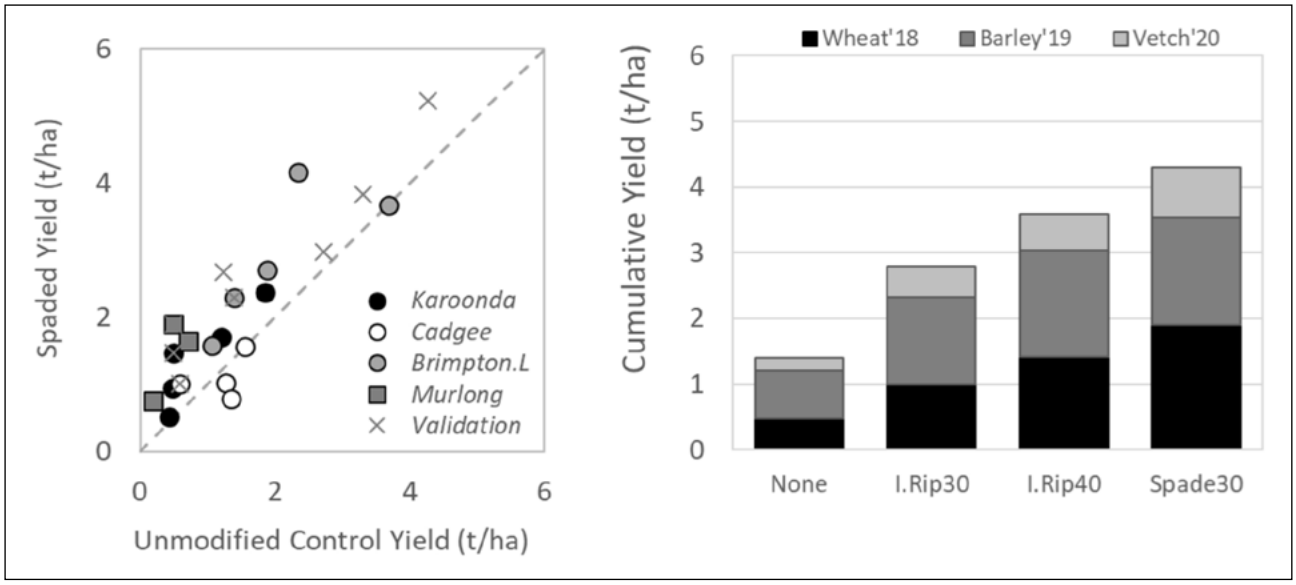


Figure 3. Yield responses in water repellent sands including: a) comparison of unmodified control yields and spaded yields at multi-year research trials (different symbols) and first year validation trials (X); b) cumulative crop yield (t/ha) responses in a severely repellent sand (Murlong) including the unmodified control, inclusion ripping to 30cm or 40cm (I.Rip30, I.Rip40) and spading (spade30).

(Ucgul *et al.* 2019) demonstrate how effective depth and quantity of inclusion can be increased by lengthening the plates. A trial conducted on a repellent sand at Younghusband in 2020 produced yield benefits of 0.75t/ha from inclusion-ripping with modified 600mm plates, over and above deep ripping alone (3.9 t/ha) where the untreated control yield was 2.8t/ha. While effective inclusion of topsoil is strongly influenced by operating conditions (e.g., moisture, operatiing depth and speed), opportunities exist for this amelioration approach through design modification alongside optimising machinery set-up and operation.

Conclusion

Although CSP00203 research trials demonstrate that yield responses can be highly variable in the seasons following amelioration of sandy soils, the majority of responses were positive. Many trials demonstrate ongoing positive effects for more than three seasons after implementation, while some demonstrate limited responses due to poor seasonal conditions or where subsoil constraints have not been adequately overcome. All sites across the Southern region which target physical constraints (without significant repellence or subsoil toxicities) demonstrated positive first-year responses to deep ripping ranging from 0.2t/ha to 1.2t/ha. While most trials produced multiple years benefit from ripping, yield penalties were evident following consecutive drought years in 2018 and 2019, with greater penalties in soils ripped deeper (60 cm versus 30 cm). These results demonstrate that early positive responses to soil amelioration in a particular season are not always an indicator of future cost:benefit performance.

In trials with water repellence, spading treatments showed an average annual yield response of +0.8 t/ha. Although spading remains the more effective amelioration approach in repellent sands, inclusion-ripping has shown smaller benefits that persist over multiple years. Reliable and effective inclusion of topsoil is strongly influenced by operating conditions (e.g., moisture, operating depth and speed), but design and operation set-up enhancements could provide opportunities to improve inclusion-ripping outcomes. Central to cost effective amelioration of sandy soils in the Mallee environment is identifying and prioritising the primary soil constraints and implementing appropriate practices that improve soil condition for enhanced root exploration and water use for multiple season benefits.

Acknowledgements

This research has been enriched by preceding research trials, the significant contributions of growers and consultants across the Southern region, and the support of the GRDC. CSP00203 research and validation activities are a collaboration between the CSIRO, the University of South Australia, the SA Government Department of Primary Industries and Regions SA, Mallee Sustainable Farming Inc., Frontier Farming Systems, Trengove Consulting,

AgGrow Agronomy, AIREP, and MacKillop Farm Management Group.

Useful resources

GRDC Deep Ripping Factsheet (https://grdc.com.au/__data/assets/pdf_file/0028/91756/grdc_fs_deepripping_lr.pdf.pdf)

References

Dzoma B, K Zeppel, N Wilhelm, H Drum 2020. Recommendations for deep ripping sandy soils. GRDC Updates, Adelaide 2020.

Macdonald LM, T McBeath, M Fraser, N Wilhelm, D Davenport, S Trengove, M Moodie, R Whitworth, B Haskins, J Desbiolles, C Saunders, M Ucgul, R Llewellyn 2019. Mind the Gap: Targeting profile amelioration in Southern region sandy soils.

Parker W, M Ucgul, C Saunders 2019. Advise to match design of inclusion plates to soil type for optimum effect. GRDC GroundCover Supplement: Soil Constraints Part 1, Nov-Dec 2019.

PIRSA 2018, GRDC Sandy soils (CSP00203) site results summary (https://www.pir.sa.gov.au/__data/assets/pdf_file/0008/297719/PIRSA_New_Horizons_Trial_Sites_Summary_2017.pdf)

Trengove, S and Sherriff, S (2018). Amelioration of sandy soils - Opportunities for long term improvement, GRDC Grains Research Update, Adelaide 2018.

Ucgul M, J Desbiolles and C Saunders (2019). Science of deep ripping. InGrain magazine, 1(5): 20-25. Accessed 18Jan2021 at https://ingrain.partica.online/ingrain/vol-1-no-5-summer-20192020/flipbook/20/

Contact details

Dr Lynne Macdonald
CSIRO Agriculture & Food, Waite Road,
Urrbrae, SA 5064
08 8273 8111
Lynne.Macdonald@csiro.au
@Soil_Mac

Return to contents

Notes

Notes

The National Phenology Initiative: predicting cultivar phenology at point of release

Corinne Celestina[1], James Hunt[1], Maxwell Bloomfield[1], Enli Wang[2], Jessica Hyles[2], Zhigan Zhao[2], Tina Rathjen[2], Ben Trevaskis[2], Shannon Dillon[2], Neil Huth[3], Bangyou Zheng[3], Loretta Clancy[3], Dion Nicol[4], Ben Biddulph[4], Felicity Harris[5], Kenton Porker[6], Hamish Brown[7] and Katia Stefanova[8].

[1]La Trobe University, Victoria; [2]CSIRO Agriculture and Food, Australian Capital Territory; [3]CSIRO Agriculture and Food, Queensland; [4]DPIRD, Western Australia; [5]NSW DPI; [6]SARDI, South Australia; [7] Plant and Food Research, New Zealand; [8]SAGI (West), Western Australia.

GRDC project code: ULA00011

Keywords

- optimal flowering period, time of sowing, simulation modelling.

Take home messages

- Optimising flowering time of wheat and barley cultivars is one of the most cost-effective ways for growers to maximise yield.
- The National Phenology Initiative (NPI) is improving Agricultural Production Systems sIMulator (APSIM) Next Gen so that it can accurately predict cultivar phenology classification and optimal sowing dates across Australia at point of release.
- The improved APSIM Next Gen model, parameterised and validated using NPI data, is more accurate at simulating phenology than APSIM Classic or the baseline APSIM Next Gen model.
- Work on the improved model is ongoing and it will be available to growers and advisers in 2022.
- In addition, the NPI is working to develop a new cultivar phenology classification scheme and new scale of cereal development.

Background

Flowering time is a critical determinant of grain yield in wheat and barley. When crops flower in the optimal period, yields are maximised by minimising losses due to frost, heat, drought and insufficient radiation (Flohr *et al.* 2017). Flowering time is determined by interactions between genetics, environment and management: the development speed of the cultivar, the environment in which it is grown, and the time of sowing. To ensure crops flower in the optimal period, accurate information on a cultivar's development speed is needed, but this information is currently not available when new cultivars are released to the market. Instead, a cultivar's development speed or classification is determined using time of sowing experiments over multiple sites and years. These experiments are costly, time consuming and environment specific. In addition, flowering time models like APSIM (Keating *et al.* 2003) perform poorly outside a narrow range of validated scenarios.

The NPI is improving the APSIM Next Gen model (Holzworth *et al.* 2018) of wheat and barley development so it is possible to accurately predict cultivar classification and optimal sowing dates across Australia at the time at which cultivars are released to the market. The improved APSIM Next Gen model will be able to be rapidly parameterised with controlled environment phenotypic data, molecular markers and/or other genomic data, removing the need for time of sowing field experiments. The NPI will deliver a tool for growers

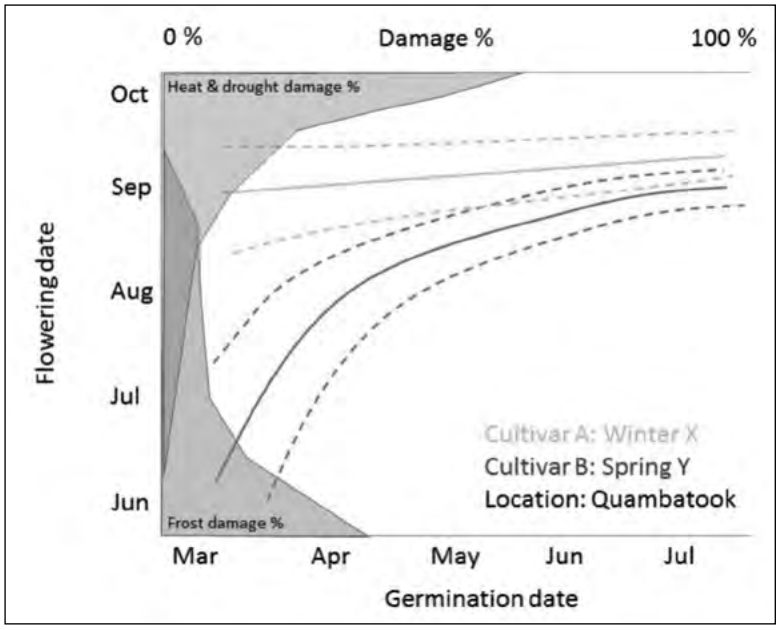


Figure 1. A mock-up of the APSIM Next Gen model output that would be available at point of cultivar release.

and advisers to more accurately predict optimal sowing date that will be available in 2022 (Figure 1). This tool will allow growers to make informed decisions about cultivar selection and time of sowing in their specific environment. It will also help to quantify the consequences of non-optimal sowing dates.

In addition to the improved APSIM Next Gen model, the NPI is also developing an improved cultivar phenology classification scheme and a new scale of cereal development.

Project methodology

The NPI is a collaborative, cross-disciplinary project led by La Trobe University with project partners from CSIRO, Plant & Food Research NZ, South Australian Research and Development Institute, NSW Department of Primary Industries, Department of Primary Industries and Regional Development WA, and Statistics for the Australian Grains Industry (SAGI) West. The NPI team includes field agronomists, crop physiologists, geneticists, modellers, and software engineers.

The NPI is using an Australian Phenology Panel comprising 64 wheat and 32 barley cultivars that have been selected to represent the diversity in both genotype and development patterns in these crops. Phenotyping of the Australian Phenology Panel has been carried out in controlled environments with factorial combinations of photoperiod (8 and 17 h) and vernalisation (nil and 8 weeks at 5°C) to derive plant development parameters (leaf emergence, time to heading, time to anthesis). These controlled environment data are being used to parameterise the APSIM Next Gen phenology routine.

A comprehensive model validation dataset has been compiled using field experiments conducted in Yan Yean (Victoria (Vic)), Wagga Wagga (New South Wales (NSW)), Callington and Urrbrae (South Australia (SA)) and Merredin and Dale (Western Australia (WA)) in 2019 and 2020. In each experiment, the Australian Phenology Panel was sown at eight times of sowing from 1 March to 15 June. Emergence and heading dates were collected on all 96 cultivars, and leaf emergence and anthesis dates were collected on a subset of 12 wheat and six barley cultivars.

All cultivars in the Australian Phenology Panel are being genotyped using molecular markers for major development gene alleles and assayed for single nucleotide polymorphisms (SNPs). Genome wide association analysis is being used to identify genetic associations with plant development parameters, with the view to incorporating these genetic parameters into the APSIM Next Gen model or using them as a proxy for phenotypic parameters.

The improved APSIM Next Gen model for predicting cultivar phenology

The APSIM Next Gen model is currently being parameterised using the controlled environment data and then validated against observations of heading date from the field experiments. Incremental improvements to the phenology routine and investigations into sources of error are underway, with promising results. To date, the APSIM Next Gen model has been improved with the addition of two new development stages related to vernalisation saturation and heading, the development of a new phyllocron model and the inclusion of short-day vernalisation.

Figure 2 shows the comparison of simulated and observed heading dates for Mace[Φ], Trojan[Φ] and Wedgetail[Φ] at the four field sites in 2019. The simulated heading dates were modelled using APSIM Classic 7.10, the baseline APSIM Next Gen, and the new APSIM Next Gen model with improvements made using NPI data. In most cases the new APSIM Next Gen model had the most accurate prediction of heading dates. The poor performance of WedgetailA at early times of sowing is suspected to be due to mis-simulation of devernalisation (when vernalised plants experience warm temperatures, resulting in a delay in heading). The modelling team are in the process of improving this aspect of model performance.

New cultivar phenology classification scheme

One of the additional outputs from the NPI is the development of an objective and nationally consistent cultivar phenology classification scheme being developed in collaboration with the Australian Crop Breeders. Until the new NPI tool for predicting phenology is available on the NVT website, these classifications are still important because they help growers make decisions around time of sowing.

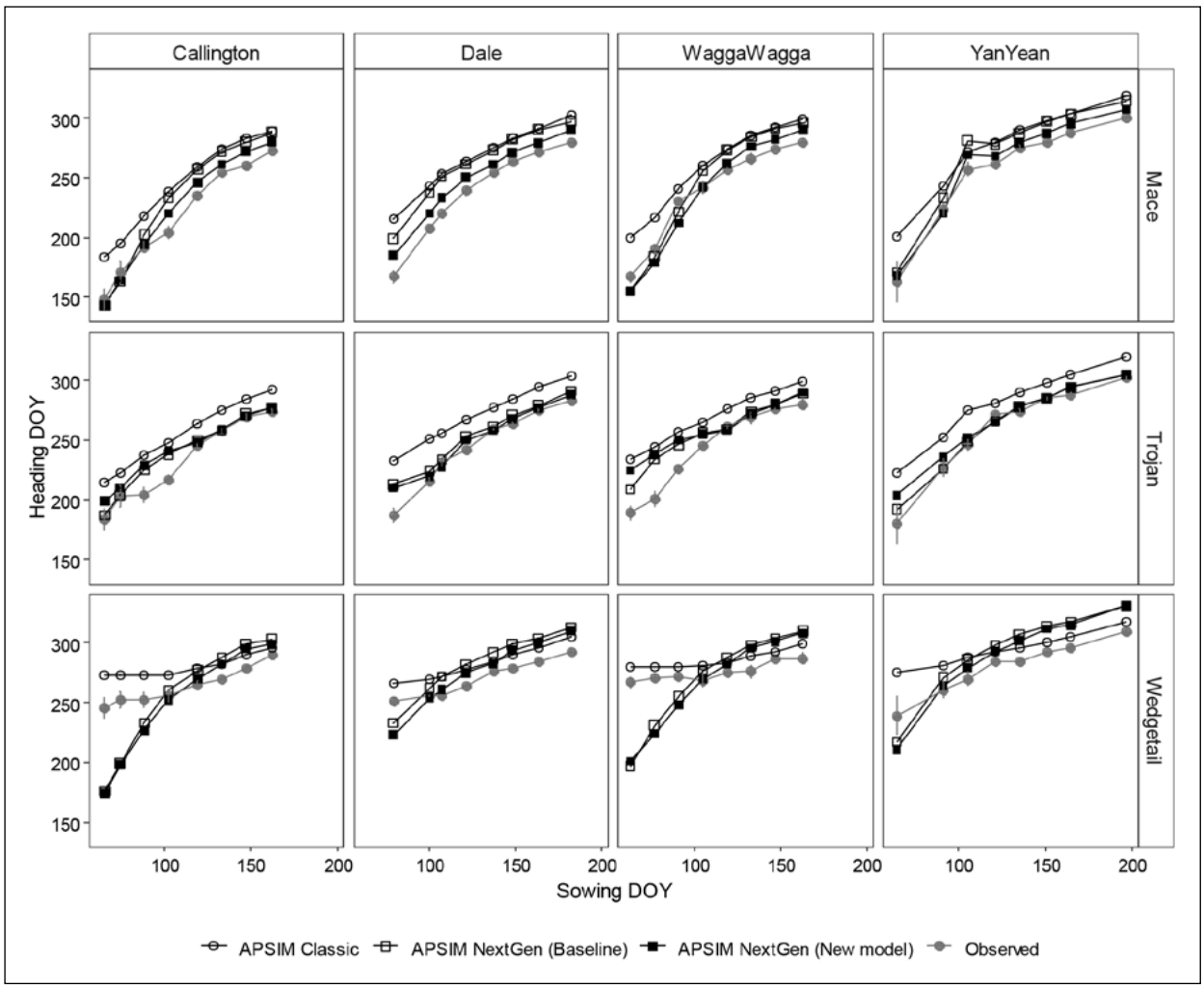


Figure 2. Comparison of ability of APSIM Classic 7.10, APSIM Next Gen (baseline) and APSIM Next Gen (new model) to simulate field observations of phenology. DOY is day of year.

However, the terminology used to describe cultivar maturity or development speed is not consistent across states (e.g., 'early maturing', 'fast maturing', 'short maturity') and the classifications are subjective. In addition, the relative time to heading changes with environment and time of sowing which makes assigning classifications difficult.

Using data from the 2019 NPI field validation experiments (five times of sowing from four field sites in SA, Vic, NSW and WA), cultivars were classified based on their degree days to heading (Figure 3). Wheat and barley cultivars in each environment were ranked according to their relative time to heading and then assigned to phenology groups ranging from 'very quick' to 'very slow'. For each classification an exemplar or type cultivar was selected from the middle of the range.

This new phenology classification scheme is being developed in collaboration with the Australian Crop Breeders' Industry Guide for Wheat Variety Maturity Description (ACB, 2021) and both resources have been used to inform the 2021 GRDC Crop Sowing Guides for South Australia and Victoria (GRDC, 2021). The scheme will be further refined in 2021 using field data from 2020.

New scale of cereal development

The second additional output from the NPI is the production of a new scale of cereal development. Existing scales of crop development like Zadoks' decimal code (Zadoks *et al.* 1974) tend to be ambiguous, subjective, qualitative and non-repeatable. While these scales are useful for describing the development state of an individual plant at a given point in time, they are not designed for identifying the timing of key development stages in a population of plants. For the NPI it was necessary to develop a new scale of cereal development to ensure that data collection was consistent across different experiments, years and operators; to accurately determine the timing of key development stages, and so that data could integrate with the APSIM Next Gen model.

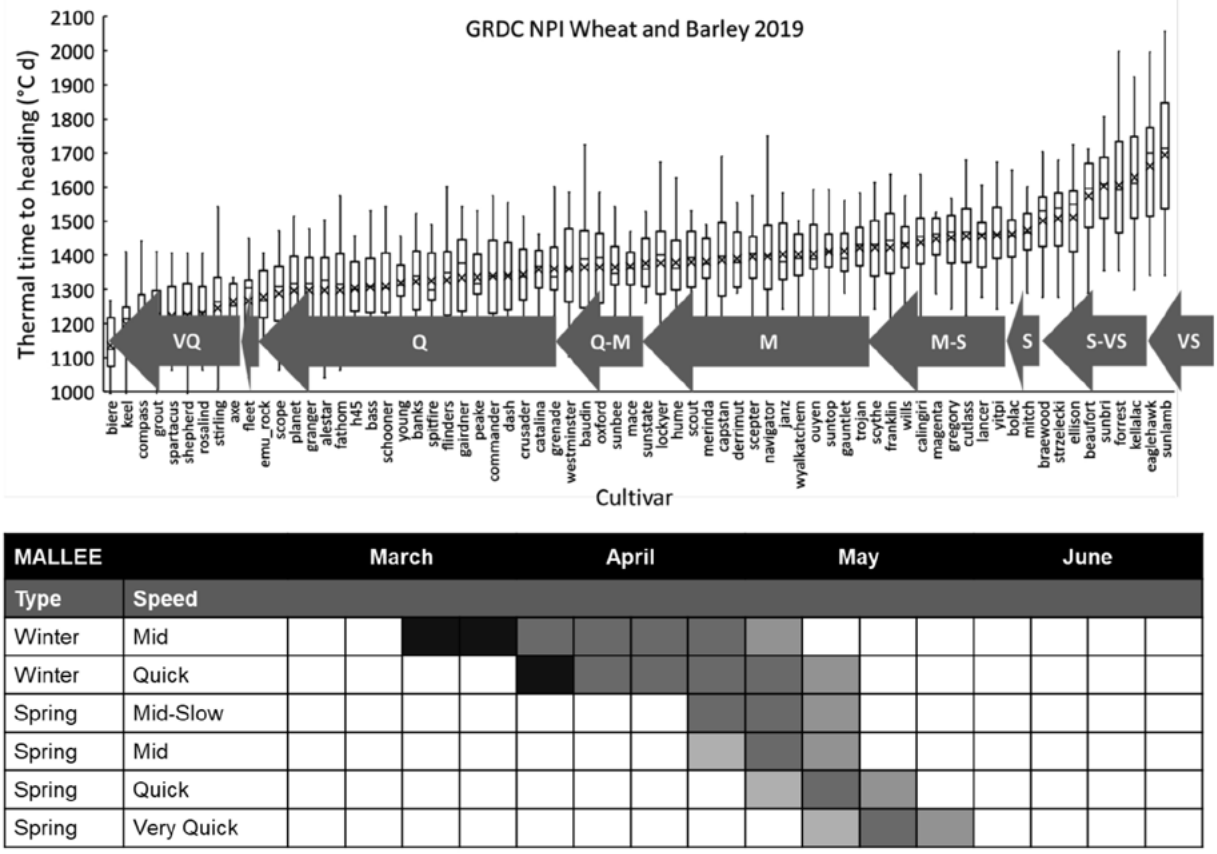


Figure 3. The new cultivar phenology classification scheme ranks cultivars according to thermal time to heading using data from four field sites in SA, VIC, NSW and WA and five times of sowing from mid-April to mid-June. Cultivars can then be assigned into a phenology class using the Australian Crop Breeders maturity guide. This information can then be used to give regional sowing time information as per the annual GRDC Crop Sowing Guides.

The new scale of cereal development has clear protocols for objective, quantitative assessment of each stage that were developed and tested using different operators in the geographically distant NPI field experiments. It identifies the median timing of key development stages; for the NPI, these were the dates of emergence and heading for each cultivar × time of sowing × environment. The scale can be applied to any population of culms. For example, in this new scale of cereal development, 'heading date' in wheat is defined as the date on which 50% of a population of culms have completed heading, with the spike fully emerged. To assess this accurately a fixed population of culms needs to be identified on which regular, repeated assessments are performed so that the population median timing can be identified.

The new development scale is currently being finalised with co-authors and will be submitted for publication this year.

Conclusion

By 2022 the NPI will deliver a tool for growers and advisors that will be able to accurately predict optimal sowing dates for different cultivars across Australia at the point of release. This will allow growers to more readily achieve optimal sowing dates and maximise yields. Underpinning this tool will be an improved APSIM Next Gen model that has been parameterised with controlled environment phenotypic data and genetic data and validated against national time of sowing field experiments. The NPI is also working to develop a new cultivar phenology classification scheme and scale of cereal development that are quantitative and objective.

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, and the authors would like to thank them for their continued support.

Useful resources

Groundcover April 2020 "Optimal sowing times for wheat and barley cultivars may soon be at our fingertips"

https://groundcover.grdc.com.au/crops/cereals/national-phenology-initiative-to-quantify-optimal-sowing-times-for-wheat-and-barley

References

ACB (2021) *An Industry Guide for Wheat Variety Maturity Description.* Available at: http://www.australiancropbreeders.com.au/

Flohr BM, Hunt JR, Kirkegaard JA, Evans JR (2017) Water and temperature stress define the optimal flowering period for wheat in south-eastern Australia. *Field Crops Research* **209**, 108–119.

GRDC (2021) 2021 *Crop Variety Guides.* Available at: https://grdc.com.au/resources-and-publications/all-publications/crop-variety-guides

Holzworth D, Huth NI, Fainges J, Brown H, Zurcher E, Cichota R, Verrall S, Herrmann NI, Zheng B, Snow V (2018) APSIM Next Generation: Overcoming challenges in modernising a farming systems model. *Environmental Modelling and Software* **103**, 43–51.

Keating BA, Carberry PS, Hammer GL, Probert ME, Robertson MJ, Holzworth D, Huth NI, Hargreaves JNG, Meinke H, Hochman Z, McLean G, Verburg K, Snow V, Dimes JP, Silburn M, Wang E, Brown S, Bristow KL, Asseng S, Chapman S, McCown RL, Freebairn DM, Smith CJ (2003) An overview of APSIM, a model designed for farming systems simulation. *European Journal of Agronomy* **18**, 267–288.

Zadoks, J.C., Chang, T.T., Konzak, C.F., 1974. A decimal code for the growth stages of cereals. *Weed Research* **14**, 415–421.

Contact details

Dr Corinne Celestina
La Trobe University
c.celestina@latrobe.edu.au
@c_celestina

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

Return to contents

Notes

Will I get an economic response from applying fungicide to canola for the control of blackleg?

Steve Marcroft[1], Angela Van de Wouw[2], Susie Sprague[3], Andrew Ware[4], Kurt Lindbeck[5], Andrew Wherret[6], Andrea Hills[7] and Nick Perndt[1].

[1]Marcroft Grains Pathology, Horsham; [2]School of BioSciences, University of Melbourne; [3]CSIRO Agriculture & Food, Canberra; [4]EPAG Research, Port Lincoln; [5]NSWDPI, Wagga Wagga; [6]Livingfarm, York; [7]DPIRD Esperance.

GRDC project codes: UOM1904-004RTX, UM00051, CSP00187, MGP1905-001SAX

Keywords

- stubble management, fungicide resistance, seed treatment, upper canopy blackleg, crown canker.

Take home messages

- The canola industry has become more reliant on fungicides to control blackleg, in some regions there is reduced emphasis on cultural practices to reduce disease.
- The decision to use a fungicide is not clear cut and should be based on the disease risk profile of the crop.
- Severe blackleg crown canker occurs when plants are infected during early seedling growth. Prior to sowing, use the BlacklegCM decision support tool to identify high risk paddocks and explore management strategies to reduce yield loss.
- Early vegetative (4-10 leaf) foliar fungicide application should be based on the risk profile of the crop, cultivar blackleg rating and estimation of the potential yield after scouting for leaf lesions.
- Fungicide application decision-making for upper canopy infection is separate to the decision process for crown canker. Fungicide applications to control upper canopy infection can result in variable yield responses. It is important to understand the disease risk before applying a fungicide.
- Knowledge on upper canopy infection is improving and it is likely that decision making will become more reliable. A decision support tool is expected to be released via GRDC investment when there is sufficient confidence on recommendations to aid decision making.

Will I get an economic return from applying a fungicide to my canola crop?

Recently, new fungicide actives and timing recommendations have produced large yield responses. However, these are variable ranging from nil to 20% yield increases in on-farm strip trials and nil to 40% yield increases in small-plot research trials. So how do you determine where your crop will sit in 2021 (i.e., within the nil to 40% response range)?

Predicting a yield response would be very accurate if you knew exactly how much disease will occur, but the level of crop damage caused by disease is determined by numerous interconnected factors. Additionally, other diseases such as Sclerotinia stem rot, white leaf spot, powdery mildew and alternaria can also influence economic returns.

The key is to identify the blackleg risk for each individual crop and then determine the cost of application compared to that of potential yield loss. In most years, this is relatively easy. For example, a

low rainfall year is low risk and in a high rainfall year with high yield potential, it is very easy to gain an economic advantage from fungicide application. But in the decile 4 to 7 years there is lots to be gained or lost from fungicide decisions.

Blackleg crown canker

Do I need a seed treatment and/or fungicide amended fertiliser?

Risk factors:

1. **Canola growing region** – high canola intensity and high rainfall = high risk. One in four-year rotations and 500m isolation between this year's crop and last year's stubble reduces risk.
2. **Cultivar resistance** – cultivars rated resistant (R) to moderately resistant (MR) or above have very low risk of developing crown cankers. Moderately resistant will develop cankers but only if grown under high disease pressure for example, canola/wheat/canola in high rainfall.
3. **Blackleg population** – if you've grown the same cultivar for a number of years and crown canker severity is increasing, you will be at a higher risk of crown cankers if you then sow a cultivar from the same resistance group.
4. **Timing of crop emergence** - severe crown canker is most likely to develop when plants are infected during the early seedling stage (cotyledon to 4th leaf). The driving factors for seedling infection are the growth stage at which first infection occurs and the length of time that the plant is exposed to blackleg infection while in the vulnerable seedling stage. Therefore, the risk of seedling infection that leads to crown canker varies from season to season. For infection to occur, blackleg spores must be mature and ready to release from stubble, a process reliant on a combination of moisture and suitable temperatures. Fruiting bodies typically become ripe approximately three weeks after the break of the season when the stubble has stayed consistently moist. Once mature, spores are then released with each rainfall event. Temperature also determines the length of time that plants remain in the vulnerable seedling stage. Plants are significantly less vulnerable to crown canker after the 4th leaf stage. Older plants will still get leaf lesions, but the pathogen is less likely to cause damaging crown canker as it cannot grow fast enough to get into the crown. Typically, plants sown earlier in the growing season (April) will develop quickly under warmer conditions and progress rapidly past the vulnerable seedling stage compared to plants sown later (mid-May) which progress slowly and remain in the vulnerable seedling stage for an extended period.
5. **Farming system** - inter-row sowing with full stubble retention influences the timing and quantity of ascospores from stubble, which are a primary source of inoculum. Standing stubble stays drier between rainfall events compared to stubble that is lying down and in contact with the soil. Standing stubble delays spore maturation and reduces the release of spores early in the season at the time when fungicide applied to seed and fertiliser are most effective. Standing stubble produces more spores later in the season, however these spores are unlikely to produce severe crown canker but may increase severity of upper canopy blackleg. However, standing stubble that is knocked down 12 months later can then produce spores early the following growing season.

In summary

An economic return is unlikely if sowing an R rated cultivar in a one in four-year rotation in mid-April with >500m from the previous year's canola crop (and you don't retain stubble). If sowing a MS rated cultivar in a canola / wheat / canola rotation at the end of May, you will likely get a large return from your fungicide application. The challenge with seed treatments and fungicide-amended fertiliser is that the decision to use these products is made a long time before sowing (or you don't have any influence over it when you purchase commercial seed), and therefore, you will not know the emergence date, and therefore, the individual season risk. But you will know the risks associated with your canola region, cultivar blackleg rating and distance to last year's stubble.

Do I need a vegetative foliar fungicide application?

As with fungicides applied at sowing, vegetative foliar fungicides applied during 4-10 leaf growth stage are also designed to protect plants from crown cankers. The main advantage with this fungicide timing is that the level of disease risk can be assessed at the time of application, considering the blackleg rating of the cultivar, whether a seed

treatment and/or fungicide amended fertiliser has been used and the prevalence and severity of leaf lesions observed in the crop.

1. Cultivars with effective major gene resistance will have none or very few leaf lesions even under high disease situations and will therefore be protected from crown canker. Cultivars are classified into Blackleg resistance groups (A, B, C, etc) according to their complement of major genes. An abundance of lesions in cultivars which are expected to have effective major gene resistance indicates that the resistance is being overcome and application of a foliar fungicide may be prudent as the underlying level of quantitative resistance is uncertain. In cultivars lacking effective major genes, the blackleg rating gives an indication of the level of quantitative resistance to crown canker, i.e., the level of resistance to crown canker in the plant following leaf infection. All cultivars that are reliant on quantitative resistance may get a similar level of leaf infection but a cultivar with an R blackleg rating will not develop crown cankers whereas an MR cultivar may develop some crown cankers and an MS-S cultivar may have severe cankering and lodged plants.
2. Fungicides applied at sowing will reduce crown canker even on crops with quite severe leaf lesions. In most cases, if a cultivar with adequate resistance is sown with a seed or fertiliser fungicide treatment then a vegetative foliar fungicide is unlikely to be necessary. Monitor your crop and make an in-season decision.
3. Leaf lesions are most damaging on the cotyledons and early leaves, and therefore, a foliar fungicide is most likely to give an economic benefit to protect this vulnerable stage.

Analysis of the fungicide trials clearly showed that fungicides only provided a yield benefit in high disease situations, such as:

1. You may have chosen to grow a cultivar with a lower blackleg rating because the cultivar is the highest yielding or you have chosen to retain seed, etc. For example, it is common practice to grow older cultivars with reduced blackleg resistance and then protect these cultivars with fungicide applications.
2. The pathogen population has changed to render major genes ineffective.
3. The season is very conducive for blackleg with spore maturity coinciding with emergence and the vulnerable stage of crop growth.

Use of the BlacklegCM App is recommended to help make blackleg management decisions. BlacklegCM is an interactive tool allowing users to compare scenarios and determine the likely yield response from altering various disease management strategies.

Upper canopy blackleg fungicide application

Blackleg Upper Canopy Infection (UCI) refers to blackleg infection of the upper stem, branches, flowers and pods. Although research is improving the understanding of these symptoms, there is still a lack of knowledge on how individual cultivars react to UCI in terms of yield loss. Furthermore, our research shows that similar symptoms of UCI can cause severe yield loss in one season and no yield loss in another. As such, our recommendations for managing blackleg UCI are constantly improving.

Should I apply a fungicide for UCI protection?

The question of whether to apply a fungicide for UCI protection is a real dilemma. Get it wrong and it will cost your crop a lot of money, but currently there is no way to accurately predict economic return from fungicide application. GRDC investment is working on improving knowledge, including determining the timing of infection leading to yield loss, weather parameters associated with yield loss and strategies for screening for genetic resistance.

Some factors however that are driving disease risk:

1. **Timing of flowering.**

   Earlier flowering crops are at a higher risk than later flowering crops as they flower in conditions more conducive for blackleg infection. Earlier flowering crops also have a longer period until harvest which allows the fungus to proliferate within the plant, thereby reducing yield potential.

2. **Spring rainfall and temperature.**

   Our preliminary data suggests that UCI, given enough time, will cause damage to the vascular tissue in the stems and branches, reducing yield potential by restricting water and nutrient flow to developing flowers, pods and seed. However, similar levels of disease can cause different amounts of yield loss depending on the weather during

pod fill. Plants without moisture/heat stress can tolerate a higher disease load before it impacts on yield.

3. **Genetic resistance.**

   Genetic resistance is the missing piece of the puzzle. As with crown canker, effective major gene resistance protects against UCI. If it is ineffective or has been overcome, the crop may be completely susceptible to UCI, however, this should have become evident by the prevalence and severity of leaf lesions observed during the seedling stage. The effect of quantitative resistance for crown canker on UCI is currently under investigation. It is clear that cultivars with good quantitative resistance do get UCI symptoms, but we are unsure whether these cultivars have less damage to the vascular tissue than more susceptible cultivars. This could be similar to the way cultivars react at the seedling stage, whereby varieties with the same level of leaf infection develop different levels of crown canker.

4. **Fungicides.**

   Our work has shown a wide window of response times with good results (if you have a damaging level of disease) from fungicide application from first flower to 50% bloom. However, for several reasons, it is suggested that 30% bloom is aimed for. Firstly, the 30% bloom stage is as late as you can go and still get good penetration into the canopy; your main aim is to protect the main stem as this will have a greater impact on yield compared to individual branches. Secondly, this timing may provide some control of any initial infections that have already occurred. Thirdly, the 30% bloom timing will provide protection for a few weeks into the future by which stage any later infections are less likely to result in significant yield loss. Pod infection is unlikely to be controlled through fungicide application. However, there was some control of pod infection at some sites in 2020 by spraying at 30% bloom but this has not been observed in previous seasons. Pod infection occurs when there are rainfall events during podding and the fungal spores land directly on the pods to cause disease, this results in an additional yield loss of up to 20%. Unfortunately, there are no fungicides registered for application during podding due to maximum residue limit (MRL) regulations. Effective major gene resistance will control pod infection.

What are the steps to determining a UCI spray decision?

1. **Yield potential** – yield potential is an economic driver. A 1% return on a 3t/ha crop is worth more money than a 1% return on a 1t/ha crop.
2. **Leaf lesions** – presence of leaf lesions indicates that blackleg is present, and that the cultivar does not have effective major gene resistance. No leaf lesions = no reason to spray.
3. **New leaf lesions on upper leaves as the plants are elongating** – this observation is not critical, but it does give an indication that blackleg is active as the crop is coming into the susceptible window. However, numerous wet days at early flowering stage will still be high risk even if there were no lesions on new leaves up to that point. Remember it will take two to three weeks after rainfall to observe leaf lesions. More lesions = higher blackleg severity.
4. **Date of first flower** – the earlier in the season that flowering occurs = higher risk. This date will vary for different regions. Generally, shorter season regions can, more safely, commence flowering at an earlier date compared to longer season regions. Earlier harvest date results in less time for the fungus to invade the vascular tissue and cause yield loss. Consequently, if you're in a long growing season rainfall region and your crop flowers in early August and is harvested in December, you are in a very high-risk situation.

How can I determine if I should have sprayed for UCI?

1. UCI symptoms are most readily observed at windrowing or even later as the plants mature. They can progress very quickly during this time.
2. Check for external lesions and ensure correct identification.
3. Where lesions are present, slice open the branch/stem and check for blackened pith which is indicative of vascular damage and likely yield loss.
4. Observe darkened branches; these branches go dark after vascular damage and are indicative of yield loss.
5. Pod infection will cause yield loss, unfortunately there is nothing that can be done to prevent pod infection.

6. Leave unsprayed strips to check for yield returns.

Which fungicide active should I use?

There are two parts to the question of which fungicide active should I use? Firstly, in terms of which active will give better control, there are few side by side comparisons that have been undertaken for blackleg control. However, the GRDC blackleg rating project has undertaken comparisons for the seed treatment fungicides which indicate the succinate dehydrogenase inhibitors (SDHI) fungicides provide longer protection compared to the demethylation inhibitors (DMI) fungicides. Ultimately, crop development stage, determining your risk, and therefore, potential economic return are more important factors when choosing a fungicide.

The second aspect of choosing a fungicide active is in regards to managing the risk of fungicide resistance. Resistance towards the DMI fungicides has been detected in approximately 30% of Australian blackleg populations over the past three years whilst no resistance has been detected for the SDHI fungicides. However, excessive use of the SDHI fungicides has the potential to select for fungicide resistance more quickly than DMIs. Therefore, limitations on the number of applications for each fungicide active within a growing season have been developed and can be found at the CropLife website (https://www.croplife.org.au/resources/programs/resistance-management/canola-blackleg/).

If you use a SDHI seed treatment you cannot use a SDHI early foliar (4-8 leaf) application. At this point, SDHI seed treatment and SDHI 30% bloom spray is considered safe. Research will be testing these different scenarios to provide accurate data for modelling fungicide management.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support. The authors would also like to thank Elizabeth Sheedy, Alistair Smith and Buffy Harrison.

Useful resources and references

BlacklegCM App for iPad and android tablets (https://www.agric.wa.gov.au/apps/blacklegcm-blackleg-management-app)

GRDC Publication – Blackleg Management Guide (www.grdc.com.au/resources-and-publications/all-publications/publications/2020/blackleg-management-guide)

GRDC Groundcover - Canola: The Ute Guide (https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-27/canola-the-ute-guide)

Marcroft Grains Pathology website: www.marcroftgrainspathology.com.au

GRDC National Variety TrialsTM website (www.nvtonline.com.au)

Contact details

Steve Marcroft
Marcroft Grains Pathology
Grains Innovation Park
Natimuk Rd, Horsham, VIC 3400
0409 978 941
Steve@grainspathology.com.au

Return to contents

Notes

New tool to predict the likelihood of an inoculation response to Group E and F rhizobia

Ross Ballard[1], Stephen Barnett[1], Daniele Giblot-Ducray[1], Herdina, Kelly Hill, Elizabeth Farquharson[1] and Alan Mckay[1].

[1]South Australian Research and Development Institute; [2]School of Agriculture, Food and Wine, University of Adelaide.

GRDC project code: UOA1805-017RTX (9176500)

Keywords

- rhizobia, DNA, nodulation, nitrogen fixation, pea, bean, lentil, vetch.

Take home messages

- A new DNA soil testing service, PREDICTA® rNod has been developed to measure Group E and F rhizobia numbers in soil to assist growers to identify the need to inoculate field pea, faba bean, lentil and vetch crops.
- PREDICTA rNod is available to South Australia (SA) and Victoria (Vic) growers via PREDICTA® B accredited agronomists in 2021 and will be launched to growers nationally in 2022.
- The DNA test will be a valuable research tool to investigate how soil chemistry and management practices affect the survival of Group E and F rhizobia in soil, nodulation and pulse performance.
- DNA tests for chickpea and lupin rhizobia are also currently under development.

Background

Grain producers have become more proficient atThe number of rhizobia present in soil is a key determinant of legume nodulation, growth and nitrogen fixation and where rhizobia numbers are low, they must be delivered in inoculants applied to the seed or soil.

Rhizobia levels in soil are affected by the frequency of host pulse crops, soil type, soil pH and high temperatures. The lack of a reliable way to estimate rhizobia populations has resulted in many growers applying inoculants as an 'insurance policy', with some of this inoculation likely to be ineffectual. On the other hand, some growers don't inoculate where rhizobia levels are too low which will compromise the nodulation of the pulse crop. Recent expansion of the pulse industry is seeing crops grown in new and marginal environments that are responsive to rhizobial inoculation.

A DNA test that can accurately and rapidly estimate the number of *Rhizobium leguminosarum* bv. *viciae* in the soil has been developed for growers and researchers. This is the species of rhizobia provided in the commercial inoculant Groups E (strain SU303) and F (strain WSM-1455). The test will help growers identify paddocks where field pea, faba and broad bean, lentil and vetch crops will need to be inoculated before sowing or not.

When the test indicates soil rhizobia levels are adequate, growers will be able to consider applying fungicides or trace elements to the seed and/or dry sowing, knowing these practices pose a negligible risk to legume nodulation.

The test will also enhance research capacity to understand how inoculation and agronomic practices (e.g., liming or rotation) influence rhizobia number in the soil and affect the performance of pulse crops.

This paper describes the development and evaluation of the DNA test that measures the number of *Rhizobium leguminosarum* bv. *viciae*, in soil.

Methods

The new rhizobia DNA test is based on a qPCR assay (TaqMan MGB), specific for *Rhizobium leguminosarum* bv. *viciae* (hereafter referred to as E and F rhizobia).

Specificity of the test was investigated using DNA extracted from 83 cultures of rhizobia, comprising 42 strains of E and F rhizobia and 41 strains of non-target closely and distantly related rhizobia (Table 1).

Sensitivity of the DNA test and correlation with viable rhizobia numbers per gram of soil were determined by calibrating the DNA test against the Most Probable Number (MPN) plant nodulation bioassay (Vincent 1970), using vetch cv. Timok[Φ] as the trap plant. This study used 41 field soil samples collected from cereal stubbles between December 2019 and February 2020.

Nitrogen (N) fixation capacity of the soil rhizobial communities was also determined in a greenhouse experiment. Shoot dry weight of field pea (cv. Kaspa[Φ]) and faba bean (cv. Samira[Φ]) reliant on the soil rhizobia for growth was compared with the shoot dry weight of plants inoculated with commercial inoculant strains SU-303 (Group E for pea) or WSM-1455 (Group F for bean).

Spatial variation of E and F rhizobia across paddocks, and on and off row was measured in three grower paddocks using the DNA test, to determine suitable paddock sampling strategies.

Results and discussion

Specificity of the DNA test

A DNA test has been designed to detect only E and F rhizobia that nodulate field pea, faba bean, lentil and vetch (Table 1). The test does not detect strains of the closely related clover rhizobia (*Rhizobium leguminosarum* bv. *trifolii*). This is important because both biovars often coexist in many paddocks. Additionally, the test does not detect more distantly related rhizobia.

Sensitivity and correlation to viable rhizobia in soil

The DNA and MPN plant bioassay methods were significantly correlated across 41 soil samples.

The MPN test was more sensitive at lower levels of rhizobia (<200 rhizobia/g soil), with several instances of detection by the plant bioassay, but not the DNA test (Figure 1).

The DNA test was able to reliably detect around 1,000 cells/g soil and was more precise than the MPN test when rhizobia DNA levels exceeded this level. Overall, there was a high correlation (adjusted R^2=0.86) between the log transformed measures of the MPN and DNA tests.

As few as 100 rhizobia/g soil are sufficient to nodulate pulse crops in the field, similar to the number applied with peat inoculant on seed. The testing service will use conservative thresholds; soils with >1,000 to 5,000 rhizobia/g (log_{10} >3 to 3.7) will be assigned a low likelihood of response to rhizobia inoculation, and >5,000 rhizobia/g soil to indicate a negligible likelihood of inoculation response.

Based on previous surveys of E and F rhizobia in soils (Drew *et al.* 2012), it was expected that around 30% of soils will be classified as having a low or negligible likelihood of response to inoculation with E and F rhizobia.

For the soils tested, several unexpected results were noted. These included instances of high E and F rhizobia numbers (2,971/g soil) despite no known history of a pulse host crop and conversely, low rhizobia numbers (111/g soil) despite inoculated faba bean having been grown in 2015. These variations underline the value of the new test in helping better target the inoculation of pulse crops.

Nitrogen fixation capacity of soil rhizobia

Ten of the field soils in Figure 1 were estimated to contain more than 1,000 E and F rhizobia/g soil (after conversion from raw DNA data), and therefore, were predicted to have a low likelihood of response to rhizobia inoculation. The N-fixation capacity of the

Table 1. Specificity results (detected, not detected) for the DNA test targeting E and F rhizobia, includes 14 rhizobia species and 83 strains.

Legume (rhizobia Group)	Strains tested	Detected	Not detected
Pea, vetch, bean, lentil (Group E & F)	42	42	0
Clovers - close relative (Group B & C)	20	0	20
Medic and lucerne (Group AM & AL)	8	0	8
Ten other rhizobia species	13	0	13

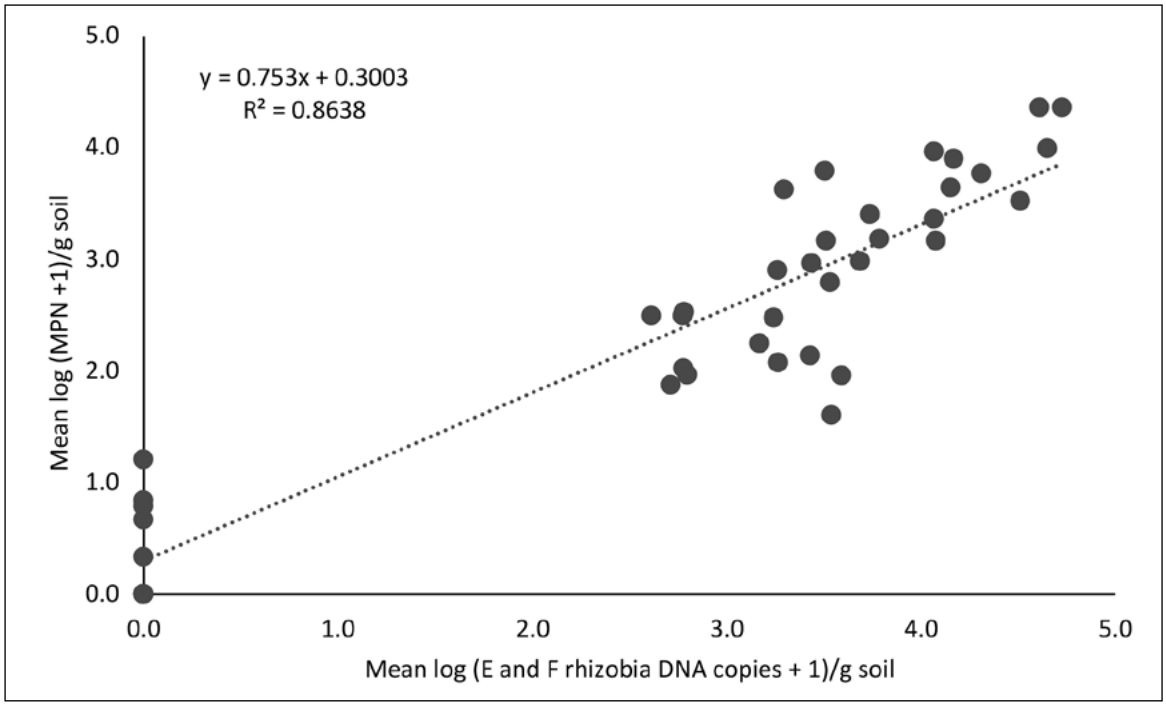


Figure 1. Relationship between E and F rhizobia DNA copies/g soil measured by DNA test and rhizobia number/g soil measured by Most Probable Number (MPN) plant nodulation bioassay, for 41 soils collected between December 2019 and February 2020.

rhizobial communities in these soils with field pea and faba bean is shown in Table 2.

With field pea, N–fixation capacity ranged for 64 to 99% relative to inoculant strain SU-303, and with faba bean from 39 to 107% relative to WSM-1455. With the exception of Soil 10, the N-fixation capacity of the soil communities should be high enough to supply sufficient fixed N for field grown plants, because plant growth rate and demand for N is lower in the field compared to plants grown in the greenhouse. Even though the rhizobia in Soil 10 were less effective, the site would be unlikely to respond to inoculation due to competition from the soil rhizobia community, so the DNA test prediction of a low likelihood of inoculation response remains reasonable.

Soil sampling

Several aspects of soil sample collection have been examined to develop suitable sampling protocols.

Table 2. Nitrogen fixation capacity of E and F rhizobia (*Rhizobium leguminosarum* bv. *viciae*) communities predicted by the DNA test to exceed 1000/g soil. N-fixation capacity calculated as % of shoot dry weight for field pea inoculated with SU-303 and faba bean inoculated with WSM-1455.

Soil	DNA copy number #/g soil	Predicted MPN E/F rhizobia/g soil	N-fixation capacity Pea, % SU-303	N-fixation capacity Bean, % WSM-1455
Soil 1	49,201	6,792	74	104
Soil 2	47,284	6,592	92	107
Soil 3	32,331	4,951	69	78
Soil 4	20,728	3,542	72	85
Soil 5	16,410	2,971	99	107
Soil 6	13,380	2,547	70	84
Soil 7	12,710	2,451	70	89
Soil 8	11,493	2,272	97	76
Soil 9	4,740	1,166	94	73
Soil 10	4,187	1,062	64	39

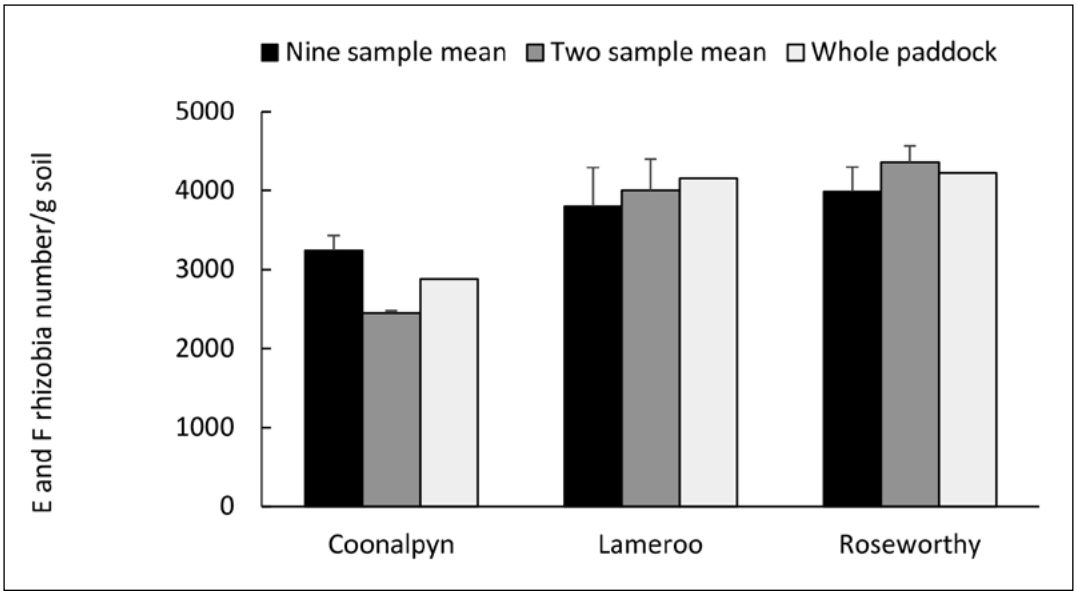


Figure 2. Effect of paddock sampling frequency (nine, two or one sample locations) at three field sites on mean predicted E and F rhizobia number/g soil. Bars above columns indicate standard error.

Spatial variation across paddocks

Where there are obvious differences in soil type or management zones within a paddock, each zone should be sampled separately for testing. This requirement is illustrated in the following examples:

- Samples from areas in a paddock that differed in pH_{Ca} (5.0 or 7.1) also varied in predicted E and F rhizobia number, 288 and 2,971/g soil, respectively.
- Samples collected from hills and flats in a paddock, varied in predicted E and F rhizobia number, 375 and 1,062/g soil, respectively.

In both examples, E and F rhizobia numbers in the different zones would be assigned to different categories of inoculation requirement in the report generated for growers.

Where paddocks were 'uniform' in soil type and management, mean E and F rhizobia numbers were similar, regardless of whether the paddock was sampled as a whole (single test sample of 500g, 45 cores), as a split paddock (two 500g test samples) or from nine different sectors (Figure 2).

The effect of sampling within or between cereal stubble rows on the number of E and F rhizobia was also investigated. Levels were not different between locations (P = 0.218) in three different paddocks (Table 3). Hence, samples for the E and F rhizobia DNA test can be taken from either position.

Time of sampling

Results to date have been based on dry soil samples collected in February preceding the pulse crop, by which time rhizobia populations have declined to levels approximating numbers persisting at the break of season.

Investigations are currently underway to determine if earlier sampling times (Oct-Nov) in the year before the pulse crop can provide a reliable estimate of rhizobial number persisting through to the next season. This timing will align with the timing of inoculant orders.

Table 3. Effect of sample position, within or between rows of cereal stubble, on the predicted number of E and F rhizobia/g soil at three field sites. Each value is the mean of nine 500 g paddock samples.

Location	Predicted E and F rhizobia number/g soil (0-10 cm)	
	Within stubble rows	Between stubble rows
Coonalpyn, SA	3,914	3,238
Lameroo, SA	4,391	3,802
Roseworthy, SA	4,832	3,991
Mean of all sites	4,028	3,677

Recommended PREDICTA rNod soil sampling protocol

For 'uniform' production zones, it is recommended that a composite 500g soil sample made up of three cores (10 mm wide x 100mm depth) is collected at each of 15 locations within a production zone or soil type (total 45 cores/sample). Unlike disease testing, there is no need to target the rows of the last crop or to add stubble.

Research applications

The rhizobia DNA test for E and F rhizobia will improve the efficiency of research programs and provide agronomists with a tool to understand the impact of management practices, such as liming, on soil health. The test has already been used successfully to:

- Select trial sites free of rhizobia group E and F for inoculation experiments.
- Compare the colonisation of soils by different inoculant strains.
- Quantify nodulation on legume roots to compare management practices.

As commercial and research sample results become available, it will be possible to generate regional summaries of rhizobia status, on a scale that has not previously been possible.

Conclusion

A new DNA test has been developed to measure E and F rhizobia numbers in soil prior to sowing field pea, faba and broad bean, lentil and vetch.

The E and F rhizobia test will form the basis of a new service, PREDICTA rNod, which will be available to SA and Vic growers from February 2021, via PREDICTA B accredited agronomists.

The test will indicate that inoculation responses are unlikely when E and F rhizobia numbers exceed 1,000 cells/g soil. Soil pH and texture results will also be reported to assist with interpretation.

Soil samples can be collected from the start of February, when rhizobia numbers should approach levels persisting at the break of season. Use PREDICTA rNod kits to submit a composite 500g soil sample made up of three cores (10 x 100mm) collected at each of 15 locations within a production zone (total 45 cores/sample).

More soils are being added to the calibration data set to support the release of the test nationally.

Further work is also being undertaken to investigate earlier sampling for growers who want to know inoculant requirements at least six months before seeding a pulse crop.

Tests for chickpea and lupin rhizobia are under development and are expected to be released in 2022.

Acknowledgements

This research was initiated by the GRDC Bilateral Project DAS00137 and completed by the Bilateral Project UOA1802-019BLX. Calibration of the test has been undertaken by the GRDC funded Nitrogen Fixation Program UOA1805-017RTX (9176500). This is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support.

The authors would also like to thank the following agronomists and growers for their support and provision of soil samples; Andy Bates, Michael Hind, Simon Mock, Jeff Braun, Mick Faulkner, Andrew Heinrich, Sam Trengove, Stuart Sherriff, John Matheson, Peter Maynard and Neville Kernick.

Useful resources

Inoculating Legumes: A Practical Guide:

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

PREDICTA B Agronomist Broadacre Soilborne Disease Manual V10.4: http://rootdisease.aweb.net.au/

PREDICTA rNod kits available from PREDICTA B accredited agronomists and Russell.burns@sa.gov.au

References

Drew EA, Denton MD, Sadras VO, Ballard RA (2012) Agronomic and environmental drivers of population size and symbiotic performance of *Rhizobium leguminosarum* bv. *viciae* in Mediterranean-type environments. Crop and Pasture Science. 63: 467-77.

Vincent JM (1970) 'A manual for the practical study of root nodule bacteria.' (Blackwell Scientific Publications: Oxford)

Contact details

Ross Ballard
SARDI Soil Biology and Diagnostics
GPO Box 397, Adelaide SA, 5001
+61 8 8429 2217
ross.ballard@sa.gov.au

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

Return to contents

Notes

Notes

The agronomic value of precision planting technologies with winter grain crops

Glenn McDonald[1], Jack Desbiolles[2], Claire Pickles[3], Genevieve Clarke[3], Sarah Noack[4], Rebekah Allen[4], Ashleigh Amougis[5], Jon Midwood[5], Stefan Schmidt[6] and David Minkey[7].

[1]The University of Adelaide, [2]The University of South Australia, [3]Birchip Cropping Group, [4]The Hart Field Site Group, [5]Southern Farming Systems, [6]Ag Consulting Company, [7]WANTFA.

GRDC project code: 9176134

Keywords

- crop establishment, seeding, grain yield, inter-plant spacing, seed singulation.

Take home messages

- Precision planting improved the uniformity of crop stands and often allowed reductions in plant density without loss of yield.
- Potential benefits will be greatest in crops with high seed input costs.
- Grain yield responses to precision planting have been variable in project trials to date and suggests adoption of the technology may not be warranted based on crop yield response alone.
- Growers using precision planting in winter crops have often struggled because of lack of technical support and have reported variable benefits, but they have provided recommendations for adoption of the technology and field operation.
- Precise and smart seeding technology is evolving rapidly with air-seeder based transitional options becoming available, which may allow a more practical and cost-effective pathway to greater planting precision.

Background

Precision planting technologies are designed to place seed at a consistent depth and interplant distance within a row to promote uniform emergence and to minimise interplant competition. The ability to precisely locate a single seed in the seeding row is referred to as singulation. Precision planters first appeared in the post-war era as a technology to improve yield in maize and they have been used extensively since then in a wide range of summer crops where expensive and high vigour hybrid seeds are planted at relatively low plant populations. The ideal case is to have every seed planted producing a productive plant and, by reducing interplant competition, to have uniform growth of plants within the stand to maximise yield per plant.

Currently most commercial precision planters use disc seeding systems with a vacuum or positive pressure seed singulation system located on each seed row which allows accurate placement of individual seeds within the row. This technology is well-known to summer crop growers in the northern region, but it is in its infancy in the southern and western regions.

The recent interest in using precision planting technology with winter crops, especially in hybrid canola, has been prompted in part by a desire to reduce the costs of using hybrid seeds and has been spurred on by reports that even placement of seeds improves yields at low plant densities, which would allow significant reductions in seeding rates. For example, field trials in Canada (Yang *et al.* 2014) reported yields with equally spaced canola plants up to 20% and 32% higher compared

to uneven spacing at low and high yielding sites, respectively. More recent work in Western Australia (WA) in canola and lupin have indicated that even spacing, to minimise interplant competition, may allow a reduction of sowing rates below current recommended rates, with predicted savings of $24/ha in seed of hybrid canola (Harries *et al.* 2019).

While these results are encouraging, there has been no systematic assessment of the value of precision planting technology in winter crop production for small grain crops in Australia. The aim of the current project is to assess the value of precision planting in canola and numerous pulse crops in the southern and western regions. The project has three main components:

(i) A paddock survey of establishment in a number of crops in 2018 and 2019 in the southern and western regions to assess the variation in seedling emergence and seedling depth and to examine what factors may contribute to this variation;

(ii) a series of small-scale and large-scale trials comparing conventional sowing (either a cone seeder or an air-seeder) with precision planting; and,

(iii) a qualitative survey of current users of precision planters for winter grain crops.

This paper focusses on the results of the field trials and the experiences of growers using precision planters. The results of the crop survey have been reported previously (McDonald *et al.* 2020).

Method

A series of small plot trials was conducted between 2018 and 2020 using a purpose-built 6-row seeder that could sow seeds as a conventional cone seeder or as a precision planter. The precision planting units used in Victoria (Vic) and South Australia (SA) were commercial row units supplied by Spot-on-Ag, in Boort, Vic (Table 4). The trial at Merredin in 2019 used a small plot seeder operated by WA DPIRD with the capacity for singulation as well as conventional sowing. Both plot seeders used disc seeding systems, except in 2018 when cone seeding could only be done with a tyned seeding system. Details of the trials are given in Table 1.

Large scale trials were also conducted with canola and faba bean near Skipton in western

Table 1. Details of the small plot trials conducted between 2018 and 2020.

Year and site	Crops	
2018, 2019		
Birchip	Canola	Seeding method (Conventional, Precision)
Hart	Lentil	Plant density (6)
		Row spacing (23cm, 30cm)
2019		
Roseworthy	Canola	Seeding method (Conventional, Precision)
		Plant density (5)
	Faba bean	Seeding method (Conventional, Precision)
		Seed treatment (Graded, Ungraded)
		Plant density (10, 20 seeds /m^2)
2019		
Merredin	Lupin	Seeding method (Conventional, Precision)
	Canola	Plant density (4)
2020		
Horsham	Canola	Seeding method (Conventional, Precision)
		Plant density (4)
	Faba bean	Seeding method (Conventional, Precision)
		Row spacing (23cm, 46cm)
		Plant density (4)
2020		
Hart	Canola	Seeder type (Conventional, Precision)
	Chickpea	Plant density (4)
	Wheat	

Victoria using a Väderstad airseeder (Seedhawk model in 2018; Rapid model in 2019) and a Väderstad precision planter (Tempo). Each trial compared the responses to row spacing (25cm versus 50cm) and sowing rate (recommended versus half-recommended) and were sown in plots 150m long.

In all trials, seedling emergence at five weeks after seeding, interplant distance at seedling emergence, normalised difference vegetation index (NDVI), biomass production at flowering or peak biomass, grain yield and yield components were measured. All trials were replicated and randomised and were designed either as split plot or as complete factorial trials with between four and six replicates. The uniformity of seed placement within the rows was assessed by the coefficient of variation (CV) of the interplant distance.

Survey of growers using precision planters

Growers who have been using precision planters with winter grain crops were surveyed. Twenty-one growers were identified in New South Wales (NSW), Vic, SA, Tasmania (Tas) and WA and thirteen interviews were conducted either by phone or face-to-face, guided by a questionnaire. The aims of this qualitative survey were to document the reasons for adopting precision planting, record what growers considered to be the benefits of precision planters over conventional air-seeders, and to record their experiences with adopting and using the technology, including the problems and limitations of precision planting.

Results and discussion

Plot trials

The emergence rate of the trials varied considerably (Tables 2 and 3). In the canola trials there were both significant increases and reductions in seedling establishment with precision planting (Table 2), however there was a consistent improvement in the uniformity of the interplant spacing with a 20-40% reduction in the CV for interplant distance. In most trials there was no significant difference in the yields between the two seeders, with significant differences being measured in two of the nine trials; in both cases precision planting improved yields.

Crop establishment in the pulses were generally higher than in canola, but as with canola, there was no consistent effect of precision planting on establishment and crop uniformity was improved substantially (Table 3). Precision planting improved grain yield by 18% or 22% in faba bean and significant increases of 10% (lupin) and 14% (lentil) were also measured. The results for canola and pulses indicated that despite variable effects on establishment, precision planting resulted in yields equivalent to or higher than those achieved with conventional sowing.

The relationships between grain yield and established plant number were examined because of the variable effects of precision planting on both plant number and yield. Among all the trials, three types of responses were evident (Figure 1 and 2): no difference in the response to plant density

Table 2. Summary of the effects of conventional and precision seeding on crop establishment, the uniformity of plant spacing and grain yield in canola. The trial at Skipton used commercial seeding and planting equipment in large plots and the remaining experiment used a small plot seeder. The significance of the difference between the precision planter and the conventional seeder is indicated: *** - P<0.001; ** - P<0.001; * - P<0.05; NS = not significant.

Site and year	Conventional sowing			Precision planter		
	Crop establishment (%)	Interplant distance CV (%)	Grain yield (t/ha)	Crop establishment (%)	Interplant distance CV (%)	Grain yield (t/ha)
Hart 2018	90	101	1.38	65***	77***	1.39 NS
Birchip 2018	64	103	0.35	59 NS	80***	0.37 NS
Hart 2019	67	99	0.54	64NS	72***	0.61*
Birchip 2019	105	103	2.15	82**	66***	2.21 NS
Roseworthy 2019	51	89	0.98	68***	61***	0.98 NS
Merredin, 2019	88	-	0.34	69***	-	0.39 NS
Skipton 2019	102	85	2.64	76***	78NS	2.68 NS
Hart 2020	48	94	1.01	52NS	59*	1.06 NS
Rupanyap, 2020	100	99	3.40	83NS	73***	3.62*

Table 3. Summary of the effects of conventional and precision seeding on crop establishment, the uniformity of plant spacing and grain yield in pulse crops. The trials at Skipton used commercial seeding equipment in large plots and the remaining experiment used a small plot seeder. The significance of the difference between the precision planter and the conventional seeder is indicated: *** - P<0.001; ** - P<0.001; * - P<0.05; NS = not significant.

Site and year	Conventional sowing			Precision planter		
	Crop establishment (%)	Interplant distance CV (%)	Grain yield (t/ha)	Crop establishment (%)	Interplant distance CV (%)	Grain yield (t/ha)
	Faba bean					
Skipton, 2018	125	84	1.33	115*	34***	1.57*
Skipton, 2019	129	86	3.95	124^{NS}	41***	3.91^{NS}
Roseworthy, 2019	86	81	2.23	72**	39***	2.25^{NS}
Rupanyap, 2020	69	104	4.56	89**	66***	5.57**
	Lentil					
Hart, 2018	101	-	1.21	77*	-	1.38*
Birchip, 2018	97	102	0.91	106^{NS}	63***	0.88^{NS}
Hart, 2019	59	95	2.55	50**	70***	2.43^{NS}
Birchip, 2019	114	99	0.69	81***	73***	0.64^{NS}
	Lupin					
Merredin 2019	105		0.70	94^{NS}		0.77*
	Chickpea					
Hart, 2020	64	89	0.99	60^{NS}	58***	1.10**

between the conventional and precision planting, a consistent yield advantage of precision planting over a range of plant densities and a greater ability to maintain yields at low density by precision planting. A consequence of the latter two responses is that precision planting would allow a reduction in plant density with little or no yield penalty. Similar relationships were reported by Harries *et al.* (2019) in comparisons between unevenly spaced and evenly spaced plantings (Figure 3), suggesting the responses observed in the current trials were associated with differences in the uniformity in plant spacing within the crop. The potential economic benefit of this is the saving on seed costs from producing the same yield with fewer plants/m^2 and little yield penalty. However, the responses to precision planting varied among experiments and it is still unclear what the main factors that influence the response are.

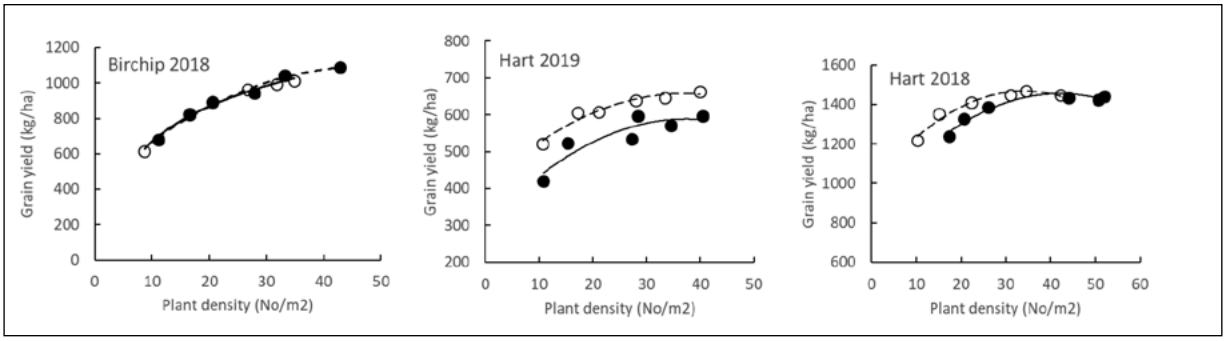


Figure 1. The relationships between the established number of plants/m^2 and the yield of canola sown either with a conventional cone seeder (●) or a precision planter (O) at 3 sites.

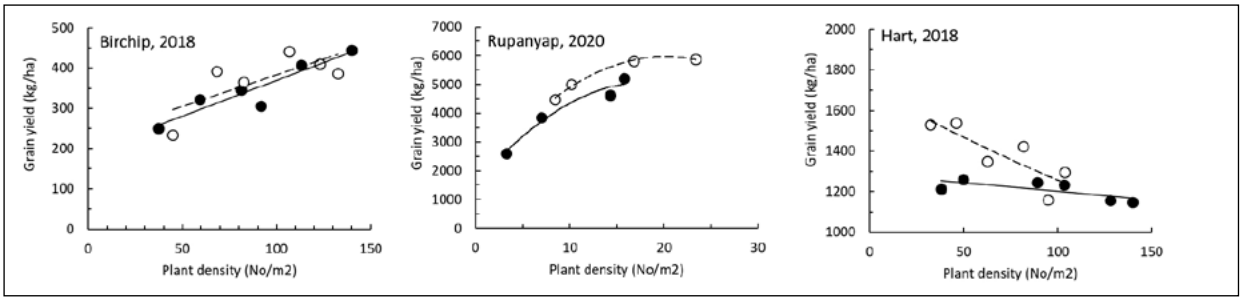


Figure 2. The relationships between the established number of plants/m^2 and the yield of pulse crops sown either with a conventional cone seeder (●) or a precision planter (O). The crops were lentil (Birchip, 2018, Hart 2018) and faba bean (Rupanyap, 2020).

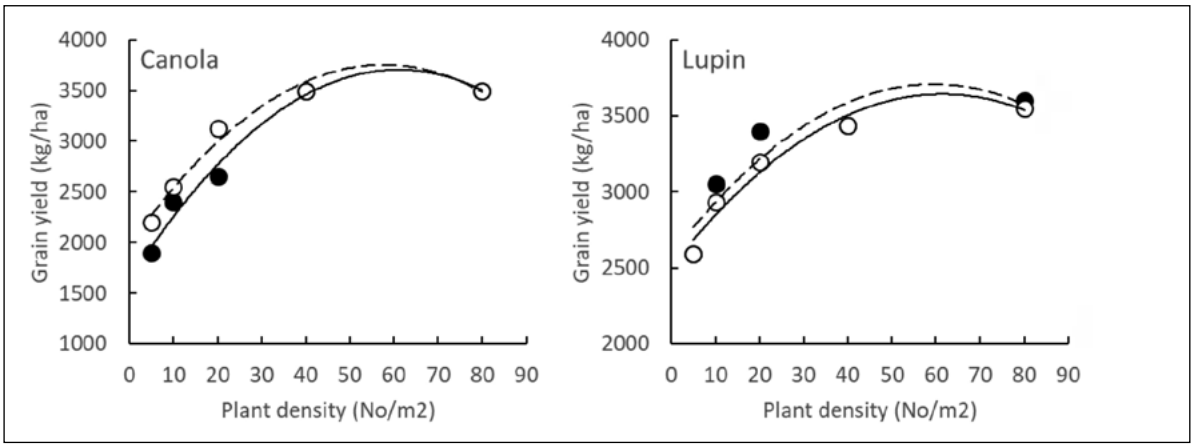


Figure 3. The response to plant density in canola and lupin by plants that were unevenly spaced (●) or evenly spaced (O) in trials in Western Australia (after Harries *et al.* 2019).

Precision planting grower survey

A small number of growers are pioneering the use of precision planters in winter cropping across the southern and western regions, with most located in Vic. There was a wide range of equipment used, ranging from old summer crop planters to newer, high-technology precision planters. About half the growers grew irrigated crops with a significant component of maize cropping, while in dryland systems numerous growers have also grown opportunity summer crops, often as part of their adoption of precision planters. The standard planting equipment comprised twin disc row units, with only one planter in WA using tyne-based row-units. Precision planters were used mainly to sow canola and a range of pulse crops (faba bean, lentil and chickpea), with some limited attempts at planting cereals.

The reasons given for initially adopting the technology included an anticipation of improved accuracy of seed placement with discs, resulting in better and more even crop emergence, an even distribution of seeds in-furrow to minimise interplant competition, and reports from overseas of reduced seed costs per hectare. The growers confirmed these benefits and reported reduced seed costs per hectare, especially with hybrid canola, as well as more uniform crop emergence and vigour, and improvements in accuracy of seed placement. Improved yields were not always reported, but when cited, occurred mainly in canola and faba bean. However, improved yields were often not the primary aim of adopting precision planting: major considerations were improving crop establishment and increasing the uniformity and vigour of the crop stand, improved crop-weed competition and providing growers with the option of reducing seed costs without a loss in yield. Some growers did not consider seed cleaning and grading (which is necessary for precision planting) as additional costs because they considered these as part of best practice for integrated weed management, irrespective of the seeding system.

The main problem and limitation that the growers encountered with the use of precision planters was the lack of local technical support and advice, unlike growers and dealers in the northern regions where precision planter technologies are well-known. Growers who had acquired lower cost, older generation planters encountered the most

difficulties with adapting their equipment (designed for summer crops) to winter cropping. Key issues highlighted by the growers included:

- Row-unit spacing was too wide for pulses and canola, necessitating two passes at planting.
- Limited or no ability to band fertiliser with the seed, requiring a separate operation and expected lower fertiliser use efficiency.
- No seed plates suitable for winter crop seed sizes, shapes and seed rates, necessitating the trial-and-error development of new ones or making do with sub-optimal seed delivery.
- Unsuitable row-hopper capacity for winter grain crops.
- Regular checks needed because there was no control system providing real-time feedback on performance.
- Planting performance was significantly affected by speed and paddock roughness.

The practical difficulties growers faced with trying to adapt new technology to their farming systems led to some limited dis-adoption of precision planters, but not a rejection of the technology. One early adopting and innovative grower commented they were now "...waiting for better technology to handle sticky clay conditions.... despite some definite success." Growers provided the following key recommendations for adopting and operating precision planters:

- Precision planting = precision placement 1st and seed singulation 2nd (i.e., the benefits of seed singulation are not realised unless accurate seed placement can be delivered, through technology features, settings and operation, and including low paddock roughness).
- Plan the shift to precision planting, and address soil constraints, paddock preparation, seed grading/cleaning/quality, residue, weed management and logistics.
- Do some homework; research, talk to users and manufacturers, and look internationally for up-to-date information.
- Ensure technical support is available with the choice of technology or be ready to struggle.
- Be confident in your choice of planter or delay selection until you are.
- Hi-Tech planters may not imply higher cost-effectiveness.
- Use clean seeds, graded and of high quality.
- Keep an eye on performance, monitor regularly, be conscious of speed.
- Precision planting of larger seeds is less challenging when starting.

Field survey: precision planters versus air seeders

The paddock survey on crop establishment included four paddocks of two growers currently using precision planters, which allowed a limited comparison of commercial performance relative to conventional air-seeders. One grower was from the southern region and one from the western region. There was no consistent difference in crop establishment between paddocks sown with precision planters and conventional seeders (data not shown). In comparison with canola crops sown using conventional seeders, three of the four paddocks sown with a precision planter had lower-than-average variation in plant numbers and seedling depth (Figure 4 and 5), but there were also a number of paddocks sown with air-seeders that showed similar or greater uniformity in plant number and seedling depth. These results suggest that while precision planters increase the ability to improve the uniformity of crops stands, there are still substantial gains that can be achieved using conventional air-seeder equipment and good results can also be achieved through careful settings and operations, and with the adoption of 'precision seeding systems'.

The project also evaluated the impact of precision planter settings on performance, highlighting the rapid negative impacts of high planting speed and sub-optimal vacuum levels on seed singulation quality. Figure 6 shows an example of a calibration with field peas on the coefficient of variation output by the sensor-based monitoring system. The data, which correlated very well with weight-based seed rate calibration, show good to excellent singulation quality (%CV≤15) at 3km/h and very satisfactory quality (15≤%CV≤30) at 6km/h with sufficient vacuum level (> 18 " H2O). Performance at 9km/h was sub-optimal with the 21-slot disc used, while a 35-slot disc could slow down the disc rotation by 40% and align the 9km/h performance between that of the original 3 and 6km/h.

Current developments in precision planting technology

There is a wide range of precision planter technologies commercially available, increasingly trending towards 'Intelligent Planting', using hi-tech sensor-based real-time monitoring and automation. Information from the major manufacturers and

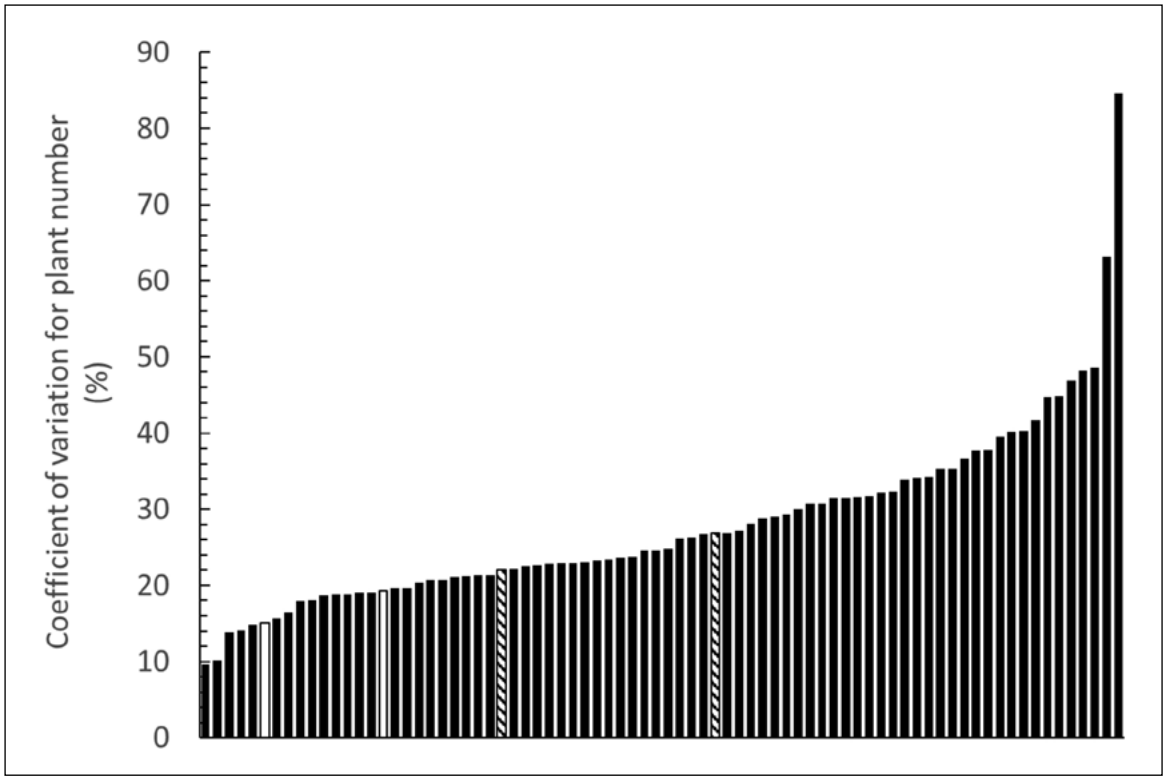


Figure 4. The range in the coefficient of variation in mean plants/m^2 across 10 sampled seeding rows for 78 canola paddocks surveyed in the southern and western regions in 2018 and 2019. Paddocks sown with precision planters from the southern regions are indicated by white columns and from the western region by cross-hatched columns.

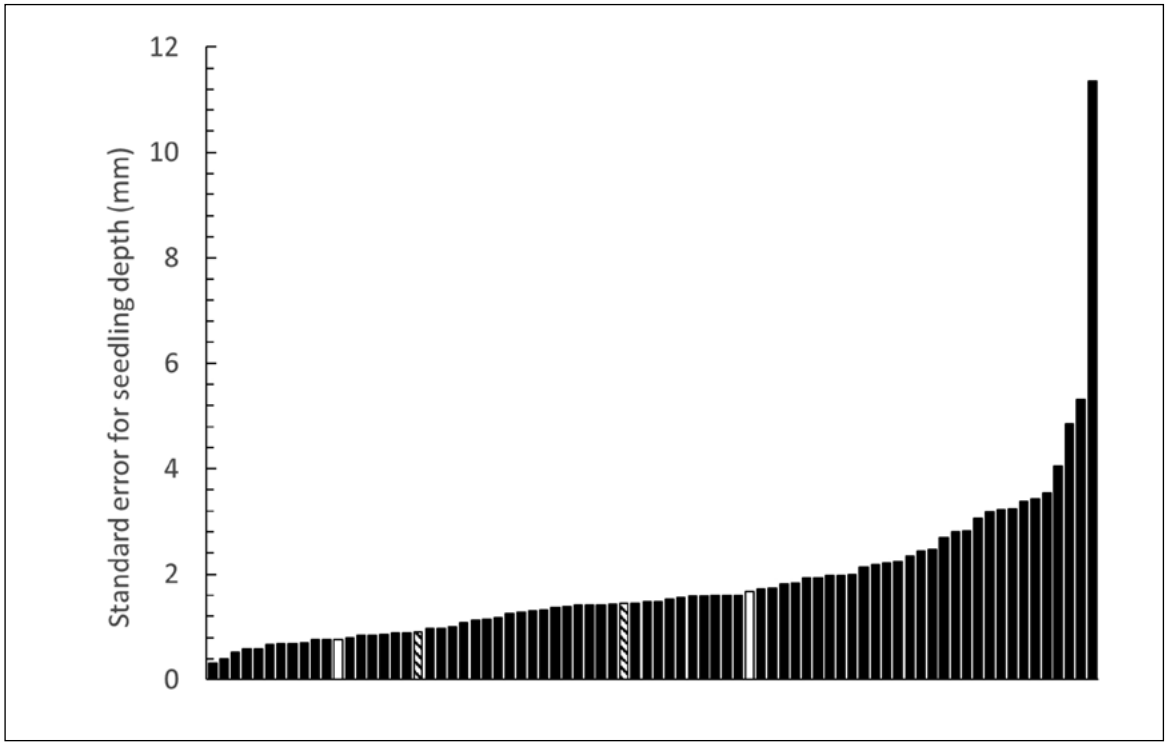


Figure 5. The range in the standard error for mean seedling depth in 10 sampled seeding rows among 78 canola paddocks surveyed in the southern and western regions in 2018 and 2019. Paddocks sown with precision planters from the southern regions are indicated by white columns and from the western region by cross-hatched columns.

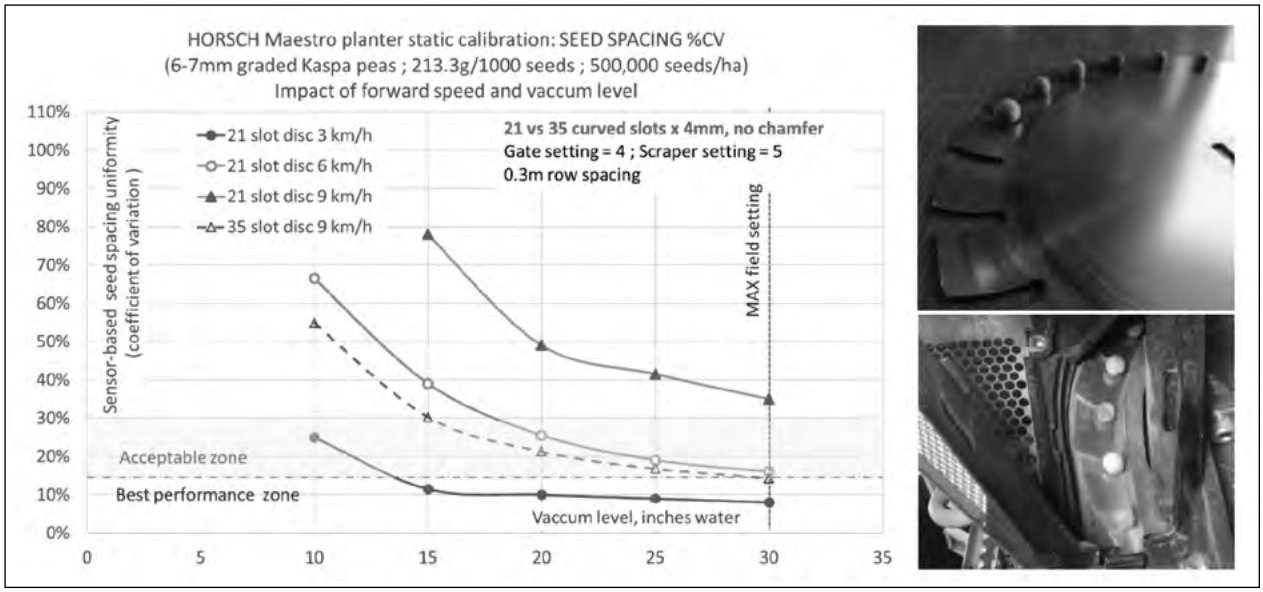


Figure 6. The impact of singulation vacuum setting and planting speed on the coefficient of variation of inter-seed spacing, with 2-disc plate designs (left); view over the singulation disc and in operation (right).

suppliers (John Deere, Precision Planting Inc., Väderstad, Horsch, Great Plains Australia, Monosem) provide some examples of current developments and features:

- Row-by-row seed delivery rate control, with curved pathway compensation and shut-off control for zero-overlap on headlands.
- Row- by-row monitoring of singulation performance using either seed mass or shape-based sensing (e.g., % skips/doubles, seed spacing index, ride quality).
- Row- by-row liquid fertiliser delivery rate monitoring and control, with swath-off control when crossing on headlands.
- Real-time sensing of in-furrow properties (e.g., organic matter, moisture content, CEC, temperature, presence of residue, general furrow uniformity).
- Pressurised or belt-guided seed delivery to furrow for high-speed planting.
- Serrated disc blade technology for improved residue cutting.
- Synchronised 200mm wide twin row configuration with triangular seed delivery pattern.

The sensor data acquired can be used to automatically self-adjust settings (e.g., weight-transfer down-force, planting depth range, furrow closing pressure, zonal rate of seed and fertiliser by row) or just inform the operator who can respond by centrally adjusting settings on-the-go (e.g., planting speed, vacuum level, average down force, row cleaner engagement). Data can also be used to generate paddock maps (e.g., soil strength, furrow-read properties and planter performance) for adaptive management purpose.

Precision planter technology is increasingly catering for winter grain crops, including:

- Improved singulation with winter grain dedicated plates and meter accessories;
- control systems suited to linear seed rate of winter grain crops;
- narrower row spacings within the 190-380mm range;
- central commodity (bulk fill) system for broadacre applications; and
- liquid and/or granular fertiliser banding options.

To improve the versatility of singulation planters, downgrading to 'bulk metering' disc plates can be done selectively with crops where singulation may be unreliable, to ensure accurate bulk seed rate is still achieved (e.g., Great Plains Ag. *Yield-Pro HDP planters*).

Intermediate technologies also exist to improve the uniformity of seed distribution across seeding rows, such as single-row metering rollers (e.g., SeedMaster *Ultra Pro II*) where row-to-row variation can be 50% less than with centralised air-seeding (PAMI, 2019). Seed singulation row-kits are also emerging as optional features on broadacre disc seeding machines – which can be selected on a paddock by paddock basis (e.g. Horsch *Funk*

metering *SingularSystem*, and the upcoming Bourgault *Air-Planter eXact* Placement XP™ meter). This integration of singulation kits onto air-seeders combines the flexibility of fertiliser placement and separation options available with air-seeding systems. Their integration with tyne-based seeding systems presents specific challenges and to date has been limited to prototypes, while limited tyne-disc hybrid systems are now commercially available. Developments of these intermediate technologies in the future could increase the versatility of precision planting in winter cropping systems in a range of soil conditions, but their mainstream adoption will rely on them being practical, cost-effective and not affecting the timeliness of sowing within a cropping programme.

A list of suppliers of and support for precision planting technologies is given in Table 4.

Conclusions

Precision planting trials conducted over the last three years demonstrated an improved uniformity of crops stand and resulted in grain yields equivalent to or better than those achieved with conventional sowing. In numerous cases, plant density could be reduced with precision planting without a yield penalty, allowing a reduction in seed costs. However, the magnitude of the effect varied considerably and further work is required to understand the main environmental and management factors that determine the agronomic benefits of precision planting. In dedicated calibration evaluation, planter performance was shown to be easily affected by suboptimal planter settings and operation.

Table 4. A list of companies currently providing precision planting technologies in Australia*.

Manufacturer or distributor	Associated precision planting technologies	Web address
AGCO Australia, Vic	White Planters, Precision Planting Inc.	www.white-planters.com
Boss Agriculture, NSW	Precision Planting Inc., John Deere	https://bossagriculture.com.au/vacuum-planters.html
Bourgault Australia, NSW	Bourgault Air-Planter XP meter and components	https://www.bourgault.com/product/en-US/air-planter-/841/ air-planter.aspx
CNH Australia, NSW	Case-IH, Precision Planting Inc.	www.caseih.com/anz/en-au/products/planting-and-seeding
Great Plains Ag. - Australia (Kubota Australia), Qld	Great Plains	https://greatplainsaustralia.com.au/product/range/yield-pro-planter
Groundbreaker Precision Agriculture (Toowoomba Engineering - Precision Ag-Solutions), Qld, N-NSW	Precision Planting Inc., Monosem, Ag-Leader, Groundbreaker components	www.groundbreaker.com.au ; www.precisionagsolutions. com.au
John Deere Australia, Qld	John Deere, Deere-Bauer, Deere-Orthman	https://www.deere.com.au/en/planting-equipment/
Landpower Australia, Vic	Väderstad	www.vaderstad.com/au www.vaderstad.com/en/planting
Muddy River Agricultural, Vic	Horsch	https://muddyriver.com.au/maestro-cc-rc-sw/
NDF Ag Design, NSW	Precision Planting Inc. , NDF downforce control	www.ndf.com.au/summer_planter.html
NORSEMAN Machinery, Qld (N-NSW)	Norseman, Kinze	www.norsemanmachinery.com
Precision Seeding Solutions, NSW (Qld)	Precision Planting Inc.	www.pssag.com
Spot-On-Ag, Vic	Harvest International, Precision Planting Inc. Prescription Tillage Technologies	https://spotonag.com.au/
Vanderfield (RDO Australia Group), Qld, NSW, NT, (WA)	John Deere, Dawn Equipment, Monosem, Horsch	www.vanderfield.com.au

** This is an extensive list to the best of the researcher's knowledge, please consult your local retailer for more information.*

A small number of growers using precision planting technology for winter grain crops in the southern and western regions have struggled with lack of technical support and information and with trying to adapt old technology to winter cropping. Nevertheless, some have experienced sizeable benefits with specific crops and are optimistic that gains in productivity and profitability can be achieved by more uniform seed placement along the row. Commercial precision planters increasingly cater for winter grain crops planting, use smart technology to monitor and automate adjustments on-the-go, while singulation kits are now slowly appearing as an additional feature of air-seeders for use on selected crops. The mainstream adoption of precision planters will require their use to not only be cost-effective but also practical, versatile and not significantly reduce seeding timeliness.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial and survey cooperation, and information sharing, and the financial support from the GRDC. The authors would like to thank them for their continued support. The support from Muddy River Ag., Landpower Australia, Spot-on-Ag and Toowoomba Engineering with machinery and technical backstop for trials are gratefully acknowledged.

References

Harries M, Seymour M, Boyce S (2019). Geometric uniformity improves yield of canola and lupin. In 'GRDC Research Update'. Perth, Western Australia

McDonald G, Noack S, Browne C, Minkey D, Midwood J, Schmitt S, Clarke G, Pearse E, Amgouris A (2020) A survey of crop establishment in canola and lentil: what have we learnt? In 'GRDC Research Update. ' Bendigo, Victoria)

PAMI (2019). Air seeder distribution and seed damage testing and validation – Final report. 44p. Prairie Agricultural Machinery Institute: Humboldt, SK Canada. Accessed January 2021 at https://www.seedmaster.ca/ultrapro.php

Yang C, Gan Y, Harker NK, Kutcher HR, Gulden R, Irvine B, May W (2014) Up to 32% yield increase with optimised spatial patterns of canola plant establishment in western Canada. *Agronomy of Sustainable Development* **34**, 793-801.

Contact details

Glenn McDonald
School of Agriculture, Food and Wine
Waite Campus
The University of Adelaide
(08) 8313 7358
glenn.mcdonald@adelaide.edu.au

Return to contents

Notes

Notes

Vetch agronomy and management

Stuart Nagel, Gregg Kirby and Angus Kennedy.

South Australian Research and Development Institute..

GRDC project code: DAS1711-015RTX

Keywords

- vetch, *Vicia*, break crops, agronomy, management practices.

Take home messages

- Choose the species of vetch and variety depending on your end goals, or desired end-use.
- Each vetch species requires different management and agronomy to achieve optimum production.
- There is no 'one size fits all' approach with vetch, the diversity of end-uses and environments in which vetch is grown, require different agronomic approaches and tools.

Background

Traditionally vetch has been a low rainfall legume best suited to sandy, neutral to alkaline soils. However, trials conducted by the National Vetch Breeding Program (NVBP) and others, across a wide range of environments and soils types have demonstrated that vetch can be productive across many farming environments, offering farming systems in many areas all the benefits associated with a productive and reliable legume in their rotations.

Vetch gives growers an extra tool in the fight against herbicide resistant weeds and cereal diseases while still offering the opportunity for a profitable enterprise in the cropping year and benefits that flow on for two to three subsequent crops.

With the increasing use of vetch in numerous different farming systems, an increasing diversity of approaches and agronomic practices are being used to get the most out of the crop. Its diversity of end-uses means that there is no one right way to do everything. However, there are some basic agronomic practices to get right before getting too creative. Your planned end-use does not have to be locked in, flexibility can come with getting the basics right and seeing how the season develops.

The most important point to remember is to treat it as a crop, not a break in the cropping regime. The more you put into the crop the better your potential return, be it yield or the ancillary benefits that come from legumes.

Paddock selection and planning are vital, knowing the weed burden/profile along with the desired/preferred end use, dictates many subsequent decisions. Vetch can be used to fill in, provide extra feed or just replace fallow, but if you are looking to maximise benefits and outputs it's important that you put the planning in.

Once you have selected the paddock, choose the vetch species and variety that best suits your conditions and major objectives. For specific details on vetch variety characteristics please refer to the 2021 Crop Sowing Guide relevant to your state or area, these can be found online at:

https://grdc.com.au/resources-and-publications/all-publications/crop-variety-guides.

Choose disease resistant varieties wherever possible, all varieties released from the NVBP are resistant to rust.

If you have hostile soils or a poor legume history, inoculate seed with appropriate rhizobia. New acid tolerant strains of rhizobia are being released

(expected release date 2022) which will assist with inoculation in areas with low pH soils to get the best out of legumes.

All legumes benefit from phosphorus (P) but do not require significant amounts of nitrogen (N), so choose appropriate fertiliser to reflect these requirements. Vetch can 'make do' with residual fertiliser from previous cereals but will benefit from well placed P, helping development and vigour.

When looking at different end-uses, time of sowing (TOS) can play an important role in strategic planning. If the crop is to be grazed, early sowing is vital to get the crop up while the soil is warm, as early growth is vital. This also applies to using the crop for green or brown manure; the bigger the biomass the better and early canopy closure is important to out compete weeds.

For hay production, TOS helps dictate when the cutting and drying window will occur. This is a balance between getting the best growing conditions and the timing for drying when the weather warms in late September. In 2020, several areas had excellent rains in March enabling very early sowing (mid-March-early April), this resulted in large dense crops developing early. Canopy closure occurred in some cases in early-mid June, however this resulted in perfect conditions for disease development. As canopy closure occurred so early, fungicide applications could not penetrate the canopy after this point, allowing disease to proliferate and causing significant damage particularly to hay crops. This shows the importance of planning TOS around your preferred end-use, as grazing early may have helped to keep canopies open longer and helped with disease suppression.

For more detailed information on disease management please refer to the paper 'Vetch Disease Management' within this publication.

Chemical selection, particularly for broadleaf weed control is still limited in vetch. Pre sowing, incorporation by sowing (IBS) chemicals and post sowing pre-emergence (PSPE) chemicals offer the best options and results. There are now in-crop options for broadleaf control, but their use will set the crop back for a period of time. It is recommended to talk to local agronomists for chemical advice specific to your soil type and region.

Rolling is recommended post sowing, depending upon the tillage system used. Rolling prepares the paddock for hay or grain harvest and can also improve seed to soil contact, but care should be taken with some tillage systems, as it can push soil back into the seed row, concentrating chemicals over the seed, potentially causing issues if there is good rainfall following sowing.

Growth regulators are becoming more commonly used in crop production to control/influence plant development. In vetch, gibberellic acid (GA) is the most common growth regulator that is used. Gibberellic acid artificially substitutes/increases the natural occurring hormone (gibberellins) in the plant promoting elongation of plant cells, it therefore elongates the plant cells and stretches the plant out, with the aim of increasing plant height. It has been used in vetch for several reasons; to increase plant height to facilitate cutting for hay, to promote growth and development after grazing and to delay onset of flowering which helps delay the cutting window for hay production. Its use should not be seen as essential, but as a tool to use in specific situations.

The Southern Pulse Agronomy group (SPA) from Clare conducted trials in 2020 looking at the interaction between GA and vetch. This trial was at two sites in one season, 2020, they found it had a significant impact on plant height for up to six weeks after application, however it did not increase fodder yields significantly and was found to have a negative impact on grain yield (pers. comms. Sarah Day). This data will be published in the 2021 Eyre Peninsula Farming Systems Summary.

For GA to work it requires moisture and nutrients to be available and timing of application is vital, particularly when attempting to delay flowering. Application to achieve this must be just prior to the commencement of flowering, however there is only anecdotal evidence on the length of the delay to flowering caused by GA. This needs further investigation.

Vetch is not vetch

There are three different species of vetch grown in Australia, common vetch (*Vicia sativa*) and woolly pod vetch (*Vicia villosa*) being the two most popular species, and purple vetch (*Vicia benghalensis*) which represents a much smaller part of the market. These different species all have different characteristics, and therefore, need different management and suit different conditions, but all produce good fodder and can return large amounts of N to the soil. The hard seed levels of woolly pod vetch and purple vetch should be a major consideration when choosing this species of vetch to sow.

Common vetch

Varieties of common vetch (CV) include Studenica$^{\Phi}$, Morava, Timok$^{\Phi}$, Volga$^{\Phi}$, Rasina$^{\Phi}$, Blanchefleur and Languedoc

Common vetch is the most widely grown species of vetch, predominately grown in low rainfall areas in South Australia (SA), Victoria (Vic), Western Australia (WA) and New South Wales (NSW), where it is seen as a good, reliable legume option in farming systems. It offers flexibility to the grower and is an excellent tool in a grower's fight against issues like soil borne diseases and herbicide resistant grass weeds, while still offering good returns in the form of fodder/grazing, hay, improved soil N and organic matter levels.

Common vetches are generally shorter season than the other species (varieties flower between 85 and 115 days) and are more tolerant to grazing. They are palatable at any growth stage, either green or dry, and the grain is a high protein feed (on average 29% crude protein and 12.5MJ/kg DM metabolisable energy) that can be used for all ruminants.

The Australian bred and released varieties Studenica$^{\Phi}$, Morava, Timok$^{\Phi}$, Volga$^{\Phi}$ and Rasina$^{\Phi}$ are all resistant to rust. Older varieties like Blanchefleur and Languedoc are highly susceptible to this disease. Rust can drastically reduce yields and may induce abortions in pregnant livestock if they are fed heavily infested plant material, it is therefore important to grow rust resistant varieties whenever possible.

In higher rainfall areas monitor for Botrytis symptoms, this disease can greatly reduce yields.

In all common vetches regrowth after grazing is very dependent on seasonal conditions, good moisture and favourable environmental conditions.

Woolly pod vetch

Varieties of woolly pod vetch (WPV) include Capello, Haymaker Plus, RM4$^{\Phi}$ and Namoi.

These varieties are better suited to medium-high rainfall areas, doing best in regions receiving a minimum of 450mm annual rainfall. All the varieties of WPV are later developing than the CV varieties, not flowering until around 125 days after sowing. Regions looking for later hay varieties should consider WPV. They have superior hay yields to CV, on average yielding approximately 1.5t/ha more dry matter in the same environment compared to CV (yields between 5-12t/ha can be achieved). However, grain yields are much lower than CV (0.8t/ha average) and the grain can be difficult to harvest/thresh.

Woolly pod vetch grows well in mixed crops situations and can tolerate some shading from plant competition, which makes it a good companion plant in forage mixes.

The grain of WPV varieties should not be fed to any livestock, as it contains high levels of toxin and can cause death in ruminants if consumed at high levels. These varieties/species should not be grazed before 15 nodes of growth or after pods have formed seed, due to the toxicity of the grain. There is no data available on what is a safe level of this grain in a dietary/fodder mix.

Care should be taken when grazing, as this species is susceptible to over grazing early in its development due to its slower growth through winter.

Management issues to consider

Make sure paddocks are relatively free of broadleaf weeds as there are limited options for control in WPV, especially in-crop and it is a poor competitor for weeds in early growth stages. The best option is to use registered herbicides post sowing pre-emergent.

Don't graze early (before 15 nodes) and ensure you cut the hay or graze before pods start to set seed.

Be aware this species has hard seeds, with hard seededness percentage of common varieties ranging from 5-7% RM4$^{\Phi}$ to >30% Namoi and they can appear as volunteers in subsequent crops. This species is cross pollinated, and if you are producing or/multiplying seeds from RM4$^{\Phi}$, isolation from higher hard seed varieties like Namoi needs to be >1km.

Purple vetch

Varieties of purple vetch (PV) include Popany, Benatas and Barloo.

Crop development of this species is similar to WPV, with later flowering time (>125 days) compared with CV. It is suited to medium to high rainfall areas with a good finish and is a high fodder producer in these areas. It is not, however, suited to lower rainfall zones. Purple vetch can tolerate some waterlogging compared to other vetch species. Similar to WPV, grain cannot be fed to ruminants but there is a small market as birdseed.

Management issues to consider

Like WPV this species has very slow winter growth and does not compete well with weeds early. One advantage is that Broadstrike® is registered for use in the variety, Popany allowing for control of a range of broadleaf weeds in crop. It should not be grazed before 10 nodes or grazed/cut for hay after pods start to set seed.

For specific details on vetch variety characteristics please refer to the 2021 Crop Sowing Guide relevant to your state or area, these can be found online at:

https://grdc.com.au/resources-and-publications/all-publications/crop-variety-guides

Conclusion

Vetch has the ability and potential to fit into modern farming rotations in most areas, particularly in mixed farming systems where growers are looking for a versatile break option that still allows for strategic action against specific cropping problems. Unlike pulses and other break crops, its end use is not solely focussed on grain production.

A successful vetch crop can:

- Increase yields and grain protein of following cereal and oilseed crops.
- Allow an extended phase of cropping.
- Decrease many cereal diseases – grass-free vetch crops can break the life cycle of root diseases, preventing multiplication and build-up of disease levels.
- Provide an opportunity to control grass weeds especially in forage use; hay is cut before many grasses set seed providing a chemical free option to avoid weed resistance. Green/brown manuring can be used with vetch to control competitive weeds which are difficult to control in other crops, e.g., brome grass and barley grass.
- Available soil N is maintained and can be improved by an average of 56, 92 and 145kg/ha after grain, hay and green manuring, respectively (data from 3yrs x 5 sites).
- Grain and hay/silage from CV varieties can be used to feed ruminants without limits.

The key to a successful vetch crop and achieving the maximum benefits from its growth is to treat it as a crop, not as a set and forget break option. Inoculate with appropriate rhizobia, control weeds where possible and monitor for insects and disease.

When successfully grown, vetch can be an effective risk management tool on farm. Allowing for a reduction in fertiliser and chemical use in following crops, reducing costs and the risks involved with in-crop N applications. This can have a large impact on profitability and the stress levels associated with input application decisions.

Acknowledgments

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

Useful resources

2021 Crop Sowing Guide (https://grdc.com.au/resources-and-publications/all-publications/crop-variety-guides).

Contact details

Stuart Nagel
SARDI
stuart.nagel@sa.gov.au

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

Return to contents

Notes

Notes

Vetch disease management

Joshua P. Fanning[1], Mitchell R Fromm[1], Jason Brand[1] and Stuart Nagel[2].

[1]Agriculture Victoria Research, Horsham; [2]South Australian Research and Development Institute

GRDC project codes: DJP1097-001RTX, DAV00150, DAS1711-015RTX

Keywords

- Ascochyta blight, botrytis grey mould.

Take home messages

- Grain yield losses in vetch of on average of 26% were observed in plots with no disease control.
- Selecting resistant varieties and applying foliar fungicides will reduce grain yield losses.

Background

The main diseases that affect vetch are Ascochyta blight (AB) and botrytis grey mould (BGM). Other diseases which are also known to affect vetch in the Southern region include rust, Sclerotinia white mould, root lesion nematodes and rhizoctonia root rot. Research into vetch diseases is very limited. Therefore, most of our knowledge on disease management is extrapolated from studies in other crops. Newer varieties, from SARDI's vetch breeding program, have excellent rust resistance, but improvements in disease resistance for other diseases is still desirable.

Similar to other crops, the key to vetch disease management is that the cost of disease control is not higher than the potential loss from the disease. This involves thinking of the end use of the crop (hay, grain, grazing or manure) and potentially changing this end use in seasons that are very conducive to disease. In addition to affecting grain/hay yield, the disease may affect the crop quality and palatability for stock.

This paper will discuss the diseases; AB and BGM.

Grain and biomass yield losses in vetch

During 2020, a 26% reduction in grain yield due to disease was measured in a field experiment at Nhill. In this experiment there were early infections of AB (Table 1), while BGM became more dominant later in the season. Biomass differences were not significant on the 14 October (Table 2), despite significant BGM severity observed in plots at that time (Table 1). Despite variation in grain yield between vetch varieties, the interaction between grain yield and treatment was not significant, highlighting no significant difference in grain yield losses between varieties.

With two diseases present in the experiment, the 26% grain yield losses cannot be attributed to one disease definitively. However, this experiment highlights the need to control foliar diseases in vetch if the crop is to be harvested for grain. Interestingly, despite a 0.6t/ha reduction in biomass in plots with no disease control, this reduction was not significant and will require further investigation.

Table 1. Severity of natural Ascochyta blight and botrytis grey mould infection (% Leaf area affected) in three vetch varieties at Nhill during 2020. The two treatments investigated were: 1) a complete disease control (Complete) and 2) no disease control (Nil).

Variety	Ascochyta Blight Leaf area affected (%)			Botrytis Grey Mould % Leaf area affected (%)					
	7/9/2020			13/10/2020			4/11/2020		
	Complete[A]	Nil[B]	Mean	Complete	Nil	Mean	Complete	Nil	Mean
Benetas	0 a[C]	3 a	1	0 a	12 ab	6	0	37	18
Morava	1 a	3 a	2	0 a	42 c	21	0	63	32
Timok(Φ)	0 a	18 b	9	0 a	17 b	8	0	50	25
Mean	0	9		0	46		0 a	46 b	
	P Value	LSD		P Value	LSD		P Value	LSD	
Variety	<0.001	3.4		0.034	10.5		0.083	ns	
Treatment	<0.001	2.4		<0.001	7.4		<0.001	8.9	
Interaction	<0.001	4.8		0.034	14.9		0.083	ns	

[A]Complete treatment had multiple fungicide applications with the aim of no disease; [B]Nil treatment had no fungicides applied; [C]Different letters indicate a significant difference in a pairwise analysis between treatment, variety or the interaction within a disease assessment date.

Table 2. Grain and biomass yields (t/ha) in three vetch varieties (3 replicates) at Nhill during 2020. The two treatments investigated were: 1) a complete disease control (Complete) and 2) no disease control (Nil).

Variety	Grain yield (t/Ha)				Biomass (t/ha) [A]		
	Complete[B]	Nil[C]	Mean	Yield Loss (%)[D]	Complete	Nil	Mean
Benetas	1.53	0.75	1.14 a[E]	51%	5.28	4.83	5.06 a
Morava	3.07	2.19	2.63 b	29%	8.08	7.63	7.86 b
Timok(Φ)	4.17	3.06	3.61 c	27%	8.55	7.57	8.06 b
Mean	3.31 a	2.46 b		26%	7.31	6.67	
	P Value	LSD			P Value	LSD	
Variety	<0.001	0.607			0.013	2.013	
Treatment	<0.001	0.429			0.347	ns	
Interaction	0.859	ns			0.945	ns	

[A]Biomass was measured 14 October 2020, at peak biomass for Morava and Timok(Φ), but Benetas had not reached peak biomass; [B]Complete treatment had multiple fungicide applications with the aim of no disease; [C]Nil treatment had no fungicides applied; [D]The variety x treatment interaction was not significant, and therefore the % yield loss between varieties is also not significant. [E]Different letters indicate a significant difference in a pairwise analysis between treatment, variety or the interaction within a disease assessment date.

Ascochyta blight

Ascochyta blight affects vetch crops early in the season with cooler wet conditions favouring disease development. When temperatures increase and the canopy dries out later in the season, visual symptoms of AB reduce. This is thought to be from the infected leaves dropping off and the vetch plant growth increasing, thus reducing the overall percentage of infected leaves.

There is significant variation in the resistance of varieties to AB, with Morava, Timok(Φ) and Rasina(Φ) being more susceptible than other released varieties (Figure 1). Consult the latest Agriculture Victoria Pulse Disease guide (https://agriculture.vic.gov.au/biosecurity/plant-diseases/grain-pulses-and-cereal-diseases/pulse-disease-guide) for up-to-date resistance ratings.

The risk of infection by AB can be reduced by choosing a more resistant variety and ensuring that there is at least three years between vetch crops. In susceptible varieties, it is thought that if severe symptoms are observed a fungicide may be warranted to prevent large biomass losses.

Botrytis grey mould

Botrytis grey mould in vetch is difficult to control due to early sowing and canopy closure. As a result of early canopy closure there is higher canopy humidity, which is conducive to disease development along with increasing difficulty of uniform fungicide coverage, even if a high-water rate is used. Although a higher temperature (>15 degrees Celsius) is optimal for BGM development, at lower temperatures the disease can develop, just at a slower rate.

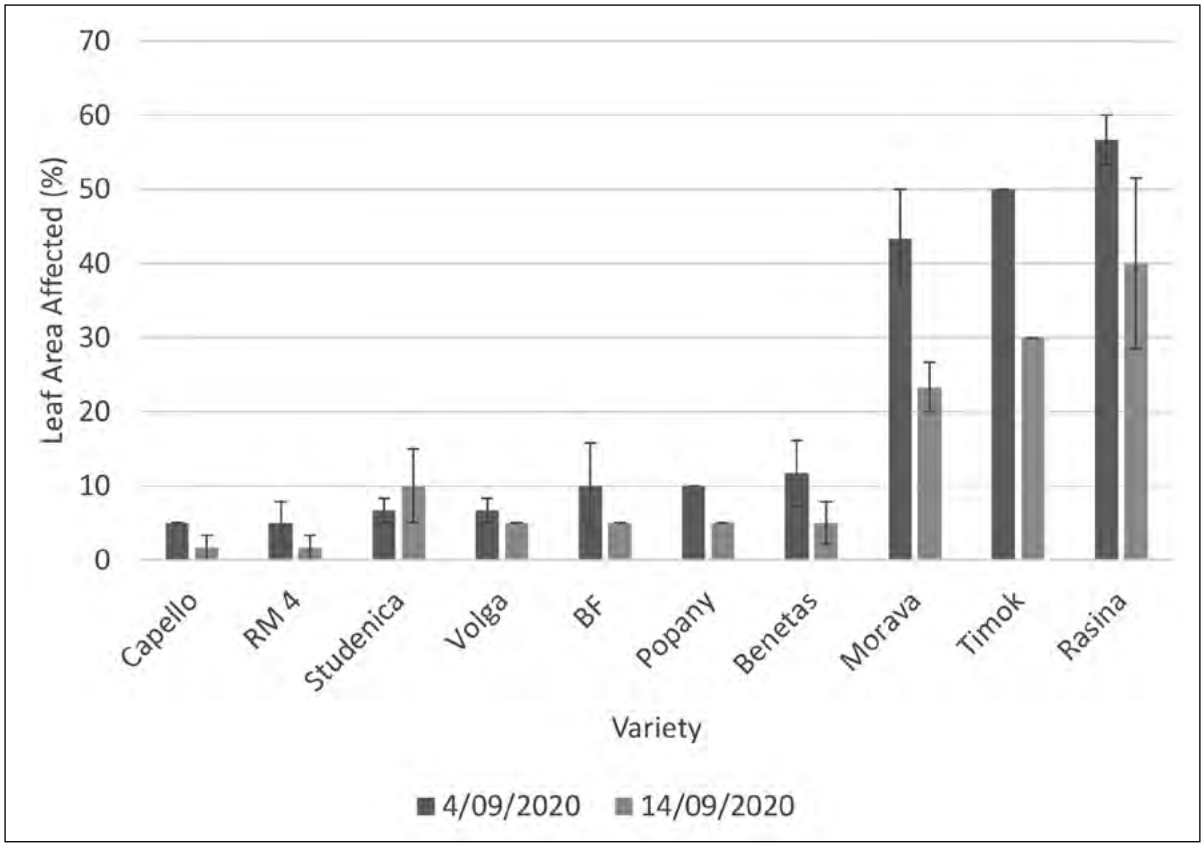


Figure 1. Mean Ascochyta blight infection in vetch varieties at Horsham during 2020.

Although most vetch varieties are susceptible to BGM there are several management practices which can be utilised to reduce disease severity in vetch crops, including:

1. Crop rotation

   As the same pathogens cause BGM in vetch, faba bean and lentil this needs to be considered when planning rotations to allow sufficient time for stubble breakdown between affected crops. This time will vary between rainfall zones.

2. Time of sowing

   Time of sowing can help to determine when canopy closure occurs. If sown too early and not grazed, canopy closure can occur too early, not allowing fungicide penetration into the crop when BGM starts to spread in late autumn/early spring.

3. Foliar fungicides

   The best defence against disease in vetch crops is a foliar fungicide applied just prior to canopy closure to prevent disease development. In other crops, newer released fungicide actives have provided longer protection against disease and may also provide longer protection in vetch. In conducive disease years, multiple fungicides may be required. It is important to check product registrations and withholding periods, especially when the vetch crop is to be grazed or cut early for hay.

4. Grazing

   Grazing may open up the canopy to reduce the canopy humidity and thus disease risk. This may be particularly relevant in early sown crops.

Conclusion

Vetch disease can cause large grain yield losses, with 26% observed during 2020 at Nhill. There are several disease control management practices that can be utilised, but it is always important to remember the end use of the crop (i.e., manured, grain, hay or grazed) as this will dictate the economic viability of the control options.

Contact details

Joshua Fanning
Agriculture Victoria
joshua.fanning@agriculture.vic.gov.au

Stuart Nagel
SARDI
stuart.nagel@sa.gov.au

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

Return to contents

Notes

Notes

Wins and tribulations of chaff lining as a weed reduction tool

Chris Davey.

WeedSmart; YP AG.

Keywords

- chaff lining, decomposition, stripper front, weed suppression.

Take home messages

- Chaff lining is an entry point into harvest weed seed control (HWSC).
- Many growers utilise chaff lining set ups for three to five years before progressing to a seed impact mill.
- Weather and soil conditions are likely to determine the amount of weed seed decay in a chaff line.
- Stripper fronts can capture as much weed seed in their chaff component as draper fronts.

Background

Originally known as 'windrow rotting', chaff lining has been championed by Western Australian growers, including Mic Fels. The concept involves funnelling the chaff fraction of crop residue (containing weed seeds) into a confined row directly behind the harvester using a narrow chute. The chaff and weed seeds are then left to rot down over time. To promote rotting, the chaff lines need to be placed in the same location year after year.

Chaff decking is a form of chaff lining, which combines dual chute placement of the chaff onto the wheel marks with the hostile environment that compaction and the constant traffic of a controlled traffic farming (CTF) system creates on the line.

SWOT analysis of chaff lining as a weed seed reduction tool

Strengths

- Capture of problematic weed seeds that can be dealt with.
- Cheaper than other HWSC options – can make your own or buy a retro fit model.
- Concentration of weed seeds into a localised, known area.
- Non-chemical.
- No burning involved.

Case Study – George Lehman (University of Sydney research): With over 2200 ryegrass weed seeds measured per linear metre of chaff line immediately after harvesting a low yielding wheat crop (0.61t/ha), just seven ryegrass plants emerged in a one metre square encompassing that chaff line (Kondinin Group Research Report, February 2020)

Weaknesses

- Percentage of weed seeds entering the header – weed type, difference within a species, harvest timing (same for all HWSC strategies!).
- Ideally, the header is required to follow the same marks each year.
- Lack of decomposition.
- Volunteer grain germinating in the line (e.g., wheat in barley).
- Nutrient concentration.
- Potential nutrient loss.
- Crop establishment through the chaff line in subsequent years.

Opportunities

- Stock feed – adding another layer of non-chemical means of decreasing weed seeds into the soil bank.
  - o This may be offset by dispersal of weed seeds back into the paddock for some species.
- Better localised crop close to chaff line?
- Targeted Spraying?
- Strategic Burning?
- Applying something on the chaff line to speed up decay?

Threats

- Piling up of chaff lines over several harvests.
- Lack of decomposition?
- Water/wind erosion if only doing one-wheel mark.
- Grazing which can result in increased weed emergence.

Case Study – George Lehman (University of Sydney research): Grazing, saw emerging ryegrass increase significantly to 84 (from seven) plants germinating in one metre square area encompassing the chaff line (Kondinin Group Research Report, February 2020)

Capturing the weed seeds during harvest

Research in the eastern states by Michael Walsh and John Broster has shown that stripper fronts can be as effective at processing the chaff component as draper fronts on headers. The stripper front has less of a chaff component as it only plucks the grain from the head, but it has been shown to be just as effective at dealing with weed seeds for HWSC. The most important thing in relation to the efficacy of the stripper front is to set it up correctly from the start to maximise the capture of weed seeds in the front of it.

Conclusion

Chaff lining is an economic/low-cost entry point into HWSC. It relies heavily on the decay of weed seeds within the line as a means of weed control and reduction of weed seed into the soil bank. However, during the past few seasons, particularly in South Australia, dry summers with minimal rain have occurred, which has led to little or no decomposition of the weed seeds in the chaff line. Evidence of this has been measured in trials by Gurjeet Gill (SA) and John Broster and Annie Ruttledge (NSW) through their trial work on weed seed decay in chaff lines.

Acknowledgements

The author would like to thank the following people for their work that has contributed to this report: Gurjeet Gill, University of Adelaide; Michael Walsh, University of Sydney; Greg Condon and Peter Newman, WeedSmart; John Broster, Charles Sturt University and Annie Ruttledge, Department of Agriculture & Fisheries.

References

Kondinin Group Research Report, February 2020 No. 121 Harvest Weed Seed Warriors

https://www.weedsmart.org.au/app/uploads/2020/05/RR_February_2020_Weedsmart.WS_.2020.pdf

AHRI, 2019, What's the cost of harvest weed seed control for YOU? https://ahri.uwa.edu.au/whats-the-cost-of-hwsc-for-you/

Contact details

Chris Davey
YP AG
1-3 Kennett Street North, Kadina
0428 466 675
chris@ypag.com.au
@CropDoctor54

Return to contents

Notes

Notes

Critical concentrations for nitrogen, phosphorus, potassium and sulphur soil tests for break crops

Nigel Wilhelm[1], Sjaan Davey[2] and Michael Bell[3].

[1]South Australian Research & Development Institute, Waite Research Precinct, Adelaide;
[2]South Australian Research & Development Institute, Struan Research Centre, Naracoorte;
[3]Queensland Alliance for Agriculture & Food Innovation/School of Agriculture & Food Sciences, The University of Queensland, Gatton.

GRDC project code: UQ00082

Keywords

- soil tests, canola, wheat, pulses, critical concentrations.

Take home messages

- Critical concentrations for soil phosphorus (P) are similar for wheat and break crops.
- Critical concentrations for mineral nitrogen (N) are higher for canola than for wheat.
- There is no new information on critical concentrations for potassium (K) or sulphur (S) for wheat or break crops.
- Canola appears to be more sensitive to P deficiency than for wheat, while yield penalties for growing pulses on low P soil are similar to or less than wheat.

Background

Soil testing for N, P, K and S is a key strategy for monitoring soil fertility of cropping soils and refining fertiliser application strategies for future crops. For this to be successful, the relationship between the soil test result and a likely response to applied nutrients needs to be well calibrated. Many of the current calibrations were developed from fertiliser trials conducted over 30 years ago, and primarily with wheat, and relationships provided robust guidelines on many soil types. Since these trials were conducted cropping systems have changed significantly (e.g., limited or no tillage, and more continuous cropping), altering soil fertility in the Australian grains industry. A detailed re-examination of the existing soil testing guidelines was undertaken to ensure they are still relevant in current farming systems.

As part of the GRDC More Profit from Crop Nutrition program (MPCN2), data in the Better Fertiliser Decisions for Cropping (BFDC) database were reviewed showing that critical concentrations for many soils tests did not exist for key crops, soils and regions. Most of these gaps relate to crops that are (i) new to cropping regions or are a low proportion of cropped area, (ii) emerging nutrient constraints that had previously been adequate in specific soil types (e.g., K, S), and (iii) issues associated with changing distributions of nutrients in the soil profile. This paper summarises work conducted over the last four years in South Australia (SA) under project UQ00082 whose aim was to close those gaps using replicated trials, especially for break crops. Under the project similar programs were also conducted in Victoria (Vic), New South Wales (NSW) and Queensland (Qld).

Trials were established on sites selected for nutrient responses and run over multiple years to develop soil test-crop response relationships. Wheat was used as a benchmark alongside a break crop at every site, with the relative responsiveness of the break crop compared to wheat, used to extend findings beyond the conditions at each trial site.

Method

The general approach was to find trial sites in the agricultural zone of SA which met the following criteria:

- Deficient for one of the target nutrients (N, P, K or S).
- Typical of major cropping environments in the state.
- When the target nutrient is K or S, avoid sandy soils, given the amount of data available for these types of soils from Western Australia.
- Trial could be conducted for 3-4 years to examine residual values of nutrients.

At each site, two identical trials were conducted each year. Prior to seeding in the first year of all trials, fertilisers supplying the target nutrient were applied at different rates to create a wide range of soil reserves for that nutrient. These soil reserves were assessed with a current commercial soil test in each plot in each trial every year, prior to seeding. For some trials, target nutrients were re-applied in subsequent years to maintain a wide range of nutrient concentrations and ensure that at least some plots would allow an estimate of nutrient-unlimited yields in each season (i.e., Y_{max}). The commercial soil tests investigated were mineral N (nitrate and ammonium-N), Colwell P, Colwell K and KCl40 S.

One trial at each site was seeded to a modern wheat variety each year and the other trial to a modern variety of break crop (canola or pulse), with basal fertilisers used on both crops to avoid any other nutrient deficiencies. The two crops were alternated between the two trials at each site every year. Performance of both crops was monitored every year and related to the range in nutrient concentrations measured with the soil tests for that year.

Critical concentrations for the commercial soil test were estimated by fitting response curves using approaches developed in the MPCN2 program and adapted for this project. The critical concentration was defined as the soil test concentration at which 90% of maximum crop growth was obtained.

Results and discussion

Figure 1 is an example of the data generated by this project and how critical concentrations were estimated. In this example, from Wasleys' in 2020, P deficiency decreased growth of Razor CL+$^{\phi}$ wheat throughout the season and grain yields in soils with low P concentrations were up to 45% lower than yields from plots with high P concentrations. The critical level for wheat in this situation was calculated to be 52mg/kg in the top 10cm. For Neelam$^{\phi}$ chickpea at the same site and in the same year, grain yields were depressed by a similar percentage to wheat and a similar critical concentration was estimated, even though growth responses to increasing soil P concentrations were barely visible at any time during the season.

A feature of the trials in this project was that the grain yield of break crops were poor in comparison to wheat at the same site in the same year. Break crops were sown on the same day as wheat and mostly yielded less than 30% of wheat, which is much lower than the 40-60% often achieved by growers.

Colwell phosphorus in the top 10 cm

The historical BFDC database was interrogated for trials conducted on similar soil types in SA, and derived 'expected' critical P concentrations for wheat of 26, 23 and 22mg/kg for Minnipa, Wasley's and Urania, respectively. These critical concentrations were quite similar, with the confidence interval (critical range) associated with each suggesting little difference in P responsiveness at these sites. There is limited information on nutrient responses of break crops in BFDC, but this suggests the critical concentrations break crops tend to be a little higher than for wheat.

Table 1. Nutrients and break crops targeted in SA field trials over the life of the project.

Target nutrient	Break Crop	Soil type	Location	Duration
Nitrogen	Canola	Sandy loam over clay	Mt Hope, lower EP	2017-2018
		Gravelly loam over clay	Yeelanna, lower EP	2019-2020
Phosphorus	Canola	Red calcareous sandy loam	Minnipa, upper EP	2018-2020
	Lentils, chickpeas	Red brown earth	Wasley's, L North	2018-2020
	Lentils, chickpeas	Brown calcareous loam	Urania, YP	2018-2020
Potassium	Canola	Brown sand/sandy loam over calcrete	Field, upper SE	2018-2019
Sulphur	Peas	Deep orange sand	Loxton, N Mallee	2018-2019

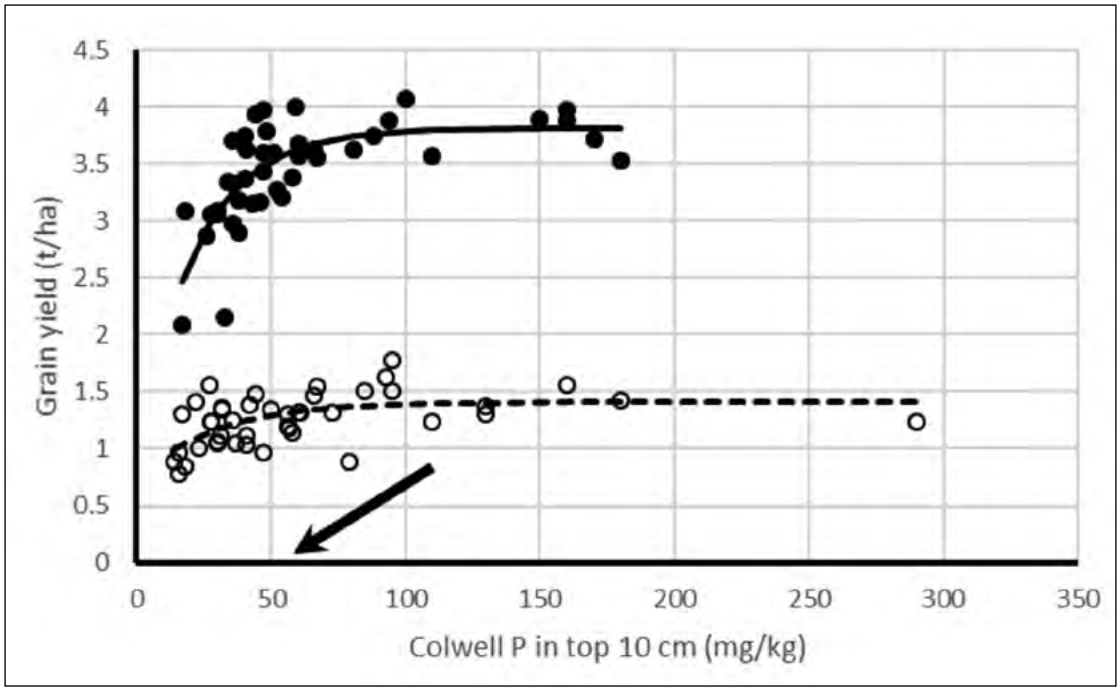


Figure 1. Response of two crops to increasing soil concentrations of P on a red brown earth at Wasley's, in the lower north of SA in 2020. Solid circles are wheat, hollow circles are chickpea. The arrow points to the Colwell P value which corresponds to 90% of max grain yield derived from the fitted curves for both crops.

For example, the critical P level for canola at Minnipa was 27mg/kg, while for pulses at Wasley's it was 25mg/kg and at Urania it was 37mg/kg.

Table 2 is a summary of the critical P concentrations based on the results from the three SA field sites conducted in this project. A wide range of production levels for wheat was experienced across the trials but the data set is dominated by dry seasons. Critical concentrations at Minnipa were very similar to those predicted by the BFDC, which are the current industry standards. However, for both Wasley's and Urania sites, the critical concentrations for all crops were much higher than suggested from current industry standards, especially in 2018 which was the first year when the treatments had only just been applied. These 2018 results should be given less weight, because implementation of treatments delayed seeding substantially and may have distorted crop requirements for soil P. That said, in both 2019 and 2020 seasons at Wasley's and Urania, critical concentrations were markedly higher that those derived from the BFDC database.

The different outcome at Wasley's and Urania appears to be due to prolonged no-till practices which result in high concentrations of P reserves close to the soil surface, rather than more evenly spread through the cultivated layer, as happened with conventional tillage practices of the past. Minnipa did not have an intensive cropping history leading up to the start of the trial, so the P concentration was more uniform throughout the top 10cm of the profile than at the other two sites. Higher critical values for Colwell P may have resulted if the site had more intensive cropping histories and hence, a more stratified topsoil. The impact of P stratification is being examined in a new GRDC project. The majority of P trials in the BFDC database were conducted prior to 1990 with more traditional tillage practices, and more homogenous surface layers.

Critical concentrations for canola, lentil, chickpea tested in the SA trials tended to be very similar to wheat at the same site in the same year. When they were significantly different, they were not consistently higher or lower than wheat in the same situation.

At Minnipa, although critical concentrations were similar for wheat and canola, the reductions in canola yield when grown in deficient soils were more severe than for wheat. This suggests that under-fertilising for P in canola grown on soils low in P may result in more severe economic penalties than in wheat. For pulses, the reductions in grain yield were often similar to wheat in percentage terms, but there were two occasions when the pulse incurred no grain yield penalties while wheat suffered 40-50% yield losses.

Table 2. Critical concentrations for Colwell P in the top 10cm for wheat and break crops at three sites in SA.

Site	Year	crop	Critical Level, mg/kg		Max yield, t/ha	Annual rainfall, percentile
			Trial	BFDC		
Wasley's	2018	wheat	93	23	1.70	7
		lentil	125	25	0.13	
	2019	wheat	63	23	3.27	4
		lentil	37	25	0.55	
	2020	wheat	52	23	3.91	34
		chickpea	51	25	1.45	
Urania	2018	wheat	120	22	4.75	17
		chickpea	-[1]	37	0.77	
	2019	wheat	33	22	2.59	1
		lentil	36	37	0.64	
	2020	wheat	37	22	4.97	45
		lentil	-[1]	37	1.12	
Minnipa	2018	wheat	21	26	0.95	13
		canola[2]	-	27	-	
	2019	wheat	31	26	1.75	9
		canola	22	27	0.25	
	2020	wheat	22	26	2.38	54
		canola	31	27	0.36	

[1]No response to increasing soil P, so no critical concentration could be calculated. [2]Canola had to be reseeded and did not reach maturity.

Mineral nitrogen in the top 60cm

Two sites (Table 1) investigated the impact of mineral N content (kg N/ha) in the top 60cm of soil on crop production. Large N responses were recorded at Mt Hope in both years for wheat and canola (50-80% yield reductions with low soil N), but relatively small N responses in both years for both crops at Yeelanna (0-40% yield reductions). The critical soil N level for canola was consistently higher than for wheat which means that in the absence of added N fertiliser, canola requires higher levels of mineral N in the soil profile to maintain productivity. Yield losses when profile mineral N was low also tended to be larger for canola than for wheat in percentage terms. The SA data set is too small to make firm recommendations about target profile mineral N totals for canola or wheat – these will be determined once the data set from the entire project is fully collated and examined.

Colwell potassium in the top 10cm

Only one site in SA (Table 1) investigated the impact of Colwell K concentration on crop production. Despite prolonged and numerous attempts to identify trial sites in the SA agricultural zone which had low concentrations of K in the topsoil, no ideal sites were found. Sandy soils were avoided because this is the one soil type where there is already extensive information on soil K requirements for cropping. The site at Field had variable soil types across the site so was not ideal for a trial. The lowest Colwell K concentrations at this site ranged between 48 and 57mg/kg, but a K response was not confirmed in either crop in either year, despite grain yields of over 5t/ha in wheat and 1-2t/ha in canola. The only conclusion that can be drawn from this site is that the current critical concentration of Colwell K indicative of a likely deficiency (50-60 mg K/kg in the 0-10cm layer) is probably still appropriate for both wheat and canola, mostly on sandy soils.

KCl40 sulphur in the top 10cm

Despite extensive inquiries with consultants, advisers and analytical laboratories, no site could be found in SA which met the project criteria of being in an important cropping district with topsoil values of S below 3, no 'bulges' of S deeper in the soil profile, and was not a sandy soil. Sandy soils were avoided because there is already reasonable information on S requirements for cropping on these soils. The site at Loxton came closest to our criteria - a deep orange sand in a low production environment with lowest S values ranging between 3.3 and 5.6mg/kg. In the two years of the trial, the field pea crops were not harvested due to dry conditions and frost, and the wheat averaged less than 1t/ha in both years. For the duration of the trial there was no evidence of S

deficiency in the low yielding crops, either visually or measured in the plant tissues. This trial, therefore, provided no evidence to challenge the current guidelines of S deficiency in wheat, which are that KCl-extractable S in the top 10cm needs to be above 3.6mg S/kg. There are no current guidelines for field pea, but the lack of visual responses in the crops in both years suggests that the current critical value used for wheat may also be appropriate.

Conclusion

Few guidelines currently exist for critical soil concentrations of N, P, K or S for canola and pulses in SA. This project has filled some of the gaps in commercial soil tests for break crops, with key findings being:

- Target concentrations of Colwell P for break crops are similar to wheat, which means that the extensive bank of information in BFDC for wheat can be used to predict soil P requirements for break crops.
- Intensively cropped paddocks which have been managed with no-till practices for an extended period may have higher Colwell P targets than situations where conventional cultivation has been more recent. This is due to less mixing of soil with no-till and P reserves accumulating close to the soil surface which is often dry and reducing P availability. Target concentrations could be 50-100% higher in no-till situations than current industry standards.
- Percentage reductions in canola yields that arise from growing the crop in soils low in P are likely to be larger than with wheat.
- Percentage reductions in lentil yields that arise from growing the crop in soils low in P are likely to be similar to or less than wheat.
- The quantity of mineral N to 60cm for productive canola appears to be higher than for wheat. More detail in this area will be provided once the data set for the entire project is interrogated.
- The current guidelines for Colwell K remain the best information available for monitoring the soil status for K for wheat and break crops where that information exists.
- The current guidelines for KCl40 S remain the best information available for monitoring the soil status for S for wheat and break crops where that information exists.

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 would also like to thank all the growers and their families who hosted our field trials. Without their cooperation and support, the project would not have been possible.

Contact details

Nigel Wilhelm
Building WT70, Hartley Grove, Waite Research Precinct, Urrbrae 5064
0407 185 501
nigel.wilhelm@sa.gov.au

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

Return to contents

Notes

Increasing reliability of lentil production on sandy soils

Sam Trengove[1], Stuart Sherriff[1] and Jordan Bruce[1].

[1]Trengove Consulting.

SAGIT project code: TC116 and TC119

Keywords

- Sandy soil, Lentil variety, herbicide tolerance

Take home messages

- Four key steps to improving lentil productivity on underperforming sandy soils are: soil amelioration, variety selection, herbicide choice and nutrient management.
- Ameliorating soil constraints increased lentil grain yields up to 347%, with an average 0.31t/ha (85%) yield response to deep ripping.
- The highest yielding varieties on loamy soil types may not be the highest yielding on underperforming sandy soils.
- Weed control methods on sandy soil types should be carefully planned to minimise yield loss due to the heightened risk of herbicide damage from soil residual herbicides.
- Nutrient requirements on sandy soil types can vary across locations and seasons. Application of molybdenum on acidic sands were shown to increase grain yields.
- Lentil growth and biomass, as measured by NDVI, was positively correlated with grain yield on sandy soils.

Background

Lentil production in South Australia has expanded significantly over the last 20 years. It is valued for its agronomic rotational benefits and its ability to generate high economic returns. The expansion in lentil area now sees the crop produced on a diverse range of soil types across the state. Observations of lentil growth and productivity has indicated that on some sandy soils' performance has been sub optimal, with significant scope for improvement. This was particularly notable in the dune swale landscape of the northern Yorke Peninsula. Two SAGIT projects (TC116, TC119) have investigated opportunities for increasing lentil productivity on the sandy soil types of this region. These sands are typically red sandy dunes with low organic carbon (0.4-0.8%). Constraints on these sands can include compaction, non-wetting, pH (both acidic and alkaline), nutrition and low biological activity. The heavy reliance on herbicides with residual soil activity for broadleaf weed control in lentil also presents challenges on these soils. However, these sandy dune soil types are not typically constrained by the subsoil toxicities of sodicity, salinity or boron that limit production on many of the heavier textured soils in the region. Thus, significant production improvement in lentil is expected if these known constraints can be overcome. This paper details the results of SAGIT and GRDC funded amelioration, variety selection, herbicide choice and nutrition trials conducted on these sandy soils.

Methodology

General trial information

Yield data from specific treatments from a range of soil amelioration trials have been summarised for the purpose of this paper. For detailed methodology of each trial contact Trengove Consulting or refer to the relevant project listed.

Soil types – Trials occurred in 2015 and from 2017 to 2020 and were located on poor performing sandy soils across the upper northern Yorke Peninsula. Soils ranged from grey alkaline sands near Alford to red/orange sands around Bute and Port Broughton. Organic carbon level was typically low with 0.94% the highest, pH values ranged from acidic sites (0-10cm pH 5.3 $CaCl_2$) to highly alkaline (0-10cm pH 8.6 $CaCl_2$) and nutrition levels also varied with Colwell P values ranging from 26 – 44.

Trial sowing dates were typical for lentil crops in the region and were sown between May 11 and May 22. Standard seeding fertiliser was applied as MAP @ 60 – 80 kg/ha.

Herbicides treatments were applied using a 2m hand boom. Pre-emergent herbicides were applied pre seeding or split with 2/3 applied pre seeding and 1/3 post seeding pre-emergent. Plots were sown using knife points and press wheels on 250mm spacing and all plots were rolled using a steel roller, either pre-emergent or early post emergent. Early post emergent diflufenican herbicide treatments were applied (June 14 – July 28) approximately 10 days prior to Intercept® herbicide treatments (July 2 – August 8). Varieties for the herbicide tolerance and nutrition trials were either PBA Hurricane XT$^{\phi}$ or PBA Hallmark XT$^{\phi}$.

All trials in these projects were randomized complete block designs with three replicates and plot dimensions were 1.5 * 10m.

Early growing season rainfall during the herbicide trial years was generally, with the exception being one day in June 2019 where 47mm was recorded at Bute (Figure 1).

Results and discussion

Amelioration

Compaction is a common physical constraint of crop growth on sandy soils in the northern YP region, it inhibits plant root exploration beyond compacted depths. Results from amelioration trials conducted in the northern YP and Mallee regions show an average lentil response to ripping of 0.31 t/ha, or 85% yield increase (Table 1). In some instances, the scale of response is much larger in lentil than for cereals at the same site. For example, a long-term trial site at Bute (Table 1, site 6) has averaged 0.51t/ha (109%) yield increase in lentil over two seasons, whereas cereal response has averaged 0.6t/ha (19%) over four seasons at the same site. The lentil responses, as measured by percent increase over the control treatment, are much greater than those measured in cereal due to the lower baseline yields in lentil. In this example the lentil response provides a much greater economic response when compared with cereals, due to their inherent higher grain price.

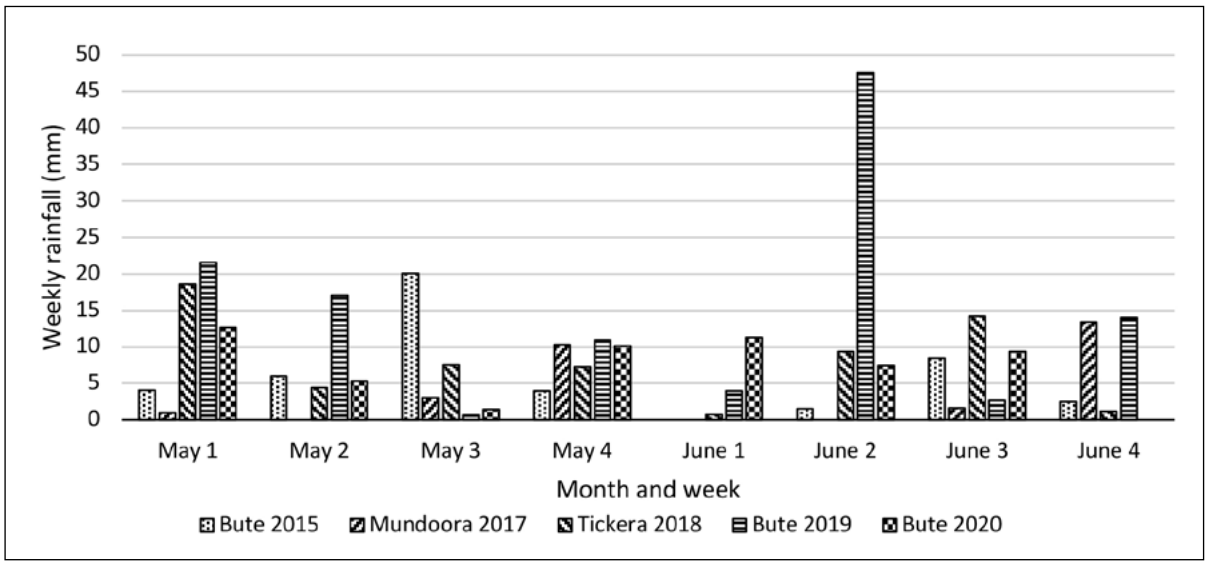


Figure 1. Weekly rainfall for the period leading up to seeding and early post emergent for all trials 2017 – 2020.

Penetrometer resistance measurements down the soil profile (data not shown) were characterised for sites five and six (Table 1). At site five soil resistance to a cone penetrometer never exceeded 2500kPa. However, at site six the untreated control exceeded 2500kPa from a depth of 17cm to the limit of measurement (at 60cm), with a peak of 4300kPa between 30-35cm. These differences help to explain the grain yield response to ripping at site six. It also highlights the need for diagnosing the presence of the constraint prior to undertaking soil amelioration works.

Other constraints identified include low fertility, low organic matter and soil acidity. Four trials testing the response to chicken litter applied at rates of 5 or 7.5 t/ha as a once off application averaged 0.26 t/ha (41%) yield increase in lentil (Table 1). As found with the ripping response, at site six (Table 1) the application of 5 t/ha chicken litter has a greater effect in lentil than for cereals with the cereal yield increasing by an average 10.6% (0.32 t/ha) compared to 37% (0.18 t/ha) for lentil. Grain yield responses were measured six years after application in this trial. However, responses of this scale have not been observed in separate nutrition trials during the same period, where chicken litter has been included as a treatment at 5t/ha. The latter trials differ in that the chicken litter was applied to the surface immediately pre-seeding and incorporated by sowing, where in the amelioration trials the chicken litter was mostly incorporated in some way, either by ripping or offset disc, and was applied at least two years prior to lentils in three of the four trials. This method of incorporation and time period from application to lentil season may be important in explaining the differences in results observed. The findings suggest that earlier application and incorporation provided an improved environment for lentil plants to uptake mineralised nutrients from the chicken litter application than when applied and incorporated with the lentil crop.

Three trials assessing options for management of soil acidity on sandy soils in the Bute region were established recently in 2019. These trials were all lentil in 2020. Only small increases in grain yield were achieved in response to lime treatments averaging 0.08 t/ha, or 4% (Table2). Without the application of lime, soil acidity will continue to increase, and it is expected that these responses will increase over time. One trial included an elemental sulphur treatment applied to reduce soil pH to demonstrate effects of increased soil acidity. Plant biomass as measured by NDVI on September 15 was lowest in this treatment, with the best treatments (PenLime Plus and Spalding lime) having a 5% higher NDVI value (data not shown).

Varieties

Across a range of lentil agronomic trials, treatments that increased crop growth on sandy soils of the northern Yorke Peninsula also increased lentil grain yield. This finding was confirmed in variety trials, where varieties with higher NDVI values at the flowering growth stage produced higher grain yield (Figure 2A), even though no other site-specific constraints were addressed. This

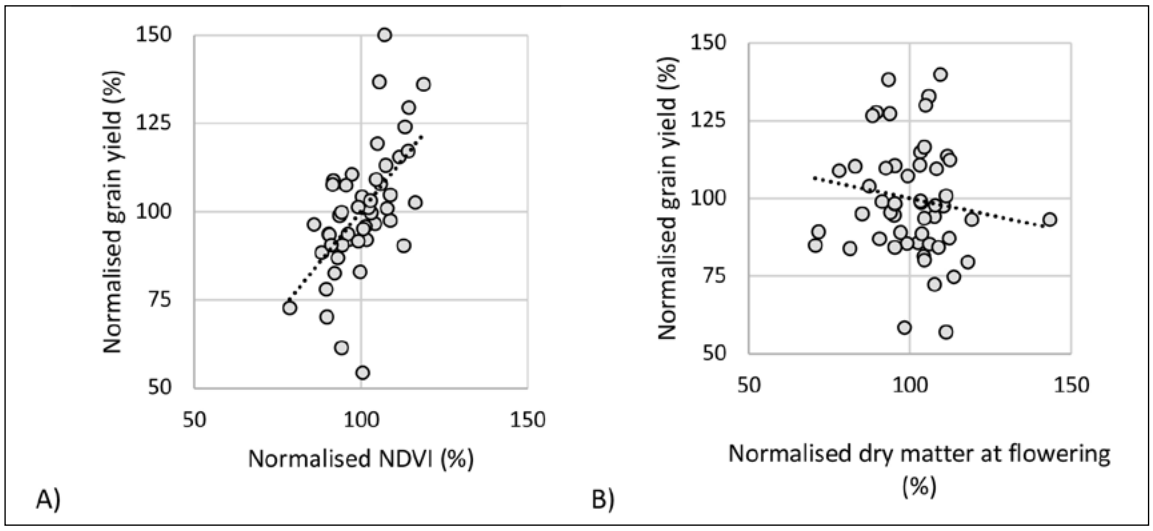


Figure 2. A) Normalised grain yield and NDVI at flowering data from lentil variety trials located on sandhills of the northern Yorke Peninsula from 2017-2020 (y = 1.1674x - 16.642, R^2 = 0.329). **B)** Normalised grain yield and biomass at flowering data from PBA breeding program located on loamy soils near Melton from 2012-2014 (source: PBA) (y = 0.2176x + 121.82, R^2 = 0.0143).

Table 1. Lentil grain yield response for a range of sandy soil amelioration trials.

Location	Project Code (GRDC or SAGIT)	Year trial established	Lentil crop year	Response to deep rip ~50cm	Response to spading ~30cm	Response to chicken litter in addition to district practice fertiliser
1. SARDI pulse agronomy –Bute	DAV00168BA: southern pulse agronomy	2019	2019	0.7t/ha (127%)	NA	5t/ha app 2019 = 0.19t/ha (63%) Nil background fertiliser applied.
2. Validation trial –Warnertown	CSP00203: southern region sandy soils	2019	2020	Rip: 0.06t/ha (7%) Rip + IP: 0.15t/ha (16%)	0.35t/ha (38%)	NA
3. Soil acidity lime incorporation trial –Bute	DAS 1905-011TRX: addressing soil acidity in SA	2019	2020	Rip: 0.53t/ha (29%) Rip + IP: 0.74t/ha (41%)	0.63t/ha (35%)	NA
4. Uni SA soil acidity fellowship trial – Bute	USA103-002RTX: mixing uniformity and crop response	2019	2020	0.07t/ha (8%)	2km/h (multi-pass): -0.09t/ha (-10%) 5km/h: 0.04t/ha (4%) 9km/h: -0.01t/ha (-2%)	NA
5. CSIRO soil amelioration –Bute Boundary Rd	CSP00203: southern region sandy soil	2018	2020	-0.05t/ha (-3%)	NA	7.5t/ha = 0.48t/ha (25%)
6. Long term soil amelioration –Bute	TC116: Increasing lentil productivity on dune and swale soils	2015	2017	0.58t/ha (149%)	NA	5t/ha app = 0.18t/ha (47%) 20t/ha app = 0.293t/ha (75%) 5t/ha app + rip = 0.84t/ha (216%)
6. Long term soil amelioration –Bute	CSP00203: southern region sandy soils	2015	2020	0.44t/ha (69%)	NA	5t/ha app = 0.17t/ha (27%) 20t/ha app = 0.22t/ha (35%) 5t/ha app + rip = 0.67t/ha (106%)
7. Lameroo 2020	SA MDBNRM	2020	2020	0.69t/ha (179%)	0.66t/ha (172%)	NA
8. Lameroo 2019		2019	2019	0.19t/ha (171%)	NA	NA
9. Kooloonong 2020	SPA (DAV00150)	2020	2020	0.71t/ha (97%)	NA	NA
10. Kooloonong 2019	SPA (DAV00150) / CSP00203	2019	2019	0.38t/ha (337%)	NA	NA
11. Carwarp	CSP00203: southern region sandy soil	2018	2018	-0.05t/ha (-12%)	NA	NA
		2018	2019	0.04t/ha (19%)	NA	NA
		2018	2020	0.09 (13%)	NA	NA

Table 2. Lentil grain yield response to lime application in a range of acidic sandy soil amelioration trials.

Location	GRDC Project	Year trial established	Lentil crop year	Starting pHca by depth increments of 5cm from 0-30cm	Grain yield response to lime
Soil acidity lime product trial - Bute	DAS 1905-011TRX: addressing soil acidity in SA	2019	2020	6.1, 5.0, 4.8, 5.2, 5.6, 6.0	0.1 t/ha (4%)
Soil acidity lime incorporation trial - Bute	DAS 1905-011TRX: addressing soil acidity in SA	2019	2020	6.1, 5.0, 4.8, 5.2, 5.6, 6.0	0.14 t/ha (6%)
Uni SA soil acidity fellowship trial – Bute	USA103-002RTX: mixing uniformity and crop response	2019	2020	5.5, 5.0, 4.4, 4.6, 5.0, 5.6	0.02 t/ha (2%)

contrasts with results from trials conducted on more loamy soils (Figure 2B) where increasing biomass was not correlated with increased grain yield. This finding suggests that the highest yielding variety on a heavier textured flat may be different to the highest yielding variety on a sand hill in the same paddock. The Willamulka NVT site is considered one of the lighter textured soil types within the suite of SA NVT lentil trials, yet by district standards it is a medium textured sandy loam flat. A four-year relative comparison of yield results from lentil variety trials on sandy soils across the northern Yorke Peninsula, to those from the Willamulka NVT and Melton PBA (loamy clay) lentil trials found that the highest yielding variety varies between the two groups (Figure 3). The high biomass later maturing variety PBA Ace$^{\phi}$ was the highest yielding line from the sandy soils cluster of trials, some 4% higher than PBA Jumbo2$^{\phi}$. Whereas in the loamy soil cluster, PBA Ace$^{\phi}$ was 3% lower yielding than PBA Jumbo2$^{\phi}$.

Herbicides

Herbicide tolerance

Yield losses associated with herbicide damage in lentil trials on these sandy soil types have ranged from 0 – 58% for individual products and up to 75% for herbicide combinations over 8 trials conducted in 2015 and from 2017 to 2020. This has been measured in the absence of weeds, with any weeds surviving the herbicide applications controlled by hand weeding from mid-winter onwards.

The herbicide products used in these trials all have different chemical properties. However, the residual soil applied herbicides were particularly sensitive to rainfall patterns post application (Table 3). The solubility value of each herbicide affects the way it moves in the soil profile with low solubility herbicides such as diuron requiring higher amounts of rainfall to move them through the soil. However, highly soluble herbicides such as metribuzin move rapidly through the soil profile after relatively

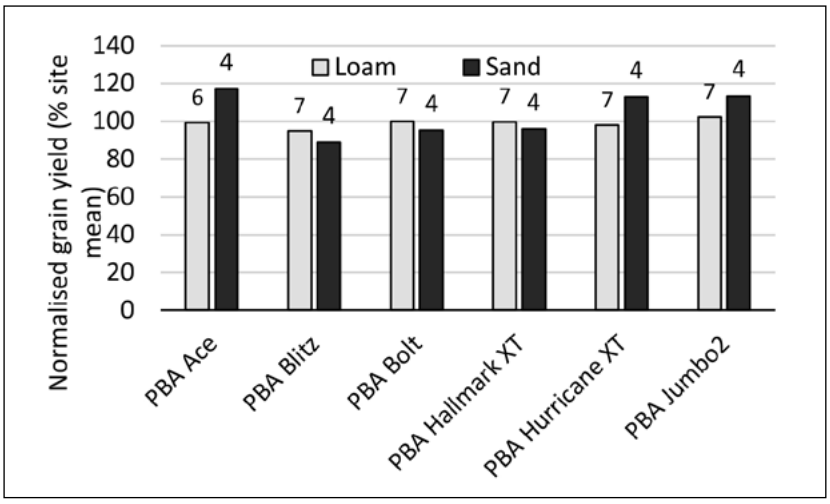


Figure 3. Average grain yield for selected commercial varieties as clustered by soil type for years 2017-2020 (Source: NVT Online, Willamulka NVT and Melton PBA yields used for loam cluster, sandy soil cluster yields from Trengove Consulting trials), number above bar shows number of trials variety is present.

smaller rainfall events. The adsorption coefficient (how tightly the herbicide binds to organic matter) and the DT50 value (days of time for 50% of the herbicide to dissipate) also have impacts on how these herbicides respond in each season and soil type. The herbicide diuron has a high adsorption coefficient and relatively low solubility and was found to often be the safest group C herbicide at the rates applied (Table 4). The seasons in which these trials were conducted generally did not have large rainfall events post seeding and in different seasons results may vary.

The products and ranges of rates that were used in these trials were selected as they were found to be representative of use patterns on sandy soils in the region, and typically at the low end of the rate range recommended for group C herbicides on sands (Table 4). Despite the low use rates crop damage and yield loss was still observed at these sandy soil trial sites in some seasons. Various group C herbicides were trialled in combination with other group B and F herbicides across different trials (Figure 4, Table 5). To summarise the effect of these group C interactions, results have been bulked across group C products and referred to as Group C plus companion herbicide. Chlorsulfuron was applied at 5g/ha IBS to simulate residual carryover from the previous season. However, it still caused significant yield loss in XT lentil varieties at these sites (Figure 4), therefore it is important for growers to recognise the heightened risk of SU residue effects on these soil types and avoid this use.

Herbicide products applied individually generally only showed low levels of crop damage and associated grain yield loss. In this series of trials, average yield loss for individually applied products was 9% compared to the untreated control (Figure 4). However, when multiple products were applied, greater levels of crop damage were observed. This is particularly the case with the soil residual herbicide chlorsulfuron where the application of group C herbicides in conjunction increased the yield loss to 50% on average. Similarly, the additional effect of Intercept where chlorsulfuron residues were present significantly increased damage with yield loss averaging 50%, whereas on its own at the rates applied Intercept® did not reduce grain yield (Figure 4).

Weed control

Individual herbicides

- Metribuzin at the range of rates applied produced the poorest weed control of the group C herbicides across all weeds assessed (Table 5).
- Control of Indian Hedge Mustard (IHM) with Intercept® was highly variable, and likely represents the presence of imidazolinone herbicide resistance in some IHM populations across the region. Despite imidazolinone resistance now reported in sow thistle in the district, average control of 79% was seen as a relatively good result.
- Diflufenican (DFF) provided good control of the brassica weeds IHM and wild turnip.

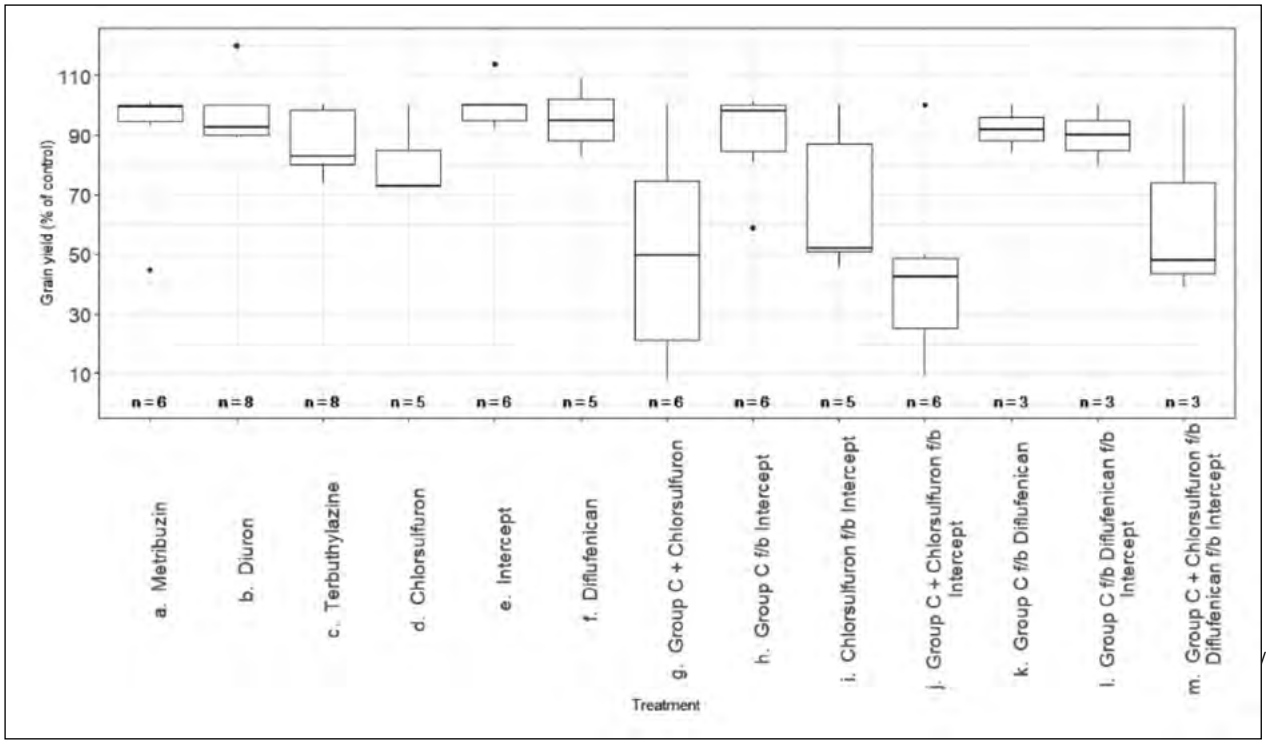
Table 3. Pre-emergent herbicide properties for products used in the herbicide tolerance trials 2015 and 2017-2020 (Source: GRDC pre-emergent herbicide fact sheet).

Herbicide	Solubility (mg/L @ 20C)	Adsorption coefficient, Koc value	DT50 value (range in reported value)
Diuron	36	680	90
Terbuthylazine	7	130	22 (6-149)
Metribuzin	1100	60	19 (14-28)
Chlorsulfuron	12500	40	36 (10-185)

Table 4. Herbicide products used and rate ranges used in trials in 2015 and 2017-2020.

Product name	Herbicide active constituent	Herbicide group	Concentration	Rate range (mL or g/ha)	Application Timing
Chlorsulfuron	Chlorsulfuron	B	750g/kg	5	IBS [#]
Intercept	Imazamox + imazapyr	B	33g/L + 15g/L	500	Post-emergent
Diuron	Diuron	C	900g/kg	550 - 825	IBS or PSPE
Metribuzin	Metribuzin	C	750g/kg	150 - 180	IBS or PSPE
Terbyne	Terbuthylazine	C	750g/kg	500 - 750	IBS
Brodal Options	Diflufenican	F	500g/L	150	Post-emergent

[#] Chlorsulfuron was applied IBS at 5g/ha to simulate residual carryover from application in the previous season.



Herbicide combinations

- Combinations of herbicides improved weed control compared to the same herbicides applied alone.
- Group C herbicides followed by DFF gave 100% control of IHM and wild turnip and good control of medic (82%) and sow thistle (94%).
- Group C herbicides followed by Intercept® provided 85% or better weed control of all four weed species.
- Group C herbicides followed by DFF followed by Intercept® averaged greater than 94% control of all weeds.

Nutrition

Chicken litter increased yield in four amelioration trial years (Table 1), as discussed previously. Tissue testing at site six (Table 1) in 2017 revealed elevated levels of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), copper (Cu), manganese (Mn) and molybdenum (Mo), in lentil whole tops compared with the control treatment, indicating chicken litter was supplying a broad range of nutrients. A trial with matched application rates of the macronutrients N, P, K, S and micronutrients Zn, Cu & Mn as synthetic fertiliser sources also elevated tissue test levels of P, K, S, Cu, and Mn but did not increase yields. Due to the differences in Mo levels between chicken litter and synthetic

Table 5. Weed control of Indian hedge mustard (*Sisymbrium orientale*), burr medic (*Medicago polymorpha*), common sow thistle (*Sonchus oleraceus*), and wild turnip (*Brassica tournefortii*) for different herbicide products and sequences in lentil herbicide trials on sandy soils across the northern Yorke Peninsula.

Herbicide product(s)	% weed control (# samples) range											
	IHM			Medic			Sow thistle			Wild turnip		
Metribuzin	58	(4)	29-82	28	(5)	0-76	45	(6)	16-69	62	(5)	50-83
Diuron	85	(4)	74-97	40	(5)	0-70	76	(6)	50-94	70	(5)	52-94
Terbuthylazine	92	(4)	83-100	63	(5)	36-82	81	(5)	61-96	85	(5)	78-100
Intercept	59	(3)	0-91	56*	(4)	0-88	79	(5)	61-88	96	(4)	88-100
Diflufenican (DFF)	97	(2)	95-100	56	(2)	34-78	59	(3)	0-94	80	(2)	63-97
Group C f/b Intercept	85	(3)	62-97	86*	(4)	71-94	92	(5)	63-100	87	(4)	74-100
Group C f/b DFF	100	(2)	100-100	82	(2)	74-90	94	(3)	88-100	100	(2)	100-100
Group C f/b DFF f/b Intercept	99	(2)	99-100	94*	(2)	92-96	95	(3)	84-100	100	(2)	100-100

**in most cases surviving medic plants were severely stunted and not competitive.*

fertiliser treatments it was hypothesised that this may have been a significant deficiency on the acidic sand at this site (0-10cm pH 5.2 $CaCl_2$). Nutrition trials were run from 2017-2020 on both alkaline and acidic sands in the region. These trials included the addition and omission of a range of essential plant nutrients. While elevated levels of some nutrients were again measured in tissue tests, no unique nutrition constraints were identified that led to improved yield.

Molybdenum on acidic sands

In 2019 and 2020 post-emergent molybdenum trials on slightly acidic sands were conducted with pH of 5.8 $CaCl_2$ and 5.9 CaCl2 0-10cm, respectively. Nine treatments ranging from 0 – 400 g/ha sodium molybdate, applied over two timings, early July and mid-August were evaluated. In both seasons strong visual plant growth responses were observed within two weeks of treatment and resulted in increased NDVI values. This also resulted in increased grain yields of 43% and 21% for 2019 and 2020, respectively. In both seasons there was no benefit from increasing the rate of sodium molybdate above 25 g/ha and timing had no impact (data not presented).

Biomass and yield

Across a suite of 24 trials on sandy soils of the northern Yorke Peninsula a consistent positive linear relationship between biomass at flowering (using Greenseeker NDVI as a biomass surrogate) and grain yield has been established. This is consistent with work by Lake and Sadras (2021) experimenting with 20 lentil lines varying in seed type and phenology in eight environments. They found yield correlated with biomass and crop growth rate in more stressful conditions, where yields were less than 1.07t/ha. However, they also found this relationship decoupled in more favourable conditions where yields exceeded 1.7t/ha. In these favourable conditions' excessive vegetative growth can lead to self-shading, reduced pod and seed set, low harvest index and higher risk of disease and lodging (Lake and Sadras, 2021). The results presented in this update paper suggest the physical and chemical constrained sandy soils of the northern YP are also plant biomass constrained, where any treatment that overcomes some or all these constraints, increases both biomass and yield. However, it is also possible that this relationship decouples on the heavier textured soils within the same paddocks where biomass is not a constraint to yield.

Conclusion

There are four main steps and considerations when planning to increase the reliability of lentil production on sandy soils identified in this study. The first step is to identify and overcome any soil physical and chemical constraints that limit crop growth and biomass, through the use of soil amelioration techniques. The second step is selecting a suitable high biomass variety such as PBA Ace$^{\phi}$, PBA Hurricane XT$^{\phi}$ or PBA Jumbo2$^{\phi}$. This decision needs to factor in the presence of any other soil types within the paddock. The third step is the selection of appropriate herbicides for the situation which should be based on the variety to be grown, soil types, soil moisture content and probable three day forecast at the time of application, the main weed targets and the level of escapes that are deemed acceptable as 100% control may come at a cost in yield reduction. The final step is correcting any nutritional deficiencies that may be present. Further gains on these soils are realistic through breeding improvements in varieties with higher plant biomass and improved Group C herbicide tolerance.

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 SAGIT, the author would like to thank them for their continued support. The authors also acknowledge the valuable input from Larn McMurray during these projects.

References

Lake, L. and Sadras, V.O., (2021). Lentil yield and crop growth rate are coupled under stress but uncoupled under favourable conditions. GRDC project code 9176630.

Contact details

Sam Trengove
Trengove Consulting, Bute SA
0428262057
samtrenny34@hotmail.com
@TrengoveSam

$^{\phi}$Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.

Return to contents

Notes

Notes

Nitrogen fertiliser use efficiency 'rules of thumb' - how reliable are they?

Roger Armstrong, Ash Wallace and Katherine Dunsford.

Agriculture Victoria Research, Grains Innovation Park, Horsham.

Keywords

- mineralisation, denitrification, crop utilisation, ^{15}N mass balances.

Take home messages

- An assessment of current 'rules of thumb' (RoT) for predicting nitrogen (N) fertiliser requirements in the southern region cropping systems has identified the need to update current assumptions.
- Deep soil N testing prior to (or just after) sowing is critical for good fertiliser N management.
- Current RoTs and other decision support systems for in-crop N mineralisation do not provide predictions at an adequate time step or scale.
- Crop utilisation of fertiliser and soil N varied markedly in response to seasonal rainfall distribution. Across all major cropping zones in Victoria, the average crop recovery of fertiliser N in the year of application is about 35% and this is recommended to replace the RoT of 50%.
- ^{15}N fertiliser mass balance studies revealed significant losses of fertiliser N, with an average of 25%, 32% and 41% of applied N in the low-medium rainfall, high rainfall and irrigated cropping systems, respectively.
- The important N loss pathways remain unknown, but identification is critical if appropriate N management strategies to minimise losses and maximise crop uptake are to be developed.

Background

Nitrogen (N) fertiliser is a key determinant of grain yield and the ability of cereal crops to achieve water limited yield potential in western Victoria (Armstrong *et al.* 2018). Because N fertilisers are one of the largest variable cost inputs (in both the southern region and nationally), accurate predictions of N fertiliser requirements are critical for grower profitability.

A national survey of more than 300 growers and advisers conducted in 2015 across a broad range of rainfall/productivity zones, including South Australia (SA) and Victoria (Vic) assessed how they made decisions and the underlying assumptions used to arrive at N management recommendations (UQ00179). The survey found that most of these busy advisers and growers utilised nutrient budgeting and general 'rules of thumb' (RoT) adjusted with localised information (experience) and specific data such as results from pre-sowing soil N testing. Many did not use elaborate decision support systems (DSS) or tools including simulation models such as Yield Prophet®, and where they did, it tended to act as a backup (validation) of the RoT. Another report (Unkovich *et al.* 2016) of adviser and grower practices in the southern region suggest a greater use of more elaborate DSS. However, these growers and advisers indicated concern about the accuracy of both simple N decision methods and the more elaborate DSS given the major changes in soil fertility and cropping systems since these tools were developed. Some expressed concern about using a DSS 'black box' especially without evidence of the embedded assumptions and caveats underpinning these procedures.

The basic components (assumptions) of most of the RoT approaches are from several assessments made each season of the estimated yield (demand) and the efficiency of N uptake by the crop from the soil and fertiliser inputs. Soil N supply depends on (i) available mineral N at sowing, (ii) within season N mineralisation from organic matter (iii) the efficiency of recovery of soil and applied N by the crop and (iv) net off-site losses of N or immobilisation by microbes. Differences between soil N supply and anticipated crop demand are then met by fertiliser application. In general, there is a supply shortfall to account for seasonal risk e.g. growers rarely fertilise to achieve yield potential because of the uncertainty of spring conditions and the risks of frost, drought or heat shock. Variability in any of these N supply and demand components can significantly influence fertiliser decision-making, and therefore alter the return on investment.

Nitrogen management is influenced by a range of factors, many which are logistical in nature. It is argued, however, that the current lack of confidence by many growers and advisers in existing N management approaches at a biophysical level stems from uncertainty surrounding the magnitude and seasonal variability of these key processes at a local scale and across soil types, and the inability to readily access relevant data used in these determinations. This paper reviews the assumptions underpinning the key components used to predict soil and fertiliser N supply in current RoTs used to guide fertiliser N management decisions for the current season. Biophysical data from recent studies focused on western Victoria is used, but this data is likely to be applicable to the whole southern region. Recent publications are referenced such as Unkovich *et al.* (2020) that have reviewed both published and grey literature relating to previous research into the processes underlying these assumptions.

Methods

Data used for assessments of assumptions (available N at sowing, within season net N mineralisation, the efficiency of recovery of soil and applied N by the crop and net off-site losses of N or immobilisation) were obtained primarily from two PhD studies (A. Wallace and K. Dunsford). The first study was based on data collected in two Australian Government funded Projects (*Action on Ground* (AonG), *'Reducing on-farm nitrous oxide (N_2O) emissions through improved nitrogen use efficiency in grains'*) and the 'Filling the Research Gap' NANORP program. Both assessed crop response to and utilisation of N fertiliser applied to cereal crops (mainly wheat) in growers' paddocks across a broad range of environments and soil types encompassing the key grain production areas of western Victoria: high rainfall > 550mm annual (HRZ), medium rainfall 400-550mm (MRZ), low rainfall < 400mm (LRZ) and irrigated cropping systems of northern Victoria. The AonG data comprised nine sites undertaken between 2014 and 2016 equating to a total of 29 site by year comparisons (Figure 1). The trials were located in grower paddocks (i.e., using grower management of the crop). At each site, a simple N rate response trial was established using a randomised complete block design with plot sizes of approximately 18m^2. Three N treatments were applied at each of the nine sites based on industry standard practice relevant to each region and the seasonal conditions. Sites received a small rate of N in the starter fertiliser across all plots at sowing (0-20kg N/ha), typically in the form of Mono-Ammonium Phosphate (MAP) or Di-Ammonium Phosphate (DAP) depending on grower management. Treatments included two rates of N fertiliser applied during the growing season plus a control which received no additional N during the season. The NANORP data comprised a total of six site by years experiments conducted between 2012 to 2014 in the Wimmera (Wallace *et al.* 2020). These experiments tested a range of different N management strategies. The utilisation and recovery in the soil: plant system of N fertiliser applied to wheat crops in both data sets was assessed using a ^{15}N mass balance approach to develop crop utilisation coefficients. Differences in the amount of labelled N applied and that recovered in the soil were assumed to represent losses. In the AonG trials, ^{15}N labelled urea was top-dressed during the vegetative or stem elongation growth stages when a rainfall event was anticipated in the following two to three days, although in higher yielding situations (especially the HRZ and irrigated sites) a second application later in the year was made in favourable seasons.

Nitrogen mineralisation data was collected from 73 grower paddocks (including those used in the AonG project) in the LRZ, MRZ and HRZ, between 2013 and 2016. Data was also collected from the SCRIME long-term rotation/tillage experiment at Longerenong (Armstrong *et al.* 2019). The contribution of net in-crop N mineralisation (net ICM – the balance of N mineralised from soil organic matter and crop residues minus N immobilised by soil microbes) to crop N supply was assessed in all studies. Net ICM of N was estimated as the difference between measurable N supply (mineral N measured at sowing plus fertiliser inputs minus

the sum of mineral N measured and crop N uptake at maturity) based on the procedure used by Armstrong *et al.* (1997):

Net ICM (kg N/ha) = Crop N x 1.1 + SN_M – (SN_S + N_{fert}).....Equation 1

Where Crop N is the total amount of N contained in the shoots of the crop at maturity multiplied by 1.1 to estimate the fraction of N allocated to roots (Angus 2001; Gan *et al.* 2011). SN_M and SN_S are soil nitrate (0 – 1.2m) at maturity and at sowing, respectively, and N_{fert} is applied fertiliser N. Only nitrate data was used for this calculation and not ammonium, since most mineral N in dryland cropping soils is rapidly converted to nitrate.

Results and discussion

Available N at sowing

The amount of mineral N in the profile prior to or just after sowing is a crucial indicator of soil N supply for the coming season. In some circumstances, sufficient N can mineralise over the preceding summer/autumn fallow, to meet crop requirements, without the need to add additional N (Dunsford 2019; Harris *et al.* 2016). At present, only a minority of paddocks are tested for mineral N in deeper profile layers ('deep N'), due principally to logistical challenges (Sean Mason 2020 pers. comm; project 9176604) such as access to a suitable soil sampler. As an alternative to direct measurement, estimates of likely mineral N can potentially be made by considering the previous rotation and rainfall. As data from SCRIME shows (Table 1), pre-sowing mineral N can be influenced equally by fallow summer/autumn rainfall (Figure 1) as by previous rotation (Armstrong *et al.* 2019). As such, delaying direct assessment of mineral soil N supply until after sowing may provide growers with increased confidence in both the starting point of N supply to a crop and potential grain yields.

Within season net N mineralisation

Studies of in-crop N mineralisation in southern region cropping systems indicate that this source of N potentially represents a significant proportion of a crop's requirement (Dunsford 2019). A comprehensive review of DSS tools including simple RoTs for estimating in-crop N mineralisation has recently been published (Unkovich *et al.* 2020). Many of these tools were developed in an era when pasture legume-leys dominated cropping systems or on acid soils in southern NSW rather than current continuous cropping, reduced tillage/stubble retention practices and alkaline soils that dominate cropping in the southern region (Dunsford 2019). Dunsford (2019) found that the 'Ridge Approach', provided a fair estimate (R = 0.46) of net in-crop N mineralisation across a large section of cropping systems in western Victoria, based on soil organic carbon (SOC) of the topsoil and actual growing season rainfall (GSR, Table 2). The Ridge method is calculated as:

N mineralisation (k/ha) = 0.15 × SOC (%) × GSR (mm).....Equation 2

If long-term average rainfall is used in the calculation, however, the reliability of the prediction is reduced considerably (data not presented). The recent extensive review of soil mineralisation by Unkovich *et al.* (2020) concluded that 'none of the currently available tools appear to provide field and season-specific information (prediction) of N mineralisation on a useful time step', or where more

Table 1. Profile (0-120cm) soil nitrate-N (kg/ha) prior to sowing of the wheat phase in response to different rotation/tillage treatments in SCRIME (2001 to 2017). n.d. = not determined. n.s. = not significant (P < 0.05).

Year Treat.[1]	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	mean
WWW	29	19	45	16	19	13	45	89	52	59	27	45	15	21	19	23	26	32.3
PWB	56	42	37	96	38	15	68	74	58	88	48	59	23	31	40	49	67	50.5
GmWB	126	85	53	91	81	62	77	119	68	206	127	91	34	80	85	57	147	89.0
CWP ZT	n.d.	n.d.	n.d.	n.d.	45	52	82	53	63	124	85	55	31	31	39	56	38	59.5
CWPRT	33	21	76	56	93	31	86	76	54	105	68	54	18	77	51	49	76	58.6
CWPCT	n.d.	n.d.	n.d.	n.d.	84	22	108	46	50	n.d.	n.d.	n.d.	35	43	44	61	83	54.9
FWP	91	74	74	n.d.	83	63	52	140	129	274	64	129	84	161	88	66	182	104.7
LLLCWP	42	35	94	23	96	71	106	115	68	167	48	73	90	78	101	87	52	81.0
Mean	*62.7*	*46*	*63*	*56.4*	*67*	*41*	*78*	*89*	*67*	*146*	*67*	*72*	*41*	*65*	*58*	*56*	*84*	*66.3*
lsd (5%)	*27.3*	*11.5*	*27.0*	*n.s.*	*34.6*	*42*	*22.2*	*56.5*	*32.4*	*88*	*45.7*	*26*	*29.7*	*86.0*	*24.0*	*29.6*	*64.7*	*11.9*

[1] *W=wheat; P=pulse; =barley; Gm=vetch green manure; ZT=zero tillage; RT=reduced tillage; CT=conventional tillage; C=canola; F=fallow; L=lucerne (Source: Armstrong et al. (2019)).*

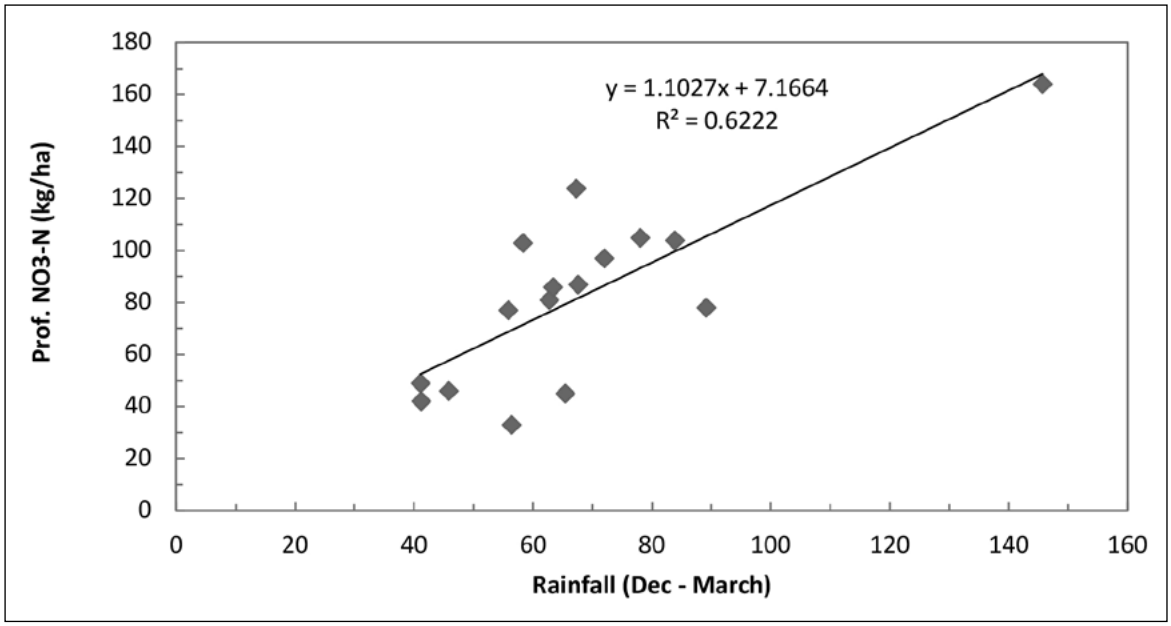


Figure 1. Relationship between rainfall (December of preceding year to March, inclusive in mm) and the amount of nitrate-N (kg/ha) in the profile (0-120cm) prior to sowing at SCRIME for 2001 to 2017. Analysis omits the value for 2011 when 375mm was received during this period.

complex models existed (e.g., Yield Prophet), 'they required detailed parameterisation unlikely to be conducted at an appropriate spatial scale'.

The efficiency of recovery of soil and applied N by the crop

A range of methods have been used to estimate fertiliser efficiency, and in particular, the quantity of fertiliser recovered by the crop. Traditionally, especially in the southern region, this was determined by measuring the difference between the quantity of N in the fertilised crop and a paired unfertilised treatment, expressed as a percentage, and referred to as the 'difference measure' (Strong 1995). Fertilised crops, however, frequently take up more soil N than unfertilised crops in a phenomenon referred to as the 'added N interaction' or a 'priming effect'. As a result, difference measure generally overestimates the efficiency of use of fertiliser N. In contrast to difference methods, the efficiency of recovery of soil and fertiliser N can be assessed using ^{15}N tracers. ^{15}N is a stable (i.e., non-ionising) form of N that occurs 'naturally' at low levels in the environment (0.00367% of all N) and effectively behaves similarly at a chemical and physiological level to ^{14}N. Although the applied ^{15}N is subject to isotopic discrimination during mineralisation-immobilisation (MIT) (Strong 1995), it is considered a better method to assess fertiliser N utilisation (and losses), especially when measurements are made of

Table 2. Correlation coefficients (r) of the relationships between net in-crop nitrogen mineralisation (net ICM) against growing season rainfall (GSR: April to October) and methods of predicting ICM, including soil tests and a simple calculator. Values are presented as *r* with significance indicated by *** *P*<0.001, ** *P*<0.01, and * *P*<0.05.

Method	Soil depth (cm)	Net positive ICM data		
		n	*R*	Significance
GSR (mm)	n.a.	108	0.47	***
Soil organic carbon (SOC) (%)	0-10	108	0.41	***
Total N (mg/g)	0-10	108	0.32	***
Pre-sowing profile nitrate (kg N/ha)	0-120	108	0.28	**
Ridge Method (kg N/ha)	0-10	108	0.46	***
Anaerobic NH_4^+ (kg/ha)	0-10	78	0.37	***
	0-20	78	0.38	***
Hot KCl Gross NH_4^+ (kg/ha)	0-10	78	0.40	***
	0-20	78	0.41	***

Table 3. Mean (and range) of crop recovery of fertiliser N using both 15N labelling and difference methods, errors between these methods and losses of fertiliser N from the crop:soil system within the season of application using pooled data from nine sites (2014 to 2016). N was applied as top-dressed urea during vegetative/early tillering stage.

Zone/ cropping system	Crop recovery using 15N approach	Crop recovery using difference approach*#	Crop recovery error when using the difference approach*	Loss of top-dressed N using 15N approach*
Low-medium rainfall dryland	34% (2 to 75%)	41% (-29 to 226%)	±52% (-52 to +172%)	25% (2 to 47%)
High rainfall dryland	34% (22 to 50%)	33% (-13 to 102%)	±22% (-40 to +64%)	32% (4 to 53%)
Irrigated	5% (12 to 60%)	49% (-13 to 64%)	±27 (-39 to +48%)	41% (26 to 57%)

residual ^{15}N remaining in the soil after harvest. This is due to its ability to accurately detect crop uptake of a relatively small amount of fertiliser N (e.g., 25-100kg N/ha) against a much larger background quantity of soil N (e.g. 2,200kg N/ha assuming soil total N = 0.2% and bulk density of 1.1g/cm^3).

A generalised value of 50% recovery of the fertiliser and available soil N within the season of application by the crop is widely assumed (Unkovich *et al.* 2020). This value is based on experimental data from field trials undertaken in the 1980s cited in Chen *et al.* (2008) in southern Australia and Strong (1995) in southern Queensland, which indicate that wheat crops recover 25 to 60% of the applied N. More recent publications cite fertiliser N recoveries by wheat of 49 and 57% in an acid chromosol in southern NSW (Smith *et al.* 2019).

Data on crop utilisation of ^{15}N labelled urea collected from western Victoria using current grower management practices and rates across a range of environments and seasons indicate a wide range of fertiliser N recoveries (2 to 75%) depending on the zone/cropping system (Table 3). The average crop recovery of fertiliser N (34 to 35%) was surprisingly similar between environments and cropping systems. The key determinant of crop recovery was rainfall (or irrigation) following application. Very low recovery of fertiliser N was measured where GSR post application was <66mm, a common occurrence in low and medium rainfall situations during the seasons tested. Crop recovery was also sensitive to the rate of application (as expected), with higher crop recovery at lower application rates. However, there was no statistical evidence (P > 0.05) that

Table 4. Crop total N uptake at maturity, N uptake from fertiliser, total N uptake, recovery of fertiliser N in crop (grain + straw) and estimated loss of fertiliser N from crop:soil system (0-40 cm) using different N management strategies in the Wimmera from 2012 to 2014. (Source: Wallace *et al.* 2020).

Treatment	Total N uptake from soil (kg/ha)	N uptake from fertiliser (kg/ha)	Total N uptake (kg/ha)	Grain yield (kg/ha)	Crop recovery of ^{15}N fertiliser (%)	Fertiliser loss using ^{15}N approach (%)
2012						
0 N	47^{b}	-	47^{c}	2456^{c}	-	-
50 N	45^{b}	24^{a}	69^{b}	3501^{b}	48.5^{a}	23.7^{b}
50 N DMPP	63^{a}	26^{a}	89^{a}	4589^{a}	52.2^{a}	24.3^{b}
0:50 N	59^{a}	28^{a}	87^{a}	3940^{b}	55.3^{a}	15.3^{a}
0:50 N NBPT	47^{b}	26^{a}	73^{b}	3672^{b}	51.7^{a}	12.9^{a}
2013						
0 N	65^{c}	-	65^{b}	3281^{c}	-	
50 N	68^{bc}	16^{c}	84^{b}	4480^{ab}	32.4^{c}	42.4^{c}
50 N DMPP	73^{abc}	18^{c}	91^{b}	4625^{ab}	36.6^{c}	24.8^{b}
0:50 N	77^{ab}	24^{b}	101^{a}	4177^{b}	47.3^{b}	20.6^{b}
0:50 N NBPT	82^{a}	28^{a}	109^{a}	4651^{a}	55.8^{a}	12.6^{a}
2014						
0 N	25^{c}	-	25^{c}	1467^{c}	-	-
50 N	41^{ab}	21^{a}	62^{a}	2046^{ab}	42.0^{a}	34.0^{b}
50 N DMPP	45^{a}	22^{a}	67^{a}	2194^{a}	43.7^{a}	29.4^{ab}
0:50 N	32^{bc}	6^{b}	38^{b}	1687^{bc}	12.1^{b}	34.8^{b}
0:50 N NBPT	31^{bc}	8^{b}	38^{b}	1825^{abc}	15.1^{b}	22.6^{a}

*0N = no N applied. 50N = urea incorporated at sowing; 50 N DMPP = urea + nitrification inhibitor incorporated at sowing; 0:50 N: urea top dressed at early-mid tillering; 0:50 N NBPT = urea + urease inhibitor top-dressed at early-mid tillering. Fertiliser N applied at equivalent of 50 kg N/ha. *Superscripts indicate significant differences (P <0.05) compared with other treatments within a given year.*

applying fertiliser produced an added N interaction (i.e., inducing an increased utilisation of soil N; data not presented), a finding that contrasts with the NANORP study where the interaction was relatively large (Wallace *et al.* 2020).

Data from a smaller spatial scale study (three experiments, all in the Wimmera) indicated a narrower range of crop fertiliser N recoveries, ranging from 12 to 56% (Table 4). This study highlighted the strong effect of seasonal conditions on the effectiveness of different N management strategies. For example, in 2012, N management had no significant effect on crop recovery of fertiliser N (range 49 to 55%), although it did affect grain yield response. In contrast, in 2014, maximum fertiliser recovery by the crop occurred when N was applied early whereas later applications (topdressing) resulted in very low crop recoveries and a trend to poorer grain yield responses due to very low rainfall received from August onwards. A positive finding, however, was that the low crop recovery under these dry conditions generally corresponded to high rates of recovery in the soil at harvest, rather than being lost. In contrast to the AonG survey data, significant interactions were recorded, indicating that utilisation of soil N was stimulated by fertiliser treatment (Wallace *et al.* 2020).

Net off-site losses of N or immobilisation

Significant losses of N can occur from the soil by a range of pathways, including gaseous losses of ammonia (via volatilisation), denitrification (predominantly as dinitrogen- N_2) and leaching (of nitrate) below the root zone.

The use of a ^{15}N labelled fertiliser mass balance approach allowed a quantitative assessment of the potential irretrievable loss of N derived from fertiliser. In our field studies, losses of fertiliser N ranged from 2 to 47% in low and medium rainfall zones (mean = 25%), 4 to 53% (mean = 32%) in the HRZ and 26 to 57% (mean = 41%) in irrigated cropping sites in northern Victoria (Table 3). Similar to crop recoveries, N management strategy significantly affected losses of fertiliser N depending on seasonal conditions, with nitrification inhibitors (DMPP) reducing losses in above average rainfall conditions and urease inhibitors (NBPT) producing significant benefits in reducing losses of top-dressed urea under dry seasonal conditions (Table 4). While the data directly estimated the loss of N derived from the labelled fertiliser applied to the crop:soil system, it could not unfortunately identify the primary N loss processes responsible. Measurements following harvest indicated little movement of ^{15}N below the topsoil (0-10cm and occasionally 10-20cm), suggesting that gaseous loss (denitrification or volatilisation) was most likely responsible rather than leaching. Furthermore, total losses of N from the system are likely to be greater than our data indicate, as our procedure only accounted for fertiliser N and not for losses of 'background' soil mineral N which was not labelled with ^{15}N.

General discussion

Despite its importance to on-farm profitability, N management remains problematic for most growers and advisers. The guiding '4R' principles of the right source, rate, time and place of fertiliser requires knowledge of both crop demand and soil N supply. Seasonal conditions remain the primary driver of crop demand for N in dryland cropping systems and to a significant extent also fertiliser use efficiency. Similarly, seasonal conditions also strongly influence the underlying assumptions of soil N supply, via its effect on both the rate of N mineralisation during the summer/autumn fallow and the rate of N mineralisation in-crop, as well as crop utilisation and losses/immobilisation of fertiliser N.

Although no one can control seasonal conditions, seasonal forecasting is steadily improving and it is thought that growers/advisers can significantly reduce uncertainty of potential N supply through measuring both soil profile N prior to or just after sowing and in-crop N mineralisation using currently available procedures. The previous widely held assumption of 50% recovery of fertiliser and soil N was reputedly based on higher recovery of soil mineral N (70%) and 30% of fertiliser N (Mike Bell, quoting Wayne Strong and Chris Dowling). This value was formulated, however, in a period when soil N supplied most of the crop's N. In current cropping systems, however, where there is less legume/pasture leys and tillage, and organic matter levels have declined, fertiliser N is the dominant source of crop N supply, a more appropriate figure for crop utilisation of fertiliser and soil of 35% is suggested for the southern region. This revised figure appears to be consistent across diverse cropping systems, although this may reflect differing influences. For example, better soil moisture in higher rainfall environments allowing for greater crop access to fertiliser being balanced by lower losses of N in drier environments.

Similarly, losses of fertiliser and presumably soil N appear to be an inherent feature of current cropping systems and based on the data appear to have been underestimated. Although many advisers in the 2015 survey were aware of the

mechanisms by which N could be lost from the cropping system, most had difficulty in identifying rates of losses occurring in their environments. Furthermore, because the emphasis of many previous field-based experiments has been on greenhouse gas emissions (N_2O), where total quantities of N in terms of kg/ha are relatively low (Wallace *et al.* 2018), there was a lack of awareness that N_2 losses from denitrification could be of much greater 'agronomic significance', as suggested by the ^{15}N mass balance data. 'Unaccounted for' N which was assumed to be lost averaged 25, 32 and 41% in low-medium, high rainfall and irrigated cropping systems, respectively, but instances of losses of > 50% were recorded across all these systems. These losses occurred at agronomically relevant rates and could be expected to become relatively larger at higher application rates. Previous research (also using ^{15}N mass balances) has found large losses (up to 90% depending on application strategy) of applied fertiliser N from HRZ cropping systems in western Victoria (Harris *et al.* 2016). In the AonG study, fertiliser N was applied via topdressing of urea (mostly during tillering to first node), so an assumption was that volatilisation was the main loss mechanism. However, there were circumstances, especially in the HRZ and irrigated cropping trials and on sodic soils in the MRZ, that background soil conditions may have been conducive to denitrification losses driven by anaerobic waterlogged conditions. Knowing the mechanism of this N loss is important, as the NANORP study clearly showed that use of an appropriate fertiliser management strategy can significantly reduce losses of N and enhance supply to the target crop if applied in the correct situation.

Conclusions

Growers can potentially improve their fertiliser N management by (i) undertaking deep N soil testing, (ii) using current RoT predictions of in-crop N mineralisation and (iii) reducing the assumed crop utilisation of soil + fertiliser N to approximately 35 rather than current 50%.

Large losses of N appear to occur regularly across low and medium rainfall and irrigated cropping systems, not just in the HRZ as previous thought. However, the ability to mitigate these losses is hampered by uncertainty as to the loss pathways. Knowledge of this information would facilitate the identification of appropriate fertiliser management strategies, which have been shown to significantly reduce losses and improve yields.

Acknowledgements

Much of the original data used in this project originated from the Australian Department of Agriculture and Water Resources (AOTGR2- 0073) project *'Reducing on-farm nitrous oxide (N_2O) emissions through improved nitrogen use efficiency in grains'* and Filling the Research Gap' NANORP program. We wish to acknowledge the invaluable discussions and insights provided by our colleagues Murray Unkovich, Mike Bell, Louise Barton and Sean Mason. Katherine Dunsford's PhD was co-funded by Agriculture Victoria, LaTrobe University and GRDC through Project DAN00168. We wish to acknowledge the significant contributions of the many grain growers of western Victoria who assisted us with conducting these experiments on their properties.

References

Angus JF (2001) Nitrogen supply and demand in Australia agriculture. Australian Journal of Experimental Agriculture 41, 277-288.

Armstrong, RD, R Perris, M Munn, P Hekmeijer, K Dunsford, K Bell, F Waldner and Z Hochman (2018) Genetics, management or environment: what are the key drivers of water use efficiency in wheat in western Victoria? GRDC Adviser Update, Bendigo February 2018.

Armstrong RD, Perris R, Munn M, Dunsford K, Robertson F, Hollaway GJ, O'Leary GJ (2019) Effect of long-term rotation and tillage practice on grain yield and protein of wheat and soil fertility on a Vertosol soil in a medium rainfall temperate environment. *Crop & Pasture Science* 70, 1-15.

Chen D, Suter H, Islam A, Edis R, Freney JR, Walker CN (2008) Prospects of improving efficiency of fertiliser nitrogen in Australian agriculture: a review of enhanced efficiency fertilisers. *Soil Research* 46(4): 289–301.

Dunsford K (2019) 'Understanding causes of poor grain yield response of wheat to phosphorus and nitrogen fertilisers' PhD thesis, LaTrobe University, Bundoora, Melbourne

Gan Y, Campbell CA, Janzen H, Lemke RL, Basnyat P, McDonald CL (2010) Nitrogen accumulation in plant tissues and roots and N mineralisation under oilseeds, pulses, and spring wheat. Plant & Soil 332, 451-461.

Harris RH, Armstrong RD, Wallace AJ & Belyaeva ON. (2016) Delaying nitrogen fertiliser application improves wheat ^{15}N recovery from high rainfall cropping soils in south eastern Australia. *Nutrient Cycling in Agroecosystems*. 106, 113-118

Smith CJ, Hunt JR, Wang E, Macdonald BCT, Xing H, Denmead OT, Zeglin S, Zhao Z, (2019) Using fertiliser to maintain soil inorganic nitrogen can increase dryland wheat yield with little environmental cost. Agriculture, Ecosystems and Environment 286, 106644.

Strong W (1995) Nitrogen fertilization of upland crops. In: Bacon PE, Ed. *Nitrogen fertilization in the environment.* New York: Marcel Dekker Inc; p. 129–70.

Unkovich, M, Herridge, D, Denton, M, McDonald, G, McNeill A, W, L (2016) Nitrogen mineralisation and N decision support tools in cropping systems of southern Australia. A milestone report for the Grains Research and Development Corporation by The University of Adelaide., Adelaide.

Unkovich MJ, Herridge DF, Denton MD, McDonald GK, McNeill AM, Long W, Farquharson R & Malcolm B. (2020) A Nitrogen Reference manual for the Southern Cropping Region. GRDC.

ISBN: 978-1-921779-99-2 (https://grdc.com.au/a-nitrogen-reference-manual-for-the-southern-cropping-region).

Wallace AJ, Armstrong RD, Harris RH, Belyaeva ON, Grace PR, Partington DL, Scheer C (2018) Reducing N_2O emissions of rainfed wheat in a semi-arid environment through fertiliser timing and use of inhibitors. *Nutrient Cycling in Agroecosystems* 112(2), 231-252

Wallace AJ, Armstrong RD, Grace PR, Scheer C, Partington DL (2020). Nitrogen use efficiency of ^{15}N urea applied to wheat based on fertiliser timing and use of inhibitors" Nutrient Cycling in Agroecosystems 116, 41-56.

Contact details

Prof. Roger Armstrong
Grains Innovation Park, 110 Natimuk Rd,
Horsham VIC 3400.
0417 500 449
roger.armstrong@agriculture.vic.gov.au

Return to contents

Notes

Notes

Prevalent invertebrates in the 2020 winter cropping season in South Australia and new tools available for management

Rebecca Hamdorf, Maarten van Helden and Kym Perry.

SARDI Entomology.

GRDC project code: CES1904-002RTX

Keywords

- insect pests, pest management, management tools.

Take home messages

- An unusually high diversity of migratory moth/caterpillar pests was reported in the 2020 winter cropping season, particularly earlier in the season due to weather events.
- Don't chase this year's pest issues next year – make decisions on the merits of each year. Every season is different and large regional differences occur.
- Key to successful invertebrate pest management is assessing the risk, carrying out observations and making informed decisions.

Background

In 2020 unusually high populations of a very broad variety of migratory moth/caterpillar pests were reported to PestFacts SA during the winter cropping season. Notably, early moth flights brought in multiple species during April and May, and caterpillar feeding started much earlier than typical. Several unusual and uncommon pests were also reported, adding to an already unusual year. This paper discusses what pests were reported and what factors contributed to their prevalence.

New resources for management of invertebrate pests are now available to help growers and agronomists in pre-season paddock planning, risk assessment during the winter cropping season and future management. A brief overview of each new resource is provided.

The key to all successful invertebrate pest management is assessing the risk first, conducting appropriate observations and making informed decisions. Blanket pest management approaches are unsustainable, costly, often ineffective and not recommended.

What insects were prevalent in 2020?

The 2020 winter cropping season was typified by early moth/caterpillar pests and continual pressure throughout the season. Several species of moths were seen in very high numbers after migrations and were widespread across South Australia (SA). An unusually wide variety of moths and caterpillars were reported overall. Regional high numbers for a few pests occurred throughout the season and several unusual invertebrate species were also reported.

Common moth/caterpillar pests observed in the 2020 season

The common moth/caterpillar pests were:

- Native budworm, *Helicoverpa punctigera*, fed on early sown crops on the Eyre Peninsula. This insect is a major pest in spring but crop damage early in the season is relatively uncommon. The spring moth trap network detected high numbers in the Mid North during peak flights (late September), but spring rains limited flights.

- Weed web moth, *Achyra affinitalis*, was particularly widespread early in season after a large migration of the moths during April. They fed on medic pastures, emerging cereals and canola crops. Larvae are fast-moving and produce large amounts of webbing which they feed under, skeletonising foliage and webbing leaves together.
- Cutworms, *Agrotis sp.*, were reported steadily across the season, often seen in mixed populations alongside armyworms and herringbone caterpillars. Larger larvae (>25 to 40 mm) chewed off leaves and stems near ground level, primarily from crops sown into paddock areas with heavier stubble. Female moths prefer to lay eggs into stubble.
- Herringbone caterpillars, *Proteuxoa sp.*, were observed at low densities in cereals and some mixed pastures, often in mixed populations with cutworms. Visually similar to cutworms but they have a herringbone pattern on the back. Reported more widely than usual this season.
- Armyworms, *Persectania ewingii* and *Leucania convecta*, damaged some vegetative cereal crops during winter, causing patches of missing plants. Reports were widespread and common throughout the season, in part in response to concern about fall armyworm and requests for reports. To date (06/01/2021), only native species of armyworm have been reported in SA.

These species commonly occurred in mixed populations with two or more other species. The larvae feed mostly at night and are more difficult to find during the day.

Several other caterpillar species were also reported, but there were only a few reports of each. What is notable is the range of species reported.

- Pasture webworm, *Hednota sp.*, fed on cereal paddocks that had recently come out of long-term pasture. This pest resides in silk-lined tunnels in the soil and emerges at night to feed when they chew off leaves and drag them back to their tunnels.
- Pasture day moth, *Apina callisto*, reported in cereals in very low numbers with no feeding symptoms evident. Caterpillars can grow up to 60mm, and they are distinctive with dull dark brown with reddish-orange and yellow markings and very prominent bristles. They prefer broadleaf plants but will feed on all crops, particularly if favoured hosts have been removed through herbicide usage.
- Pasture tunnel moth, *Philobota productella,* were observed early in the season on cereals. Caterpillars construct vertical, silk-lined tunnels that protrude above the soil surface forming 'chimneys'. More prevalent on cereals after a pasture phase.
- Brown pasture looper, *Ciampa arietaria,* were reported a few times on pasture, often in mixed populations. The caterpillars feed on broadleaf plants, have two wavy yellow lines running down their brown body and move in a characteristic looping motion.
- Diamondback moth (DBM), *Plutella xylostella,* while total reports of DBM were low, when reports were received the numbers were often high/near threshold. Several agronomists noted in discussions that DBM numbers were higher than average in 2020. Low reporting of DBM might be a function of reporting bias - growers and agronomists know and deal with DBM regularly so don't report it, especially compared to rare or unusual pets.
- Cabbage centre grub, *Hellula hydralis.* Moths were reported in large numbers several times during 2020, but not many caterpillars were found after searching.
- Woolly bear caterpillars, Family: Arctiidae, were reported feeding in high numbers along the fence line of a canola crop coming out of the scrub. Woolly bear caterpillars are opportunistic and are a very rare pest, more likely to feed on weeds.
- Caper white butterfly, *Belenois java teutonia*, had a large-scale migration in mid-late spring, and huge masses of them could be seen along roadsides fluttering around. They are highly migratory but only feed on several species in the *Capparace* family, most notably caper bushes (*Capparis spp.*). They are not an issue for broadacre agriculture.

Other common pests observed at higher numbers in the 2020 season

Other common pests seen at higher numbers were:

- Redlegged earth mite (RLEM), *Halotydeus destructor*, occurred in unusually high densities in and around Lower Eyre Peninsula from late May onwards. Pastures that received a well-timed TimeRite® (i.e., the best date for spraying in spring to control RLEM, https://www.wool.com/land/timerite/) insecticide treatment in spring 2019 experienced substantially lower densities than untreated pastures and crops.

- Russian wheat aphid (RWA), *Diuraphis noxia*, remained at low overall densities. A dry summer in most areas led to very low seasonal risk. Areas in the mid North and upper Eyre Peninsula, where high February rainfall caused barley grass to start growing early followed by a dry June and July where the cereals were particularly drought stressed and had stunted growth, saw higher RWA populations.
- Rutherglen bug, *Nysius vinitor*, was reported in high numbers in medic pastures that also contained a lot of capeweed. Feeding symptoms were limited to capeweed and medic. Numbers were increasing in several areas closer to harvest. This highly migratory bug most likely developed on native plants growing in early season rainfall areas.

Other unusual/rare invertebrates observed in the 2020 season

Other unusual/rare invertebrates were:

- Ryegrass mealybug, *Phenacoccus graminicola*, was reported on barley and volunteer cereals in two locations but in low numbers and no noticeable feeding symptoms. They were also reported, unusually, on lentils in low numbers. A continuous green bridge of grasses over summer and into autumn, and favourable summer conditions, is likely to have been the cause of these small populations.
- Leafhopper, (Cicadellidae) species unknown, was reported on canola early in the season in high numbers, but only minimal feeding symptoms were seen. Leafhopper migration and activity is favoured by warming conditions, so populations did not persist for long.
- Bean root aphid, *Smynthurodes betae*, was reported on the roots of some poor- looking faba bean. These root aphids are globular and white. They have only been recorded in SA twice before and are unlikely to be an issue in future. Their primary host is pistachio, but secondary hosts include beets, potatoes, some pulses and a range of asteracea weeds.
- Purple scum collembola, *Hypogastura vernalis*, was seen in large numbers multiple times across the season after large rains. The large numbers (thousands of individuals, often seen floating in rafts on puddles) seem concerning, but there are no known records of plant damage caused by the purple scum collembolan. They are beneficial to the soil, playing an important ecological role in decomposition.

What conditions led to these pests being an issue this season?

Moths/caterpillars

Unusually high moth and caterpillar activity early in the season is thought to have resulted from significant moth migration events in early autumn. Rainfall in inland source areas causes growth of insect host plants, warm temperatures support population build-up and flight, and suitable wind systems transport the insects into cropping zones.

The sudden appearance of several migratory moth species in crops around the same time provides strong evidence for large migration events. Large flights of weed web moth and at least three other species were recorded on first at the SA-Victorian border, then 10 hours later further down in the South East, several areas in metropolitan Adelaide and then moving across the Eyre Peninsula region in late March and early April. Wings of many of the moths reported were tatted and broken, suggesting they originated farther afield.

This major migration event followed significant rainfall in parts of inland and eastern Australia during February and March (Bureau of Meteorology 2020), which likely supported population growth.

Redlegged earth mite:

Redlegged earth mite (RLEM) typically undergoes three generations during the winter cropping season. In the third generation, mites produce over-summering diapause eggs, which are retained in the body of the female. Over-summering diapause eggs hatch the following autumn when suitable conditions occur; at least 5mm rainfall coinciding with mean daytime temperatures under 16°C for 10 days.

During 2019, parts of the Eyre Peninsula received substantial rainfall in spring (Bureau of Meteorology 2019). Moisture around the TimeRite® date can lengthen the spring growing season and lead to production of more over-summering mite eggs. In autumn 2020, high rainfall coinciding with cool temperatures occurred in late April across parts of Lower Eyre Peninsula, which is expected to have caused a synchronous hatching of RLEM during crop emergence. In years with a less synchronous autumn break, RLEM hatching occurs in a more staggered fashion, leading to lower initial densities and allowing crops to out-grow some early damage.

Other pest invertebrates:

The variety of rare or unusual pest invertebrates seen in 2020 is likely due to favourable climatic conditions, and in some cases the availability of a

green bridge over summer. A lot of these unusual broadacre pests aren't well understood, and as they are so infrequent and aren't typically a concern, very little research is done into them. All rare and unusual pest invertebrates seen this season did not warrant control.

New tools available for pest invertebrate management

Several new tools have been created and updated for integrated pest management (IPM) practices.

Lucerne seed web moth degree-day model web application

The SARDI Etiella degree-day model is now available as a web-based interface (Useful Resources).

Users input GPS coordinates to obtain the predicted *Etiella* degree-day accumulations for their location in real time and can compare with previous years of interest. This tool, developed as part of a SAGIT-funded Etiella project, replaces the need to manually download and input daily maximum and minimum data for your nearest weather station from 21 June onwards.

The date when the model reaches 351 degree-day accumulations corresponds to the predicted date of 10% onset of peak moth flight activity. New findings of the *Etiella* project recommend commencing in-crop monitoring of lentil crops around 7-10 days earlier than this date, at 300 degree-day accumulations.

Best practice management guides

New best practice management guides have been developed for RLEM, green peach aphid and DBM. Each guide includes a Risk Assessment Guide for assisting with planning decisions and key IPM decision points and timing (Useful Resources). Podcasts have also been developed to support this work (Useful Resources).

Russian wheat aphid economic threshold calculator

Through the GRDC investment UOA1805-018RTX 'Russian wheat aphid risk assessment and regional thresholds', investigated regional risk and management tactics for Russian wheat aphid (RWA)' an economic action threshold calculator has been developed to help growers and agronomists determine if they should treat for Russian wheat aphid (RWA); based on the impact to crop yield and cost.

The calculator indicates if the economic injury level is likely to be exceeded between GS30 (start of stem elongation) and GS50 (start of head emergence), and therefore, if control of RWA should be actioned. This action threshold can be applied to winter and spring cereal varieties.

Recommended approach

While it is tempting to implement blanket approaches to pest invertebrate control based on the pests from last season, it is rarely a successful approach. Climatic conditions play an important role in the development of invertebrate pests and as this differs widely, season to season, so do the pests. Do not assume pest issues in 2021 will be the same as those experienced in 2020. Each season is different and brings different pests, so blanket approaches are not sustainable.

Strategic decisions are advised by assessing risk on a seasonal basis, complete with observations of pest occurrence. Growers and agronomists are encouraged to familiarise themselves with the best practice management guides and resources (Useful resources) and incorporate them into pre-season farm/paddock planning.

Some general factors that contribute to seasonal risk:

- **Green bridge** vegetation during summer and early autumn, particularly February to May, which can support aphids, DBM, resident pests such as many of the beetles and weevils. In general, more green bridge increases the risk of these pests and possible virus transmission (in some aphids).
- **Paddock history** provides useful hints about possible risk and should be considered during pre-season planning. Factors to consider include previous (resident, not migratory) pest problems, crop rotations, weed control, insecticide use and seasonal conditions.

Moth/caterpillars

Migratory species like moths are difficult to predict in advance but easy to manage if detected early. Moth numbers are poorly correlated with numbers of caterpillars, so flights should be used as a prompt to monitor for caterpillars several weeks later. Early detection can be achieved by keeping an eye out for moth flights, monitoring emerging crops and subscribing to free regional notification services such as PestFacts SA newsletter. This service relies on your reports.

Will the moth/caterpillar pests be a problem again in 2021?

By their very nature, issues with migratory pests are transient and tend to occur in boom/bust cycles. Typically, they arrive suddenly in large numbers, breed locally through a generation, then new adults disperse elsewhere. Immigrant moth populations generally do not persist locally in any substantial numbers beyond a single generation, as their primary habitat occurs in inland source areas.

Migrations would need to occur again in 2021 for these pests to be problematic. While migrations of the scale observed in 2020 are relatively uncommon, monitoring and early detection is the key to successful management.

Redlegged earth mite

The risk of high RLEM populations this season depends on last year's crop/pasture type, weed status, seasonal conditions, RLEM numbers and the susceptibility of the next planned crop.

Large numbers of RLEM in spring can be indicative of a high-risk situation the following autumn. If a well-timed TimeRite® spray was implemented, it should be effective at reducing populations. Only use the TimeRite® strategy in high-risk situations. Some crops, such as lentil and chickpea, are poor RLEM host plants and in weed-free paddocks, low RLEM numbers can typically be expected the year following these rotations.

Plan autumn insecticide strategies according to paddock risk, using the RLEM Risk Assessment Guide (Useful Resources). Avoid pre-emergent insecticides in low-risk situations as this will suppress beneficials and may encourage pesticide resistance. Monitor susceptible crops closely in the first three to five weeks after emergence. If insecticides are warranted, follow guidelines in the Resistance Management Strategy for Redlegged earth mite (Useful Resources).

Conclusion

Every season brings different pest invertebrate management challenges. Avoid chasing last season's pest problems and assess each season on its own merits. The key to successful pest invertebrate pest management is assessing and managing risk.

Acknowledgements

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

Useful resources

PestFacts South Australia e-newsletter, PestFacts Map and Twitter @PestFactsSARDI

https://www.pir.sa.gov.au/research/services/reports_and_newsletters/pestfacts_newsletter

PestNotes Factsheets

https://www.pir.sa.gov.au/research/services/reports_and_newsletters/pestfacts_newsletter/pestnotes_pest_information_sheets

Economic threshold calculator for Russian wheat aphid

https://www.pir.sa.gov.au/research/services/pest_management/rwa_action_threshold_calculator

SARDI degree day model web app for Etiella

https://www.etiellamodel.app/

Redlegged earth mite, Best Management Practice and Risk Assessment Guide

https://grdc.com.au/redlegged-earth-mite-best-management-practice-guide-southern/

https://grdc.com.au/news-and-media/audio/podcast/using-all-our-tools-for-pest-management-redlegged-earth-mite

Redlegged earth mite, Resistance Management Strategy

https://grdc.com.au/FS-RLEM-Resistance-strategy

Green peach aphid, Best Management Practice and Risk Assessment Guide

https://grdc.com.au/green-peach-aphid-best-management-practice-guide-southern/

https://grdc.com.au/news-and-media/audio/podcast/using-all-our-tools-for-pest-management-green-peach-aphid

Diamondback moth, Best Management Practice and Risk Assessment Guide:

https://grdc.com.au/diamondback-moth-best-management-practice-guide-southern

https://grdc.com.au/news-and-media/audio/podcast/using-all-our-tools-for-pest-management-diamondback-moth

Broadacre grains pest knowledge cards

https://grdc.com.au/new-knowledge-on-pests-and-beneficials-in-grains

TimeRite® https://www.wool.com/land/timerite/

References

Bureau of Meteorology (2020) 'Recent and historical rainfall maps', Available at http://www.bom.gov.au/climate/maps/rainfall/?variable=rainfall&map=anomaly&period=month&region=nat&year=2020&month=02&day=29 [Verified 6 January 2021].

Bureau of Meteorology (2019) 'Recent and historical rainfall maps', Available at http://www.bom.gov.au/climate/maps/rainfall/?variable=rainfall&map=anomaly&period=month&region=sa&year=2019&month=09&day=30 [Verified 6 January 2021].

Contact details

Rebecca Hamdorf
SARDI, Waite Campus, Urrbrae SA 5064
(08) 8429 0682 | 0429 547 413
Rebecca.Hamdorf@sa.gov.au

Return to contents

Notes

Notes

Early results from trials addressing topsoil and subsurface acidity in South Australia

Brian Hughes[1], Andrew Harding[1], Nigel Fleming[3], Bonnie Armour[1], David Woodard[1], Sam Trengove[2], Stuart Sherriff[2] and Brett Masters[1].

[1]PIRSA; [2]Trengove Consulting; [3]SARDI.

GRDC project code: DAS1905-011RTX

Keywords

- soil acidity, liming.

Take home messages

- At new trial sites yield improvements in acid sensitive crops, such as lentils, are being observed in the second year after lime application.
- At old existing trial sites more rapid and greater yield increases were observed in response to lime sources with finer particle size and higher neutralising value, higher application rates, and where lime was incorporated.
- At sandy trial sites soil modification treatments such as claying, ripping and spading have had a greater yield response than top-dressed lime in the first instance.
- Lime has increased the availability and uptake of molybdenum, which is important for nodulation and has decreased levels of plant manganese.
- At several trial sites, results have shown Scepter$^{\Phi}$ wheat to be very tolerant of acid soils.
- In low rainfall areas greater time is required for lime dissolution and effectiveness at increasing soil pH, but liming marginally acid soils can be considered as a medium-term preventative treatment.

Background

Areas affected by soil acidity are expanding across South Australia's (SA) cropping zone particularly where poorly buffered soils (e.g. sands with low organic matter) are being used for intensive cropping rotations with high yields and high nitrogen fertiliser inputs. Under no-till systems, soil acidity appears in a patchy distribution both horizontally across the paddock and at depth. pH stratified profiles are common on some soil types and after liming, often with an acidic layer around 7 and 15cm depth. pH mapping has been expanding to detect in-paddock variation, however, subsurface and stratification issues are often not detected with current soil testing procedures.

The GRDC investment 'New knowledge and practices to address topsoil and subsurface acidity under minimum tillage cropping systems of South Australia' brings together project partners from the Department of Primary Industries and Regions (PIRSA), the Department for Environment and Water, the University of Adelaide, Trengove Consulting, Murray Lands and Fleurieu Landscape Boards, Penrice Quarry Products and AgCommunicators to research soil acidification across a range of soils and farming systems in SA. The project aims to generate new information regarding lime movement and its effectiveness when applied to different soils and environments in modern farming systems.

Since the project started in 2019, 11 new trial sites have been established across SA, including several sites where soil acidity is a newly emerging issue. Other project components include the assessment of old trials, case studies and demonstrations regarding lime movement, establishing new soil monitoring sites, a PhD student focussed on infra-red soil measurements in-paddock, improved pH indicator tests and other indicators which can be used for assessment of paddock variability, and the establishment of the new soil acidity website and extension material.

The project is reviewing key issues when managing acidification under modern farming systems including, understanding soil variation, pH stratification and impacts, lime quality and rates, incorporation/cultivation impacts, complementary products, determining acidification rates and liming requirements in low to medium cropping rainfall areas.

Method

Trial sites have been established in a range of SA soil types, rainfall zones and liming histories, with two sites having been limed previously (Table 1). Elemental sulphur treatments have been applied to most sites to accelerate acidification and mimic future productivity losses if treatment is not undertaken.

Results and discussion

Impact of treatments on dry matter and yield

New sites

In 2020 lentil dry matter (Figure 1) and yield (Figure 2) responses to lime applied in 2019 were observed at Sandilands on a brown loamy sand over red clay. A combination of high-quality lime at a high rate with cultivation, gave the best result. At Bute on a sand over clay, yield responses to ripping, inclusion plates and spading were observed (Figure 3) but did not influence the lime response. The lime product trial showed a dry matter response to Spalding and Angaston lime products, however, this response did not result in a significant yield increase (Figure 3). Koonunga and Kapunda trial sites were both sown with Scepter(Φ) wheat which showed little response to lime due to its acid tolerance, although nutrient levels in plant tissue were affected by the treatments.

Old sites

Old trial sites located at Wirrabara and Koppio generated mixed results. Both trials were sown by the grower, predominantly with acid tolerant varieties. After three years, results from Wirrabara showed that finer quality lime gave the best results accumulated over several years while the best results from Koppio followed treatment with subsoil organic matter, ripping and lime.

Table 1. Replicated trial sites being monitored in SA.

Site – year established	Soil type – pHca by depth increments- 5cm	Main treatments
Wirrabara 2015	Sandy loam over brown clay- 5.5/4.3/4.1/4.4	lime types, rates, cultivation 2019, sulphur
Koppio 2017	Sandy clay loam with ironstone gravel over yellow- red clay 4.7/4.4/4.2/4.7	subsurface lime, rates, organic matter, ripping, sulphur
Kapunda 2019	Fine sandy loam over red-brown clay 5.2/4.5/4.7	lime type, rates, cultivation, gypsum, sulphur
Koonunga 2019	Sandy loam over red-brown clay 5.2/4.2/4.5/5.1	rates of lime, cultivation, deep cultivation, gypsum, deep calciprill, CaNO3 demo, sulphur
Sandilands 2019	Loamy sand with ironstone gravel over red clay 4.4/4.1/4.5/5.1	rates/types of lime, cultivation, gypsum, local lime, ripping, sulphur, ripping
Bute North1 2019	30cm sand over clay 6.1/4.8/4.8/5.2	1. lime sources, rates, 2. incorporation methods, ripping, spading, inclusion plate, offset disc and combinations
Lameroo 2020	Thick sand over clay 5.0/4.5/4.6	lime rate, incorporation methods, biochar, clay, lime types
Brooker 2020	Shallow sand over clay 5.3/4.5/5.7/6.7	lime rates, sulphur, incorporation
Spalding East 2020	Light sandy clay loam sodic Red-brown Earth 4.4/4.4	lime rates, comparison limes, cow manure, incorporation
Yumali 2020	40cm sand over clay 5.0/4.6/4.8/4.8	lime rate/type, sulphur, incorporation by rotary hoe, biochar, clay, deep ripping
Mallala 2020	Shallow sandy loam sodic Red-brown Earth 4.8/4.5/4.5	lime rate/type, sulphur, incorporation by offset disc, biochar x 2 sources, chicken manure, gypsum

In addition, demonstrations have been set up at Karte and Yumali, and new liming trial sites at Kybybolite, Sherwood and Kangaroo Island through an SFS/NLP/GRDC project.

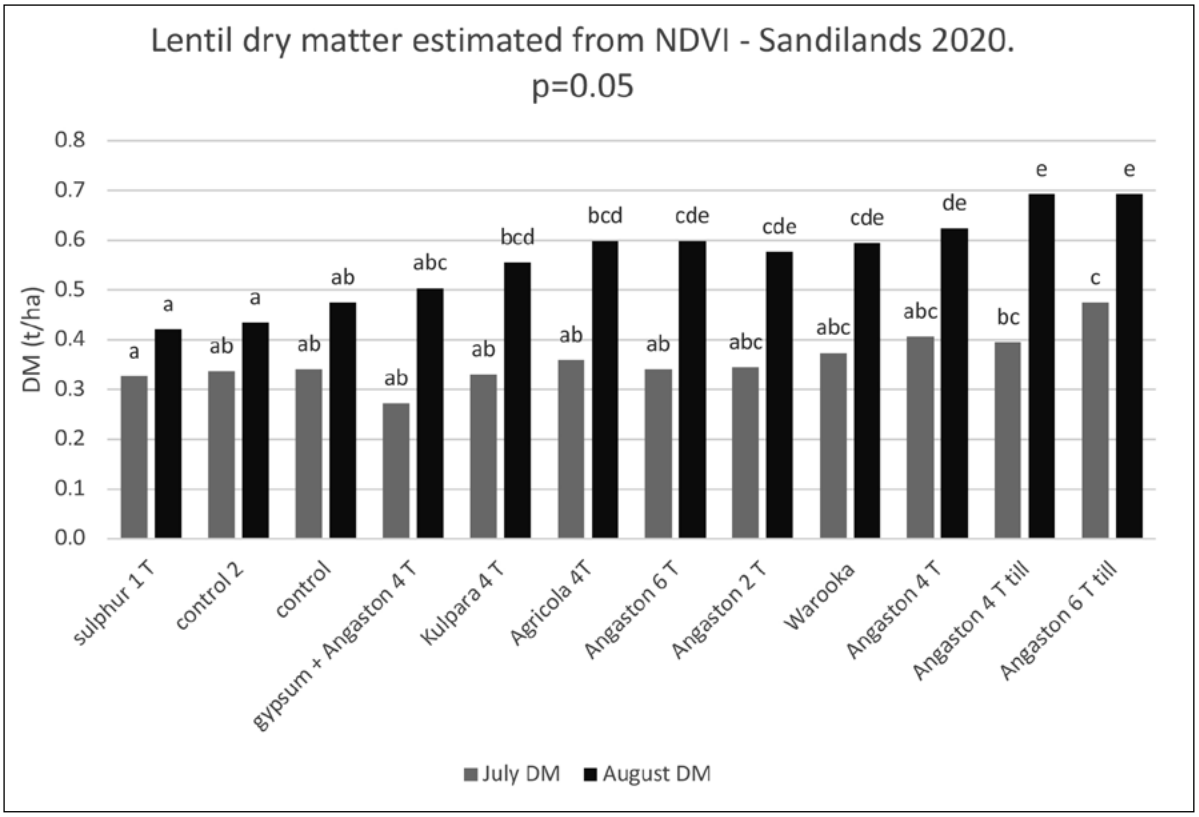


Figure 1. Mean dry matter of lentil at Sandilands, July and August 2020.

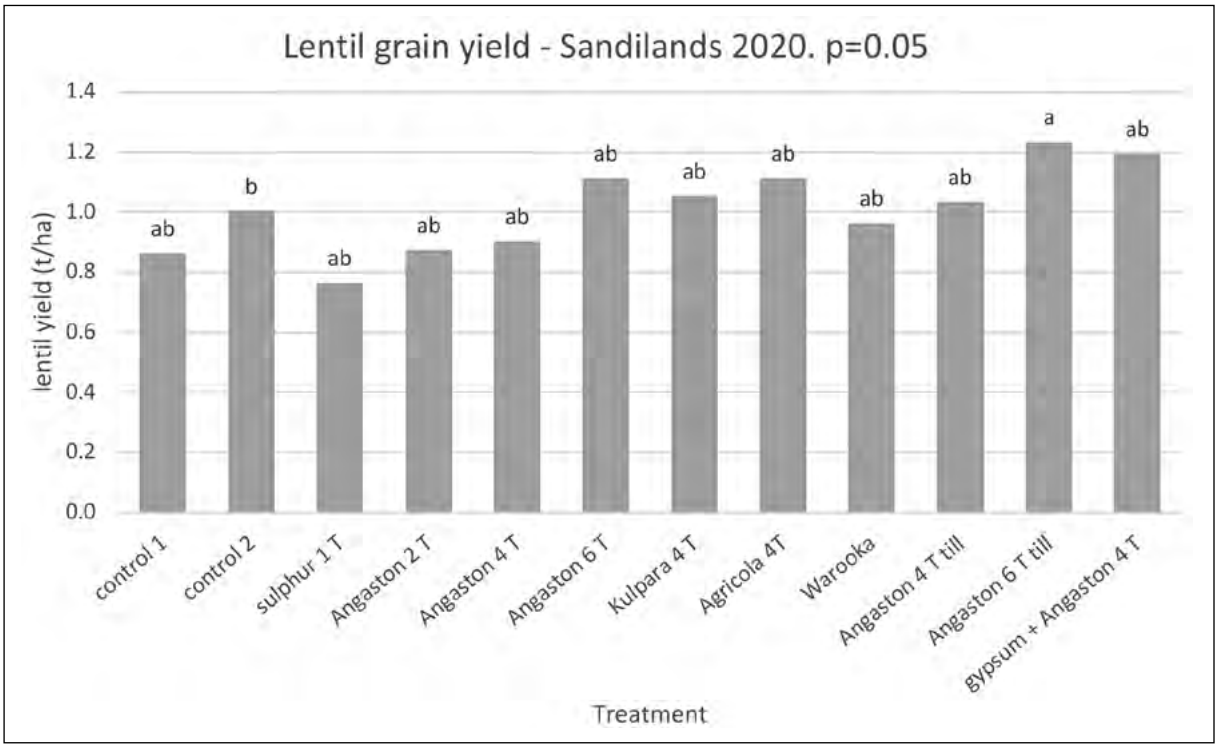


Figure 2. Mean grain yield of lentil at Sandilands 2020.

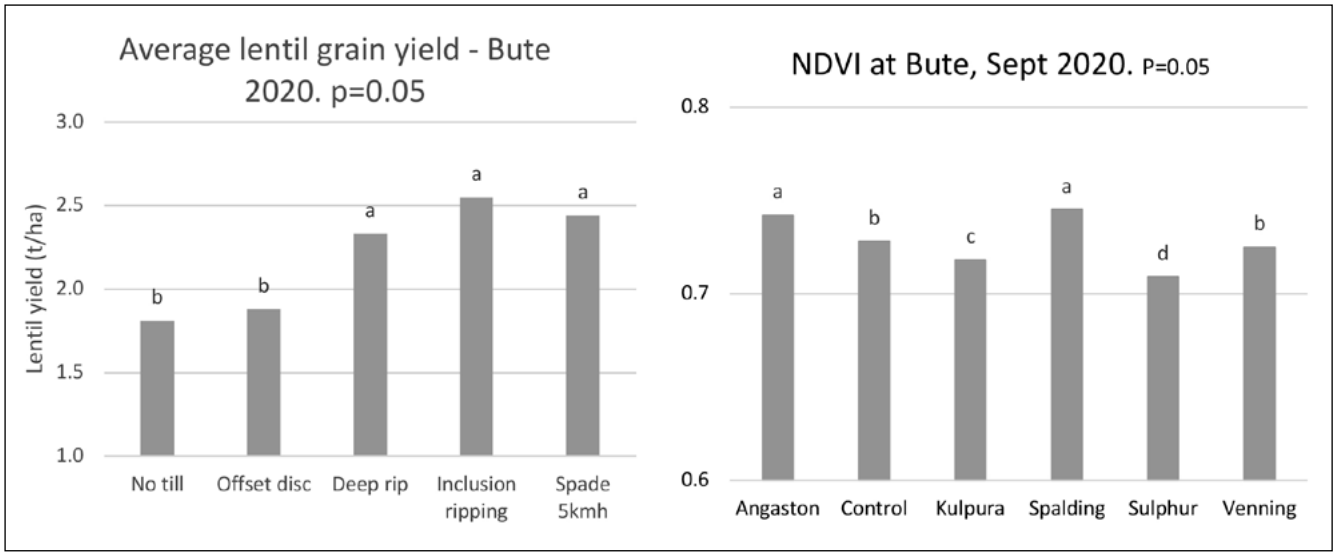


Figure 3. Grain yield of lentil following soil modification (left) and normalised difference vegetation index (NDVI) of lime source trial at Bute 2020 (right).

2020 sites

Several trial sites established in 2020 showed interesting results although increases in yield and/or dry matter were mostly due to factors other than lime.

The Mallala trial site sown to lentil, showed a significant increase in dry matter with chicken manure or fertiliser treatments. The poorest yield was in response to the elemental sulphur treatment. Nodulation of the lentils appeared more prolific under the manure and lime + cultivation treatments, indicating lime may have a small impact. While trends continued to harvest, the yield differences between treatments were not significant at p=0.05 due to the variability across the site.

The Spalding East trial site showed a good barley dry matter response to manure and incorporated lime, but the yield response was not significant, due partly to the impact of frost. Normalised difference vegetation index (NDVI) highlighted a dry matter response to broadcast products in 2020, however a small response to incorporated lime products was observed.

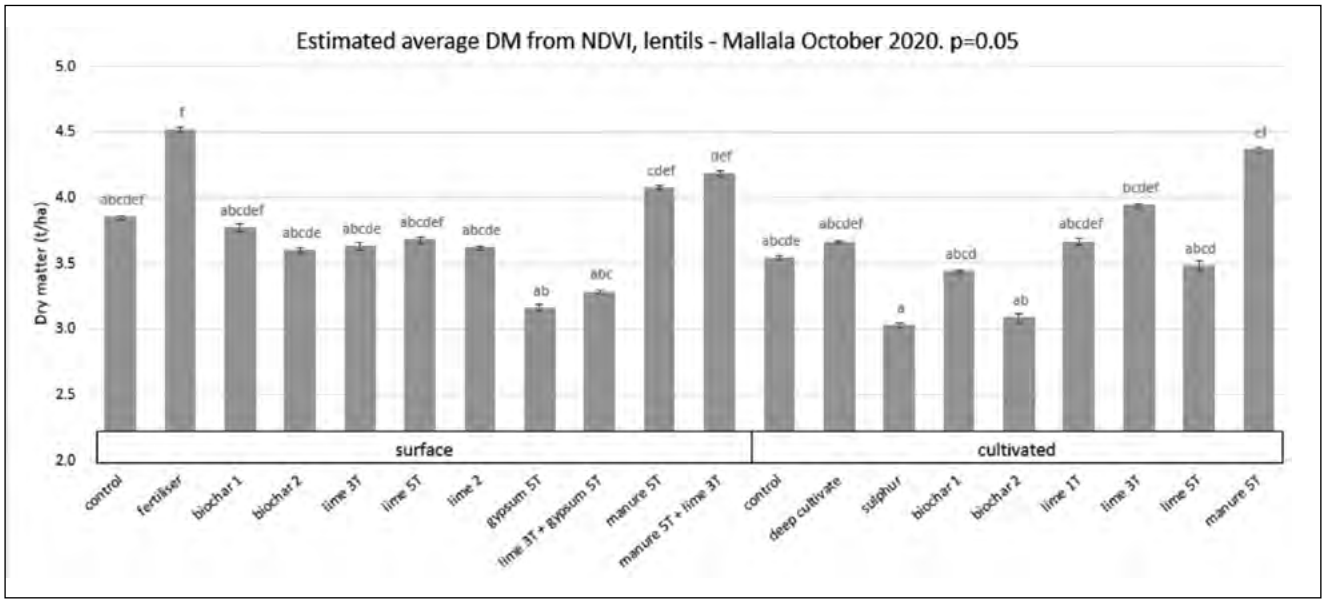


Figure 4. Average dry matter in lentil estimated from normalised difference vegetation index (NDVI) at Mallala October 2020.

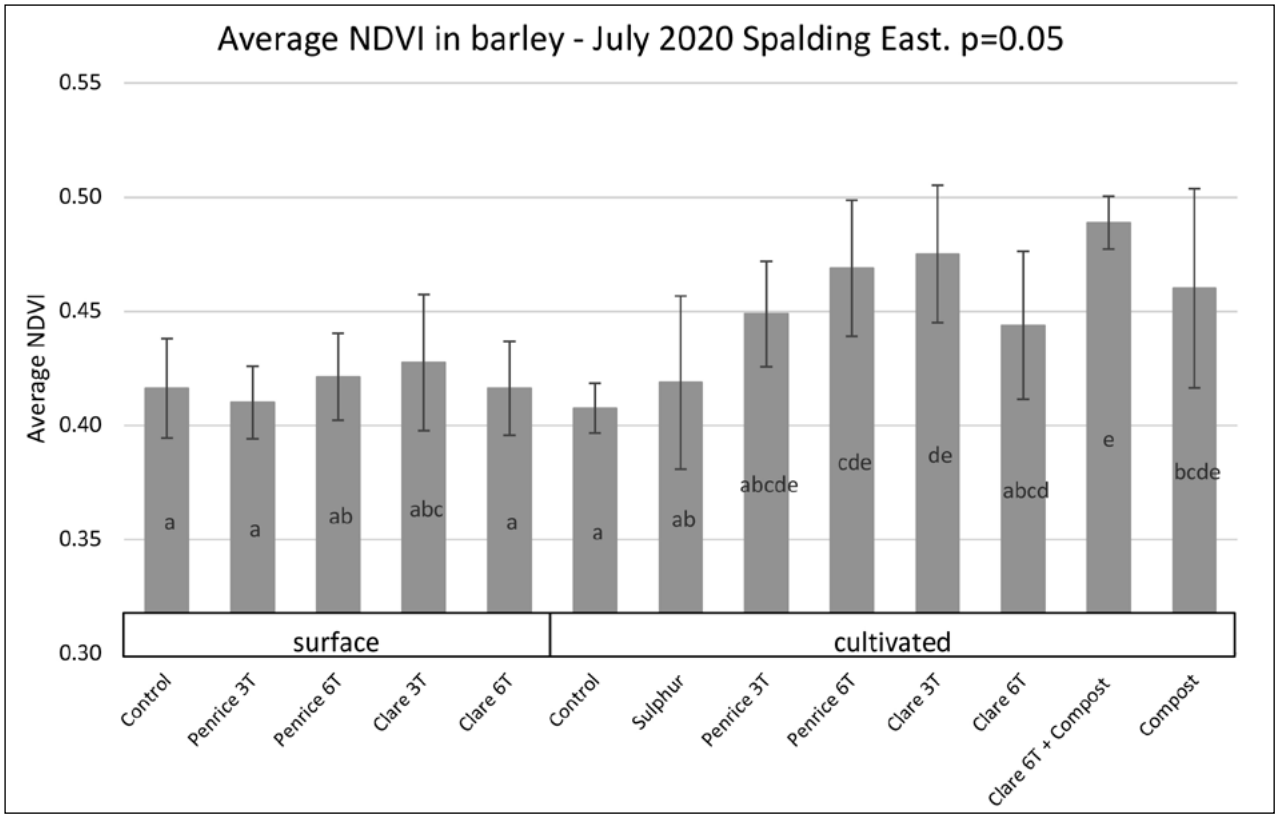


Figure 5. Average normalised difference vegetation index (NDVI) of barley in response to numerous treatments at Spalding East July 2020.

The Yumali trial site on a thick sand over clay showed large growth differences in barley throughout the season with the highest grain yield on a lime plus ripping and cultivation combination. Claying and deep ripping only produced the next highest yields. All surface lime treatments, regardless of rate, produced similar results to the untreated control, highlighting the lack of a rapid lime response without incorporation in this environment.

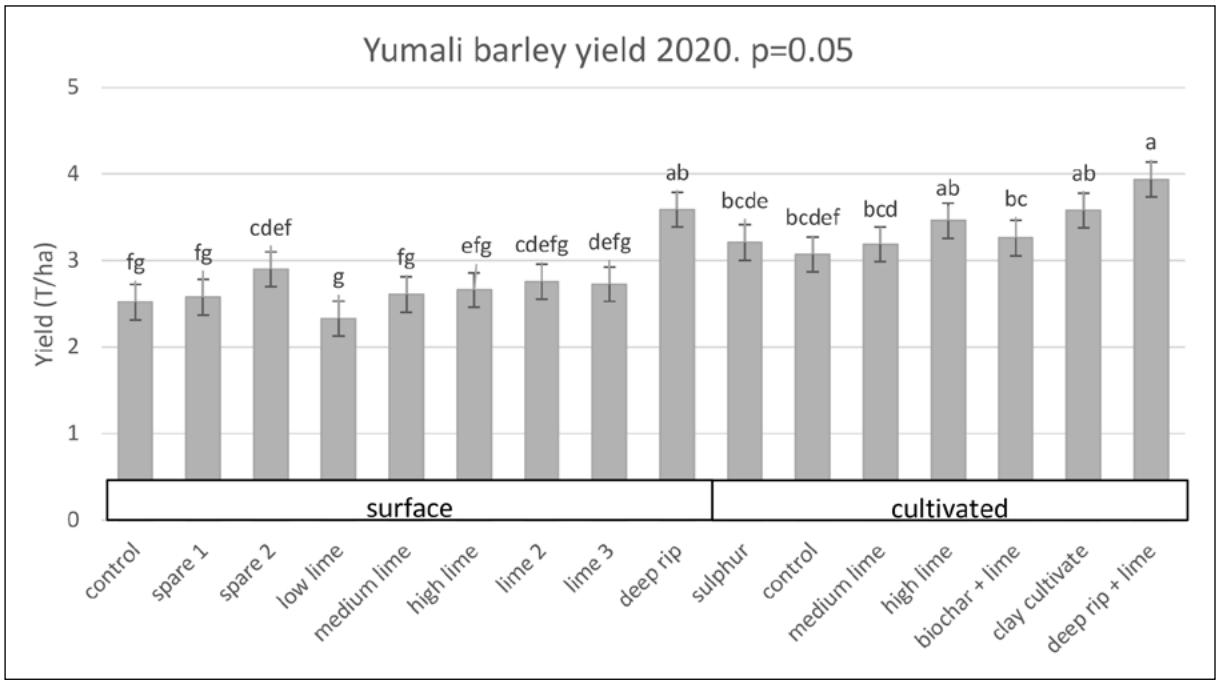


Figure 6. Grain yield of barley in response to numerous treatments at the Yumali trial site in 2020.

There were no significant responses at Lameroo and Brooker during 2020. The Lameroo site was sown to oats which are considered acid tolerant.

Impact of treatments on trace elements

It is well known that the availability of molybdenum (Mo) in soil declines with acidification. In 2020 plant testing was undertaken at several of the sites where the positive impact of liming on Mo uptake was observed, particularly in legumes where it impacted nodulation rates substantially. Figures 7 and 8 indicate large increases in Mo availability and uptake in lentil and barley, particularly where high rates of lime were mixed into the soil.

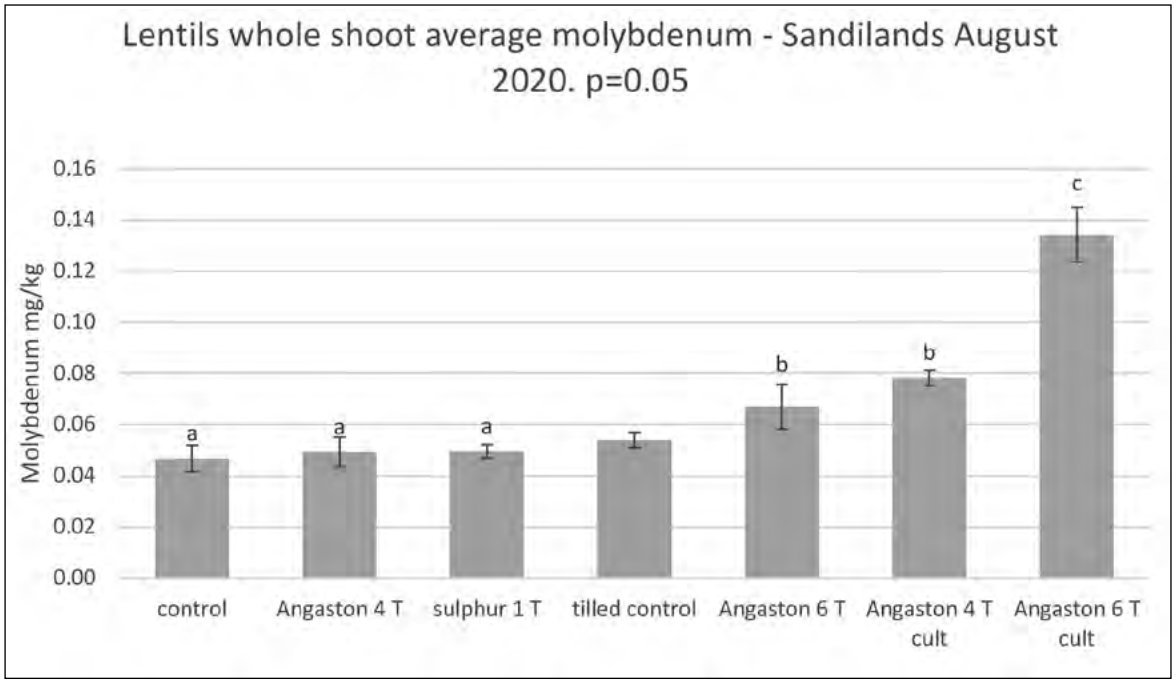


Figure 7. Average amount of molybdenum in lentil whole shoot in response to lime treatments at Sandilands 2020 (n.b. there are no critical levels specific to lentil, however <0.3 mg/kg is considered low for field peas).

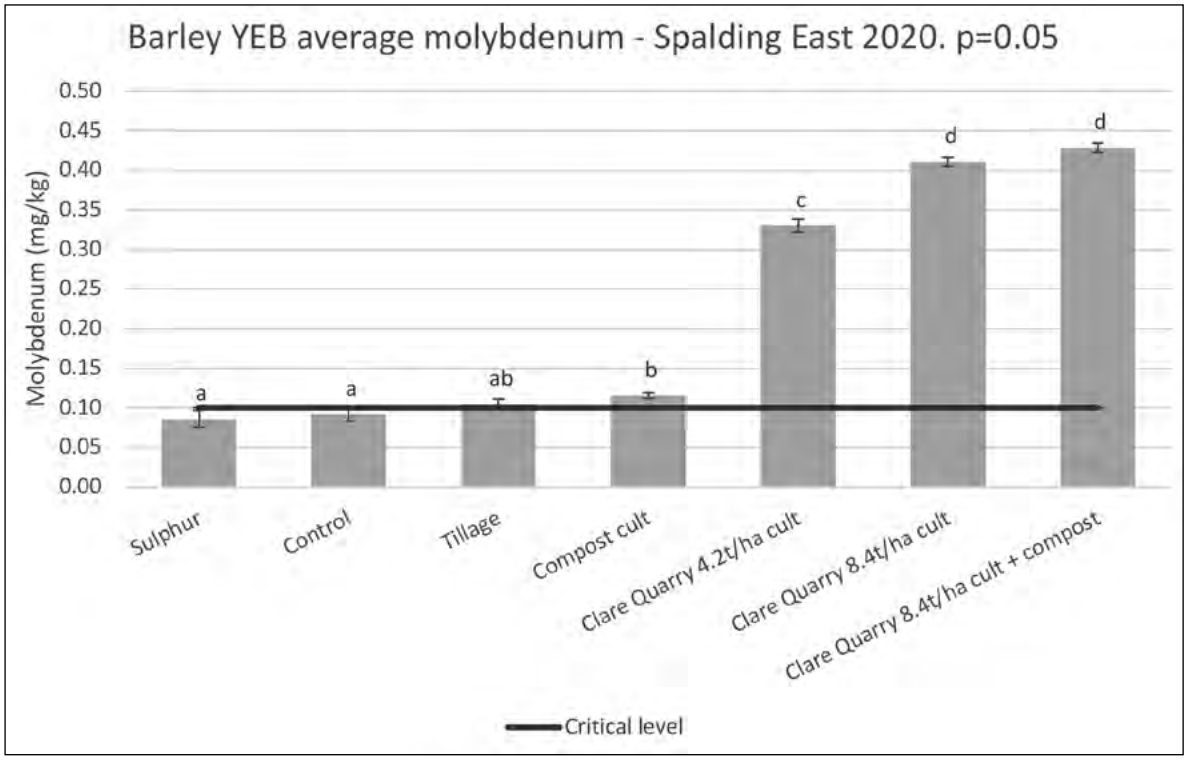


Figure 8. Average amount of molybdenum in barley YEB's in response to treatments at Spalding East, 2020.

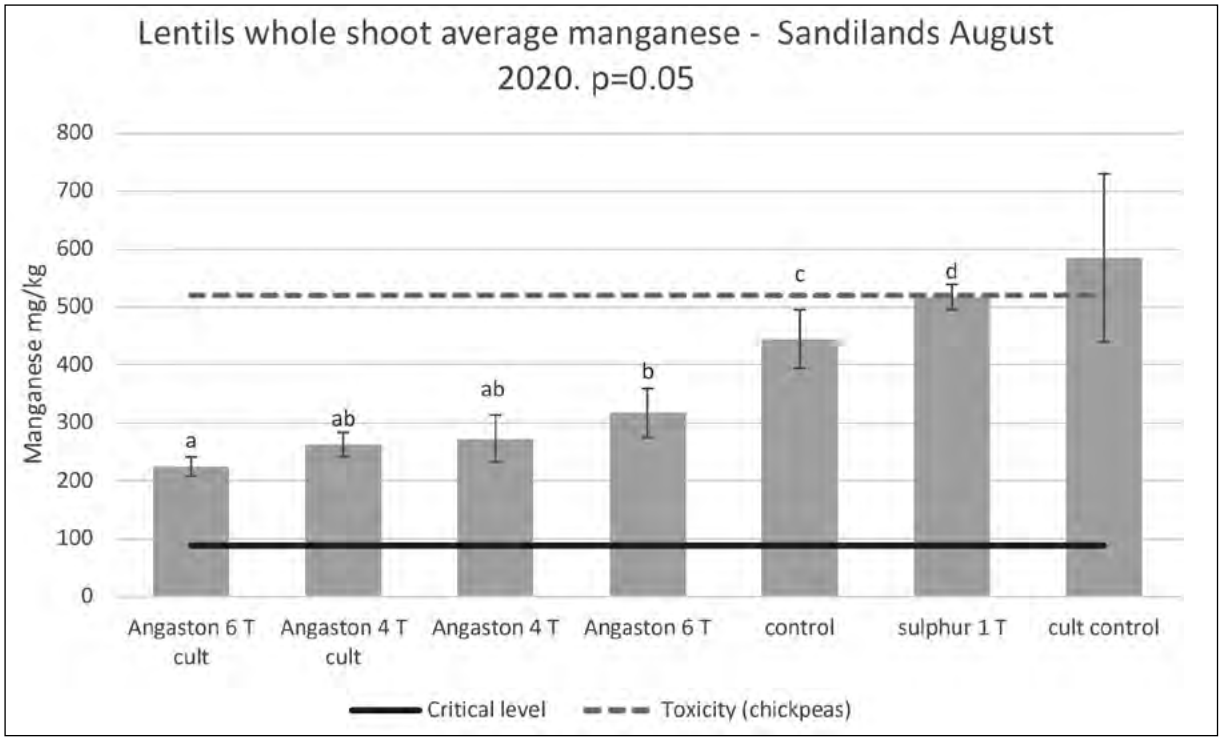


Figure 9. Average amount of manganese in lentil whole shoot in response to treatments at Sandilands, 2020.

At many sites, the level of plant manganese was reduced in response to lime treatments, although deficiency levels were not reached at any site monitored (Figure 9). This response will be monitored as lime becomes more available in subsequent years. Notably, where no lime was applied the lentil plant manganese levels at Sandilands were close to the manganese toxicity level of chickpea - no toxic levels are available for lentils.

Answers to key questions

Lime quality

Lime quality impacted response time at older trial sites, Tungkillo and Wirrabara, where finer limes with higher neutralising values produced more rapid pH changes and crop responses where the same rates were applied (Tungkillo) or rates were modified to account for the neutralising value (Wirrabara) However, on the new trial sites, response to lime quality in the first year or two was small. Stratification below 75mm was still evident under no-till at Wirrabara, several years after the lime treatments.

Lime rate

Higher lime rates (4-6t/ha) produced greater responses in combination with tillage at Sandilands and in the first 4 years after application at Wirrabara and Tungkillo. These rates are significantly higher than those used by most growers.

Incorporation

Dry matter responses to lime applications were greater in cultivated plots compared to top-dressed lime without incorporation at Sandilands. Response to tillage was both positive and negative at various new sites, with and without lime.

Deep ripping with lime gave a good result at a trial site at Sandilands and deep ripping in combination with cultivation and lime was the best treatment at Yumali in year 1.

At an old demonstration site at Koonunga (Nietschke) lime was applied at 7.8t/ha (as two split applications, 2014 and 2017) and surface applied. In 2017 an additional treatment was applied adjacent to the trial where only 3.8t/ha of high quality lime was incorporated with a mouldboard plough to around 15cm to rapidly address a major subsoil acidity issue in the paddock. Monitoring of the site showed the mouldboard plough immediately correctly subsoil pH while for the surface applied it took five years to reduce the aluminium at 20cm to safe levels for crop growth. This reinforces the approach that once signs of subsoil acidity become evident, it is better to address ongoing acidification immediately, rather than waiting and trying to ameliorate a major problem in a few years' time.

Complementary products

Gypsum

Application of gypsum produced a negative response at some sites in 2019, however, in 2020 a lime plus gypsum treatment at Koonunga and Sandilands produced a positive crop response. High rates of gypsum can make molybdenum deficiency worse, where deficiency is an issue.

Manures

The application of chicken manure at Mallala and cow manure at Spalding East, produce a positive response, particularly dry matter. Although at Mallala, a fertiliser equivalent gave a similar result. Compost alone at Mallala increased substantially the number of nodules on roots in comparison with un-limed plots. The benefits from compost are expected, in part, to be due to the boost in legume nodulation and nitrogen fixation rather than the ability of the organic matter to ameliorate the soil acidity.

Clay

The application of clay substantially increased barley dry matter and yield at Yumali, but had only a minor impact on oats at Lameroo.

Conclusions

Recent results from old lime trials demonstrate the benefits of good quality lime with fine particle size and high neutralising value which produced more rapid increases to soil pH, and crop responses compared to inferior lime sources.

Results achieved from trials conducted on new sites seem to highlight that incorporation of lime provides a quicker response and return on investment, although responses appeared to be slow in some situations even with tillage. Low pH at depth can be corrected by the incorporation of lime, whereas the application of very high rates to the surface without tillage will also correct the subsoil, but much more slowly.

For sandy soils, trials have highlighted the need to address multiple limitations, such as compaction or high soil strength, non-wetting and nutrient deficiencies in addition to correcting soil pH.

It should be noted that in many cases the results presented are preliminary and that data collected in coming years will provide improved information on liming practices such as appropriate rates, overcoming subsoil acidity and impacts on trace element uptake, especially in low to medium rainfall areas where little data exists.

Acknowledgements

This research was initiated by a GRDC project in collaboration with PIRSA, DEW, Riverland and Murraylands Landscape Board, Hills and Fleurieu Landscape Board. This is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support. The authors would also like to thank N. Wilhelm and H. Drum, SARDI for trial support.

Useful resources

Soil acidity website (https://acidsoilssa.com.au/)

Hughes, B (2018) Tungkillo Landcare Group Lime Trials- Technical Report available from Riverland and Murraylands Landscape Board.

Contact details

Brian Hughes
Nuriootpa Research Centre, Box 245 NURIOOTPA. SA 5351
0429691468
brian.hughes@sa.gov.au

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

Return to contents

Notes

Notes

GRDC™

GRAINS RESEARCH
& DEVELOPMENT
CORPORATION

Final session
Day 1

GRDC™

GRAINS RESEARCH & DEVELOPMENT CORPORATION

Farming the Business

Sowing for your future

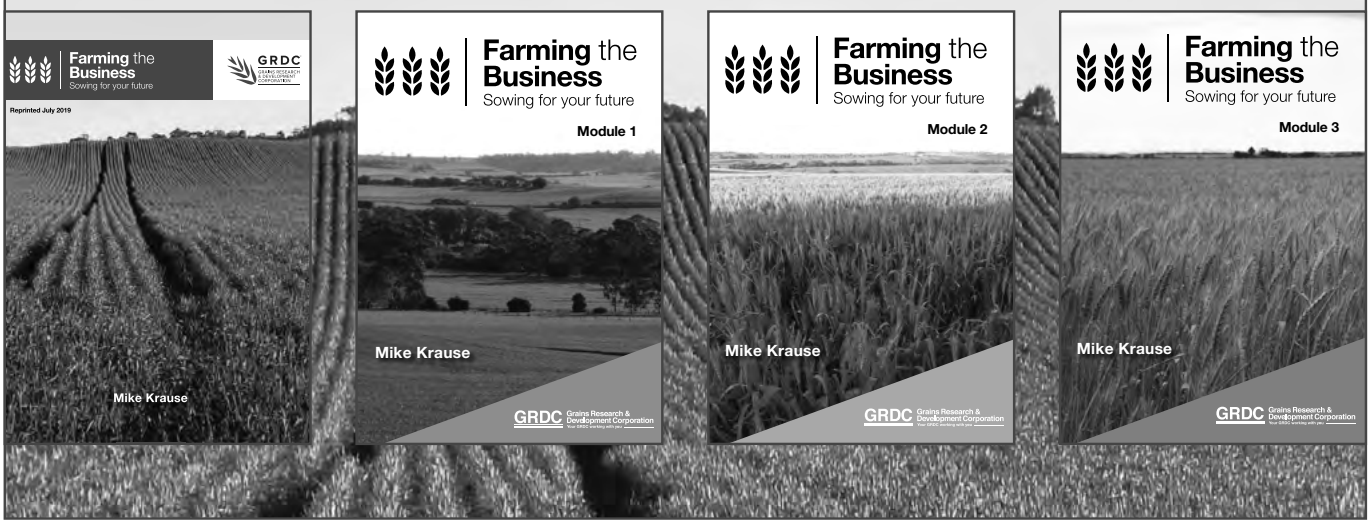
The GRDC's **Farming the Business** manual is for farmers and advisers to improve their farm business management skills.

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

- **Module 1: What do I need to know about business to manage my farm business successfully?**
- **Module 2: Where is my business now and where do I want it to be?**
- **Module 3: How do I take my business to the next level?**

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

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



Level 4, 4 National Circuit, Barton ACT 2600 | PO Box 5367, Kingston ACT 2604 | **T** +61 2 6166 4500 | **F** +61 2 6166 4599 | **E** grdc@grdc.com.au | **W** www.grdc.com.au

GrainInnovate – innovation through disruption (TeleSense Aust example)

Marcus Kennedy.

TeleSense Aust.

Keywords

- agtech, internet of things, IoT, commodity storage, commodity handling, machine learning.

Background

TeleSense provides industrial internet of things (IoT) monitoring solutions for post-harvest commodity storage and transport. It helps to manage risks in the world's perishable commodities supply chain by using machine learning algorithms. Whether assets are stationary or moving, TeleSense uses cloud-based technology to simplify monitoring. The solutions help eliminate human error, improve operational efficiency, and increase profitability.

What are the products that are applicable to grain growers and how will growers benefit from their use?

TeleSense is helping grain growers and managers protect and maximise the value of their stored agri-products. It helps early detection of risks such as moisture, concentrated heat, mould and insect infestation that would result in grain spoilage, reduction in quality and potential complete loss though an explosion or fire. TeleSense provides a more efficient approach to monitoring grain at remote sites, is a safer method of monitoring valuable products and can be used in conjunction with aeration systems to improve efficiency of energy usage.

Providing continuous and automated data collection (temperature and moisture), TeleSense provides grain managers more timely and accurate insights, and thus allows better data-driven decisions on management of stored grain. Traditionally, data collection has been patchy, manual and an expensive process, and decisions reactive.

TeleSense uses artificial intelligence and 'machine learning' software algorithms, data science and customer sensors to monitor, analyse and predict the quality of grain in storage and in transit.

How is investment from the GrainInnovate fund helping SwarmFarm help the Australian grain producer?

It is encouraging to have GrainInnovate provide local Australian support for agtech innovation. GrainInnovate's investment and active participation provide strategic leadership, support and resilience for the local Australian agtech company – at both an individual entrepreneur and an ecosystem level. It is helping build improved collaboration across the growing agtech sector, bringing together entrepreneurs with research and commercial partners, and in doing so, developing an enduring and more commercial innovation focus for Australian agriculture.

Acknowledgement

The development of our products is made possible partly due to the significant contributions of growers through the support of the GRDC, the author would like to thank them for their continued support.

Contact details

Marcus Kennedy
marcus@telesense.com

Return to contents

Notes

GrainInnovate – innovation through disruption (FluroSat example)

Marie Marion.

FluroSat.

Keywords

- agtech, decision support tools..

Background

FluroSat is an innovative agtech company, that delivers agronomic decision support tools globally. Founded in Sydney, Australia in 2016 we have offices in the US, Australia, and Europe.

Over the last four years, we have grown to serve market leaders in crop consulting, retail and manufacturing of agricultural input, farm machinery and food processing.

What are the products that are applicable to grain growers and how will growers benefit from their use?

1. Track your Crop Performance

   Get near-real-time snapshot of your crop growth status, growth speed and crop biomass across all fields. Group fields by crop type and variety or hybrid and benchmark their performance across the season.

2. Scout smartly with Crop stress

   Receive weekly crop stress alerts that show where crop stress might be developing. Scout them early and make sure no pest or disease gets away!

3. Get site-specific nitrogen recommendations

   Save on input costs and improve crop yields with one-touch science-based nitrogen recommendations. Adjust recommended application rates with farm-specific environmental and financial factors in.

Acknowledgement

The development of our products is made possible partly due to the significant contributions of growers through the support of the GRDC, the author would like to thank them for their continued support.

Contact details

Marie Marion
FluroSat
0413 121 609
marie@flurosat.com

Return to contents

Notes

GrainInnovate – innovation through disruption (SwarmFarm example)

Andrew Bate.

SwarmFarm Robotics.

Keywords

- agtech, autonomous robots, weed detection.

Background

SwarmFarm Robotics is an Australian agtech company that has pioneered the commercial deployment of autonomous agricultural robots in the broadacre grains industry. SwarmFarm robots are commercially available and over the past four years, early adopters of our robots have weeded, sprayed or mowed over 200,000 acres of farmland in Australia.

What are the products that are applicable to grain growers and how will growers benefit from their use?

SwarmFarm Robotics has two products: we build autonomous robots for agricultural field tasks, and we have an ecosystem, called SwarmConnect® so that independent machinery developers can deliver new solutions for agriculture. We partner with implement manufacturers to help them release new apps and attachments on board our robots.

Our robots are lightweight and are particularly suitable for weed detection technology such as WeedIT Optical Spot spraying cameras.

How is investment from the GrainInnovate fund helping SwarmFarm help the Australian grain producer?

The investment from the GrainInnovate fund is helping us to scale the business so we can speed up the build and delivery of robots to Australian grain farmers.

Acknowledgement

The development of our products is made possible partly due to the significant contributions of growers through the support of the GRDC, the author would like to thank them for their continued support.

Contact details

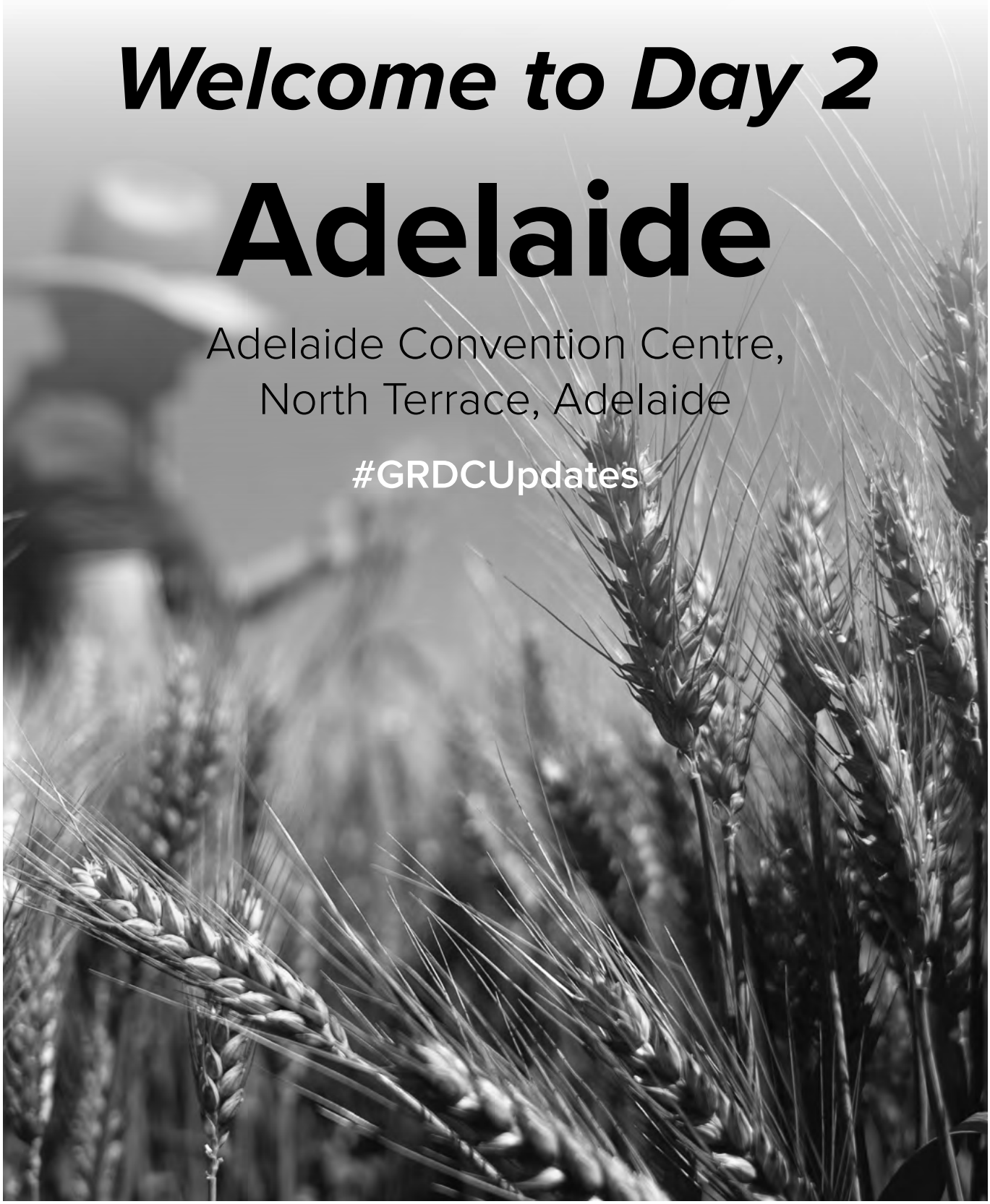
Andrew Bate
SwarmFarm Robotics
"Bendee", P.O. Box 19, Gindie, QLD 4702
0428 186 371
andrew@swarmfarm.com
www.swarmfarm.com

Return to contents

Notes

GRAINS RESEARCH UPDATE

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION



Welcome to Day 2

Adelaide

Adelaide Convention Centre,
North Terrace, Adelaide

#GRDCUpdates

Dealing with the Dry

As grain growers across Queensland and New South Wales and parts of Victoria and South Australia continue to be challenged by drought conditions, the GRDC is committed to providing access to practical agronomic advice and support to assist with on-farm decision making during tough times.

Visit our 'Dealing with the Dry' resource page for useful information on agronomy in dry times and tips for planning and being prepared when it does rain.

www.grdc.com.au/dealingwiththedry

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

P Level 4 | 4 National Circuit, Barton ACT 2600 | PO Box 5367, Kingston ACT 2604 **T** +61 2 6166 4500 **F** +61 2 6166 4599
E grdc@grdc.com.au @theGRDC

Contents — DAY 2

EARLY RISERS SESSION

CONCURRENT SESSION

FINAL SESSION

FURTHER INFORMATION

PROGRAM DAY 2 - FEBRUARY 10th

8.15 am **EARLY RISERS: Enabling technologies** - P 151 ***Tom Giles,*** *GRDC and* ***Tom Bishop,*** *University of Sydney*

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

	Hall C	Room E1	Room E2	Room E3
9.00 am	**Achieving the big yields** - P 165 ***Eric Watson,*** *Ashburton, NZ wheat grower &* ***Nick Poole,*** *FAR Australia*	**The health report - pulse disease update (R)** - P 173 & 183 ***Sara Blake*** *&* ***Blake Gontar,*** *SARDI*	**Phosphorus application recommendations based on soil characterised zones and testing - does it pay? (R)** - P 193 ***Sean Mason,*** *Agronomy Solutions*	**Reducing input costs without compromising pulse production potential (R)** - P 199 ***Sarah Day,*** *SARDI*
9.40 am		**To spray or not to spray – what does the Russian Wheat Aphid threshold calculator advise? (R)** - P 207 ***Maarten Van Helden,*** *SARDI*	**Frost mapping – a future management tool** - P 215 ***Uday Nidumolu,*** *CSIRO*	**Cereal disease wrap up (R)** - P 217 & 223 ***Tara Garrard,*** *SARDI &* ***Sam Trengove,*** *Trengove Consulting*
10.20 am	**MORNING TEA**			
10.50 am	**Novel agronomy strategies for improving yield (R)** - P 231 & 237 ***Kenton Porker,*** *SARDI*	**Integration of non-chemical tactics to improve brome grass management (R)** - P 245 ***Gurjeet Gill,*** *The University of Adelaide*	**Latest management tactics for snail control** - P 251 ***Kym Perry,*** *SARDI*	**Reducing input costs without compromising pulse production potential** - P 199 ***Sarah Day,*** *SARDI*
11.30 am	**GM technology - farming system learnings from WA** - P 257 ***Geoff Fosbery,*** *Farm Focus Consultants*	**Phosphorus application recommendations based on soil characterised zones and testing - does it pay?** - P 193 ***Sean Mason,*** *Agronomy Solutions*	**The health report - pulse disease update** - P 173 & 183 ***Sara Blake*** *&* ***Blake Gontar,*** *SARDI*	**Cereal disease wrap up** - P 217 & 223 ***Tara Garrard,*** *SARDI &* ***Sam Trengove,*** *Trengove Consulting*

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

	Hall C	Room E1	Room E2	Room E3
12.10 pm	**To spray or not to spray – what does the Russian Wheat Aphid threshold calculator advise?** - P 207 ***Maarten Van Helden,*** *SARDI*	**Integration of non-chemical tactics to improve brome grass management** - P 245 ***Gurjeet Gill,*** *The University of Adelaide*	**Use of chemicals and residues arising - impact, understanding and potential trade issues** - P 263 ***Gerard McMullen,*** *National Working Party on Grain Protection*	**Novel agronomy strategies for improving yield** - P 231 & 237 ***Kenton Porker,*** *SARDI*

12.50 pm **LUNCH**

1.30 pm **Keeping the glyphosate option - the state of play** - P 269 & 273 ***Katie Asplin,*** *CropLife Australia*

2.10 pm **Herbicide forum - experiences fitting the new chemistries into the farming system** - P 277 ***Chris Preston,*** *The University of Adelaide;* ***George Pedler,*** *George Pedler AG;* ***Jeff Braun,*** *The Agronomist P/L and* ***Scott Hutchings,*** *Cox Rural Keith*

2.50 pm **CLOSE AND EVALUATION**

On Twitter? Follow **@GRDCSouth** and use the hashtag **#GRDCUpdates** to share key messages

GRDC

NATIONAL VARIETY TRIALS™

NVT tools

CANOLA | WHEAT | BARLEY | CHICKPEA | FABA BEAN | FIELD PEA | LENTIL | LUPIN | OAT | SORGHUM

Long Term Yield Reporter

New web-based high speed Yield Reporting tool, easy-to-use means of accessing and interpreting the NVT Long Term MET (Multi Environment Trial) results.

Crop Disease Au App

Access to current disease resistance ratings & disease information.

Long Term Yield App

Easy access to the analysed NVT Multi Environment Trial (MET) data.

www.nvtonline.com.au

Available on the App Store

Google play

Examples of using machine learning for mapping soil constraints and soil moisture to support improved decision making

Tom Bishop[1,2], Brett Whelan[1], Patrick Filippi[1], Liana Pozza[1], Niranjan Wimalathunge[1], Sebastian Haan[2], Richard Scalzo[3].

[1]Precision Agriculture Laboratory, Sydney Institute of Agriculture, The University of Sydney.
[2]Sydney Informatics Hub, The University of Sydney.
[3] ARC Industrial Transformation Training Centre for Data Analytics for Resources and Environments (DARE), The University of Sydney.

GRDC project codes: 9177574, 9175880

Keywords

- digital agriculture, machine learning, soil constraints, soil moisture, spatial prediction.

Take home messages

- Machine learning techniques using digital data will enable soil constraints and soil moisture to be mapped across cropping farms.
- The uncertainty in the maps is being reduced by research into the best models and data representation techniques.
- Soil surveys using electromagnetic induction and gamma radiometrics provide valuable data for the prediction and mapping processes for both soil constraints and soil moisture.
- Growers should consider a soil sampling and analysis program to 1m using a site location method that attempts to cover the extent of farm variability. This will provide a very valuable data set for combination with freely available off-farm data.

Background

These GRDC investments focus on exploring the application of machine learning (ML) analytical methods to important industry issues in partnership with the University of Sydney (USYD), other research institutions and commercial collaborators. There have been significant developments in machine learning techniques, which differ from mechanistic or process-based models that are commonly used in cropping because they use data-driven approaches to discover relationships between variables.

Machine learning approaches are being employed in an effort to harness their ability to handle large amounts of digital data that is now available to growers and consultants from a wide range of sources. The data comes from publicly available soil and climate data bases, satellite-derived information and on-farm surveys and monitoring which can be inputted into analysis for improved decision-making on-farm.

Two projects are briefly highlighted in this paper.

Machine learning to map soil constraint variability

This program, supported by GRDC, USYD, Precision Cropping Technologies (PCT), Lawson Grains and Viridis Ag aims to develop tools to map fine-scale whole-of-paddock 3D variability of agronomically important soil constraints (sodicity, pH, salinity, gravel), and to map the depth at which these

chemical/physical barriers become limiting and impact plant available water capacity (PAWC). These data layers should improve prediction of crop yield variability pre- and in-season at the within-field scale, which in turn should improve input management and profitability.

The project is using three different suites of data, which can be broadly categorised into freely available soil data (A), on-farm data (B), and using a combination of the two (C). The freely available data being used is: Landsat (30m), Sentinel (10m), temperature - degree days (5000m), rainfall (5000m), DEM (5m), terrain attributes (30m), airborne gamma radiometrics (90m), and the Soil and Landscape Grid of Australia (90m). Point soil sample data is also available from a national soil data set (National Soil Site Collation) and access to the USYD's large soil database (primarily New South Wales (NSW) and southern Queensland (Qld)) is also available. The on-farm data is supplied by the commercial partners (Lawson Grains, ViridisAg and PCT) and consists of: yield monitor data (10m) - many years of data on different crops, soil ECa surveys (10m), gamma radiometric surveys (10m), management data (field scale), and field-based soil sample data (strategic within-field).

The on-farm data is available on a large proportion of the approximately 200,000 hectares currently managed by Lawson Grains and ViridisAg. The data provided by industry partners is extremely valuable, as it is not just an aggregation of unstructured data but has been extensively cleaned and validated by PCT using their processing protocols. This adds considerable value to the modelling aspects of the project because the quality of data is known which should minimise error and maximise trust in agronomic validity of the results.

Progress has been made on creating three dimensional (3D) maps to represent the soil constraints in both vertical depth, and horizontal space using the three different data sets. The research is currently assessing a number of ML methods in order to identify the most appropriate approach.

The ML methods being tested are:

- a fast implementation of random forests for high dimensional data.
- XGBoost, a gradient boosted tree method.
- Bayesian Neural Networks (BNN).
- Bayesian Linear Regression (BLR).

Concurrently, the use of the different data sets is being used to determine the extent of any benefit from using freely available off-farm data in the modelling and prediction processes.

Summary of early results

Preliminary testing for any benefit of adding the off-farm data has indicated that the inclusion of external soil data from non-cropping areas added little to the ability to predict ESP, pH and EC on the two test cropping farms. Off-farm soil data needs to be vetted for land use.

Using a data set for a 5000ha farm where 48 whole-profile soil cores were chemically analysed in four depth increments, and soil ECa and gamma-radiometrics were also available, the use of Bayesian Neural Networks (BNN) and Bayesian Linear Regression (BLR) appear to be the best of the models assessed so far for predicting ESP, pH and EC. All the techniques that were tested build single prediction models for each of the ESP, pH and EC variables over the whole profile and used 'soil depth' as a variable in the model. For all models this was the main variable of importance in predicting a soil constraint, followed by various mixes of the gamma radiometrics, soil ECa, and satellite-derived information from the red band in average or poorer cropping years during the last 10 years. This highlights the direct value of the on-farm soil ECa and gamma radiometrics surveys and the indirect utility of remotely sensed information that identifies production limitations over a time period.

The predictions of pH and EC were better than ESP based on the Root Mean Square Error (RMSE). The ESP is by far the most variable of the properties across paddocks and down soil profiles on the test farms. By changing the predictions from estimates at points to estimates over an area/volume (50m x 50m x 0.1m) the RMSE is reduced by 30-50% and should make estimating depths to ESP thresholds more accurate.

A sample of the data and the outputs for the 5000ha test farm is included here to demonstrate the predictions and show the maps that are being produced as the work progresses. Figure 1 shows the stratified random sample locations, sample numbers in each field and depths sampled.

Samples

- Collected May 17th 2020
- 5 fields:
  - OD01 = 10
  - OD02 = 8
  - OD03 = 12
  - ODO4 = 10
  - OD05 = 8
- 4 depths:
  - 0-15 cm
  - 15-30 cm
  - 30-60 cm
  - 60-90 cm

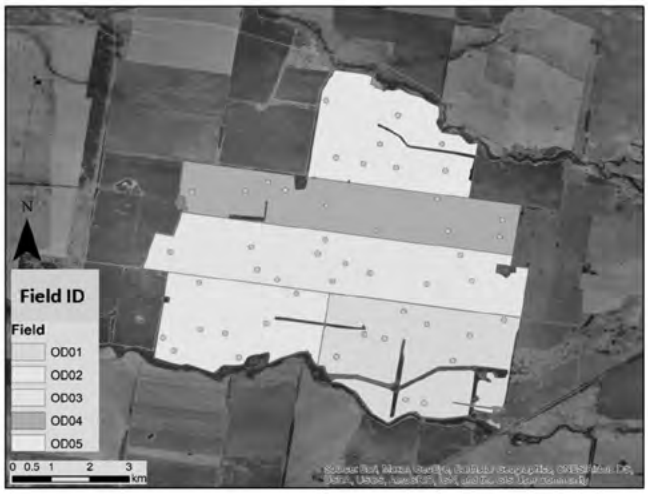


Figure 1. Forty-eight sample locations on the 5000ha test farm.

ESP: Distribution for each depth

Depth (cm)	Min	Q1	Median	Mean	Q3	Max	Skew
0-15	1.4	3.3	4.0	3.9	4.5	6.8	0.1
15-30	1.7	5.1	6.2	6.1	7.1	9.7	-0.2
30-60	2.9	7.8	9.5	9.3	11.0	15	-0.2
60-90	3.5	9.4	13.0	12.1	15.0	22.0	-0.2

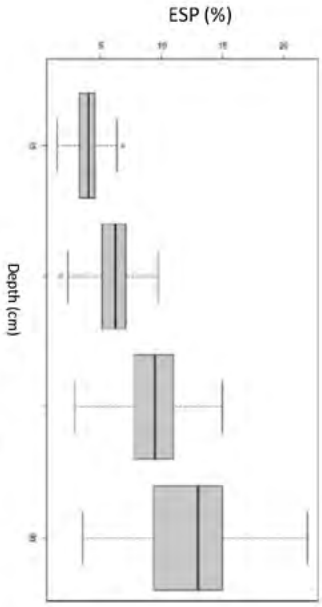


Figure 2. Range of ESP raw data in the 48 samples on the test farm.

pH: Distribution for each depth

Depth (cm)	Min	Q1	Median	Mean	Q3	Max	Skew
0-15	6.3	7.3	7.7	7.6	8.0	8.5	-0.4
15-30	7.2	8.2	8.6	8.5	8.8	9.2	-0.9
30-60	7.8	8.7	9.0	8.9	9.2	9.5	-1.0
60-90	7.2	7.9	8.2	8.5	9.2	9.7	0.2

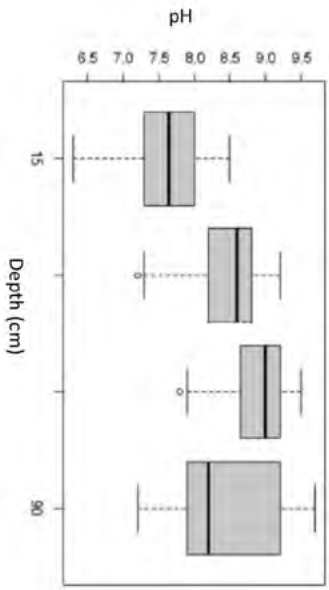


Figure 3. Range of pH raw data in the 48 samples on the test farm.

EC: Distribution for each depth

Depth (cm)	Min	Q1	Median	Mean	Q3	Max	Skew
0-15	0.06	0.12	0.14	0.17	0.19	0.66	2.9
15-30	0.07	0.14	0.17	0.23	0.30	0.69	1.5
30-60	0.10	0.18	0.23	0.34	0.29	2.67	4.1
60-90	0.25	0.41	1.40	1.50	2.67	3.50	0.2

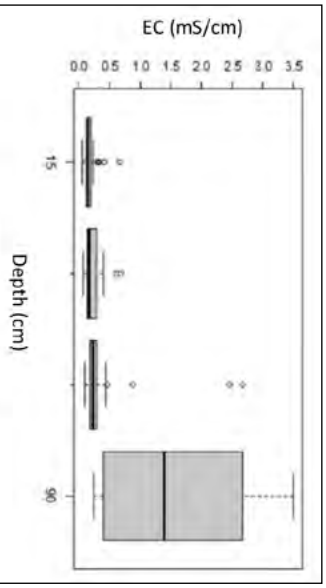


Figure 4. Range of EC raw data in the 48 samples on the test farm.

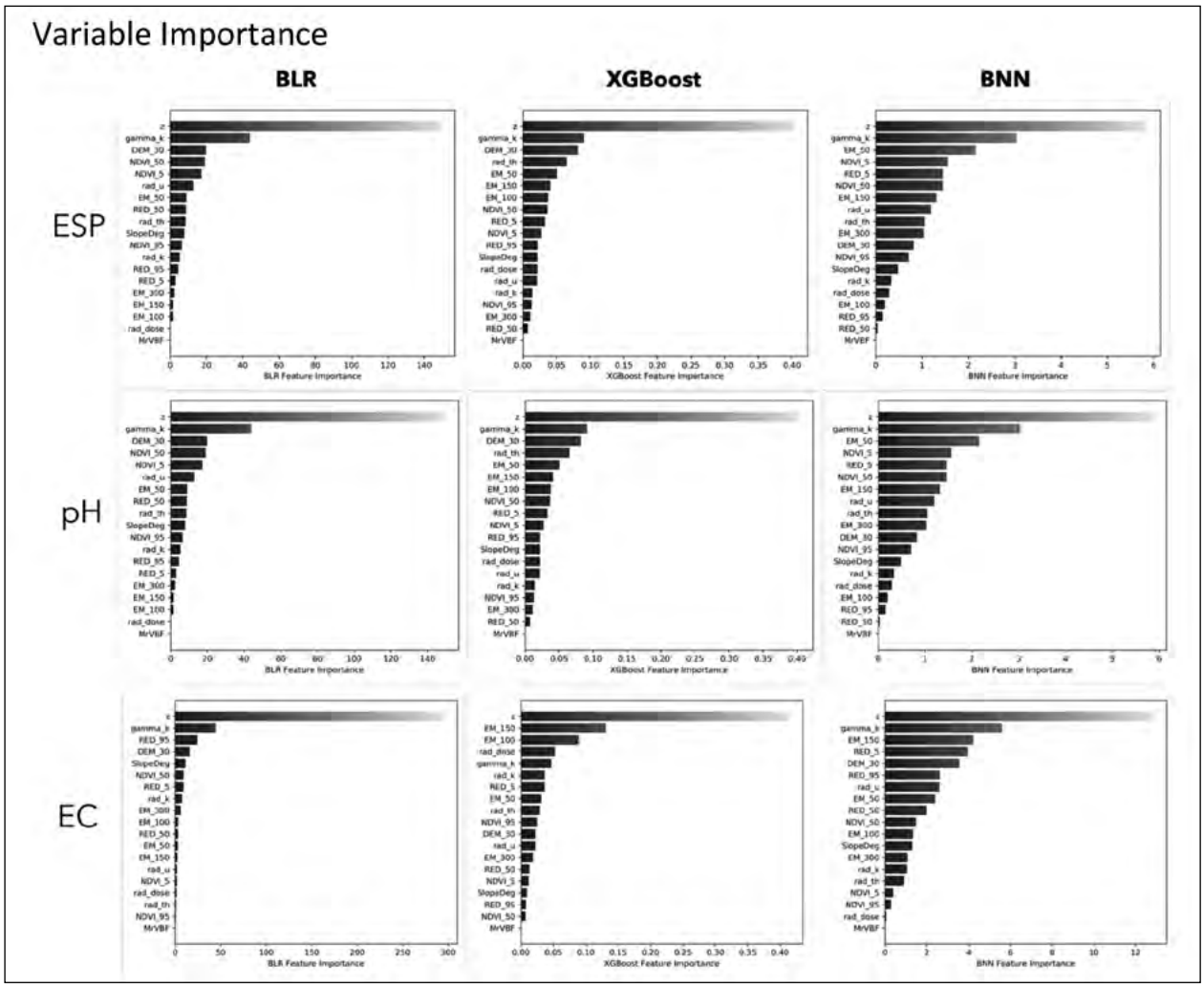


Figure 5. Importance of variables used in the prediction of ESP, pH and EC using 3 different ML models (Bayesian Linear Regression, XG Boost, Bayesian Neural Networks) are ranked. "z" = depth is ranked as number 1 in all models followed predominantly by the "K" band from the gamma radiometric soil survey. The feature importance scales on the x-axis are different because fundamental differences in the modelling approaches impact the method of importance calculation. Ranking and relativity within each model type are the focus.

Table 1. Model fit for ESP data using the different models. The two best methods of the models tested (BNN and BLR) are highlighted. A single model is fitted to describe the variability over the whole profile depth which provides the "mean" model (e.g. BLR) The "+GP" indicates the addition of a Gaussian process on the residuals of the mean model.

Model Name	RMSE	Norm RMSE	R2	MAE
Depth Model	2.7059	0.6682	0.5535	2.0108
Depth Model + GP	2.7717	0.6845	0.5315	1.9829
BLR	2.605	0.6433	0.5861	1.8765
BLR + GP	2.5878	0.6391	0.5916	1.8622
BNN	2.538	0.6268	0.6071	1.8274
BNN + GP	2.6098	0.6445	0.5846	1.8423
XGBoost	3.4202	0.8446	0.2866	2.5094
XGBoost + GP	2.5912	0.6399	0.5905	1.8173

Table 2. Model fit for pH data using the different models. The best method of the models tested (BNN) is highlighted. A single model is fitted to describe variability over the whole profile depth which provides the "mean" model (e.g. BLR) The "+GP" indicates the addition of a Gaussian process on the residuals of the mean model.

Model Name	RMSE	Norm RMSE	R2	MAE
Depth Model	0.6106	0.8446	0.2866	0.5122
Depth Model + G	0.6113	0.8456	0.285	0.4896
BLR	0.61	0.8438	0.2881	0.4985
BLR + GP	0.5853	0.8095	0.3446	0.4603
BNN	0.5407	0.7479	0.4406	0.4408
BNN + GP	0.5805	0.803	0.3552	0.474
XGBoost	1.369	1.8937	-2.586	1.1971
XGBoost + GP	0.5806	0.8031	0.3551	0.459

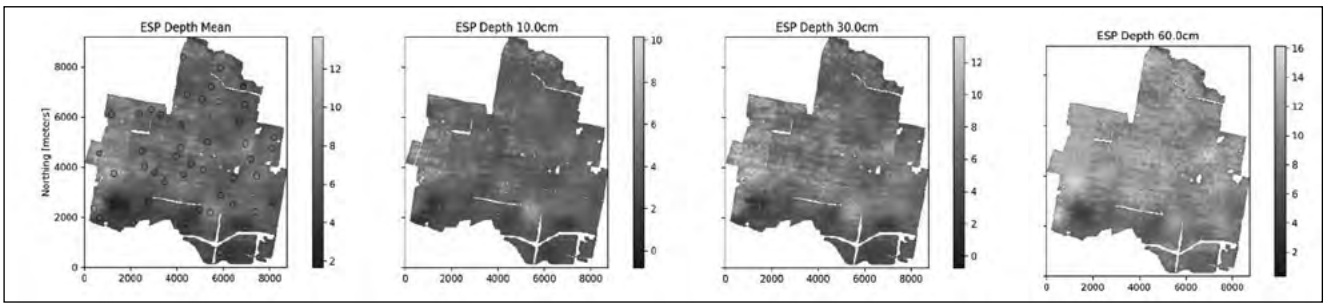


Figure 6. Predicted ESP (%) across the farm using BNN plus GP. Profile average ESP and ESP at three different depths down the profile are shown.

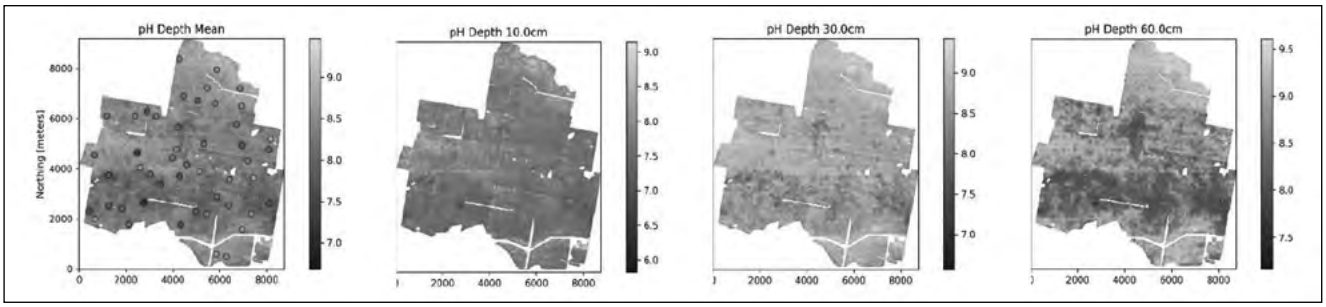


Figure 7. Predicted pH across the farm using BNN plus GP. Profile average pH and pH at three different depths down the profile are shown.

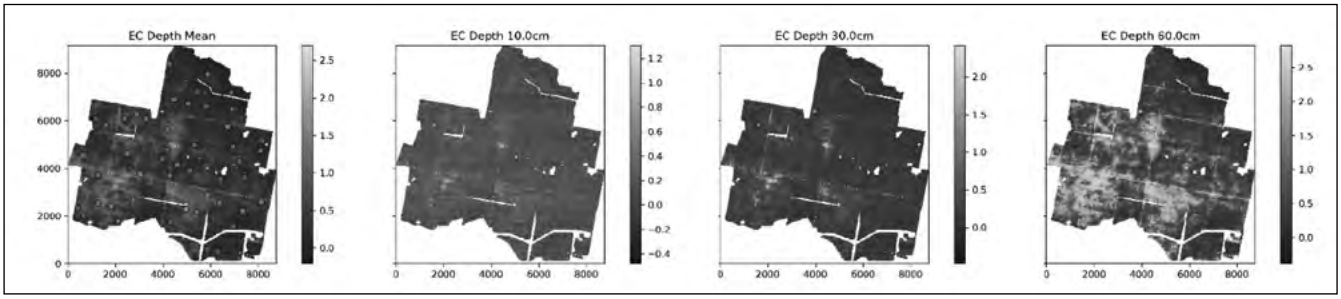


Figure 8. Predicted EC (mS/cm) across the farm using BNN plus GP. Profile average EC and EC at three different depths down the profile are shown.

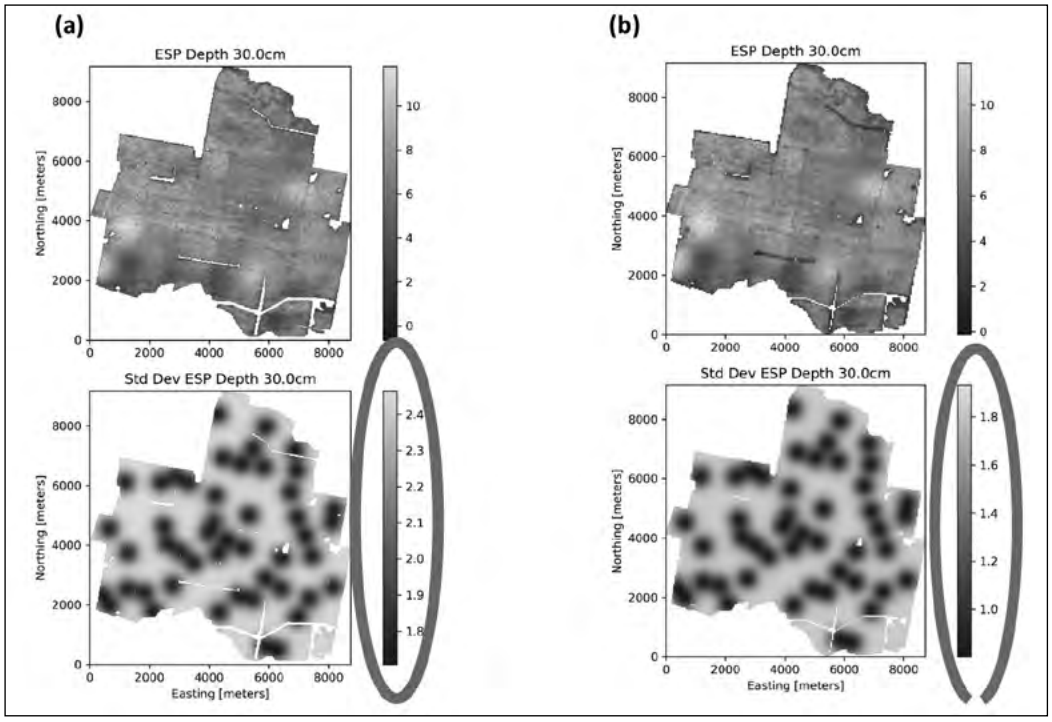


Figure 9. Predicted ESP using BNN plus GP. (a) point predictions and associated standard deviation (Std Dev), and (b) block predictions and associated reduction in Std Dev.

Area/volume predictions versus point predictions

In Figure 9a, the ESP is predicted at 30cm depth at the specific points on the whole farm grid. This is an estimate of what the value should be right at each point. In Figure 9b the values represent the average in a 50m x 50m x 0.1m block centred around each point on the whole-farm grid. The standard deviation is reduced by nearly 50% which reduces the uncertainty in the predictions by the same amount.

Moving forward

- The BNN and BLR methods will be moved forward to test on more cropping farms to get better information on model performance in different areas and also to test if a reasonable 'general' model can be built from data from numerous farms.
- Freely available soil data will be processed to build a cropping-only subset, which will be further subset into regional soil types in order to test for improved value to the prediction process.
- Targeted independent soil sampling to test the maps produced will be undertaken.

Soil water nowcasting for dryland cropping in Australia

This project is a partnership between GRDC, USYD, CSIRO, University of Southern Queensland (USQ) and the BOM. It aims to deliver a scientific framework to nowcast plant available water (PAW). Nowcasting refers to predicting the current state of an attribute of interest. The approach here will be based on digital data but will be agnostic to the type of soil water data streams. It will extract the best features of all in terms of accuracy and spatial and temporal resolution to provide improved PAW predictions using scale-able, modular modelling frameworks that can be operationalised into new analytic products by commercial third-parties. The agnostic nature of the approach means that it should be able to accommodate the next generations of sensors, remote sensing platforms and water balance modelling approaches. The project will test, develop and refine data-driven, data assimilation, soil water balance modelling and ensemble-based approaches, i.e., different analytical frameworks to prediction PAW using the combined expertise of the five different research organisations and strong collaborations with grower networks and industry, including the Society for Precision Agriculture in Australia.

Summary of early results

Due to the declining cost of soil moisture probes, there is an increasing proliferation of soil moisture probe networks across Australia operated by grower groups, universities and state agencies. Many of these offer real-time and publicly available soil water measurements. However, it is unknown whether the networks represent the full range of conditions such as farming systems, terrain, soil, and weather that control the spatial and temporal variability of soil moisture. Therefore, the project's first objective was to assess how representative the current publicly available soil probe networks are of Australia's entire grain cropping region. If they have sufficient coverage and could be calibrated in some way, they could be used in a machine learning model to predict soil moisture or uses to calibrate water balance models.

In addition, a workflow to apply our water balance model for any location in Australia has been developed to provide daily predictions at a 90m resolution for multiple depths in the soil profile. This model will be improved on over the project.

Identification of gaps in current soil moisture probe networks

A digital data cube at a 1km resolution was created for the whole of Australia based on the following data sources which were chosen to represent soil moisture dynamics, focusing on the concepts of soil water storage, soil water use, water flow and the soil properties that influence these processes: (i) soil as represented by the Soil Landscape Grid of Australia; (ii) weather as represented by BOM rainfall and temperature surfaces; (iii) vegetation as represented by Landsat imagery; and, (iv) terrain as represented by elevation, slope and slope-aspect. Table 3 documents the 33 data layers used.

The locations of 371 soil moisture probes installed across grain cropping regions that were accessible to the CSIRO were used to represent the available soil moisture probe network (Figure 10). At these locations, the information from the digital data cube of Australia (33 layers) was extracted to describe the extent of variation in these properties across the soil moisture probe network. The idea being to use a ML technique to compare the extent of variability represented across the probe network to the extent of variability across Australia and the grain cropping regions.

The process used to tackle this issue is based on work done by Meyer and Pebesma (2020). This method delineates the area of applicability (AOA) of a derived model based on a dissimilarity index (DI). The AOA is the area in a multidimensional predictor data space (in this instance the Australia wide data cube of 33 layers) where reliable predictions from a machine learning model made from a training

Table 3. Covariates to describe the characteristics of the study area. Seasonally averaged means that there are four different values for the relevant property.

	Covariate	Source	Resolution	Characteristics
Spatial	DEM, slope	Geoscience Australia	30m upscaled to 1km	Topographically controlled effects
	Land use	MODIS	500m upscaled to 1km; 5yrs	Land management
	Topographic Wetness Index (TWI)	ASRIS	90m upscaled to 1km	Topographic control on hydrological processes
	Clay % (0-30,30-100 cm)	SLGA	90m raster upscaled to 1km	Water holding capacity
Spatial & temporal	Evapotranspiration(ET)	MODIS	1km, 10yrs seasonally averaged	Seasonal crop water use
	Enhanced Vegetation Index (EVI) (0.05, 0.50 & 0.95 percentiles)	MODIS	500m upscaled to 1km; 10yrs seasonally averaged	Seasonal vegetation greenness 0.05 percentile – bare soil 0.5 percentile – average greenness at normal condition 0.95 percentile – peak greenness stage of crops
	Precipitation(P)	SILO	5km, downscaled to 1km; 10yrs seasonally averaged	Relates to soil water content
	Temperature (min, max & average)	SILO	5km, downscaled to 1km; 10yrs seasonally averaged	Temperature difference effects which relate to ET
	Solar radiation	SILO	5km, downscaled to 1km; 10yrs seasonally averaged	Relates to evaporation

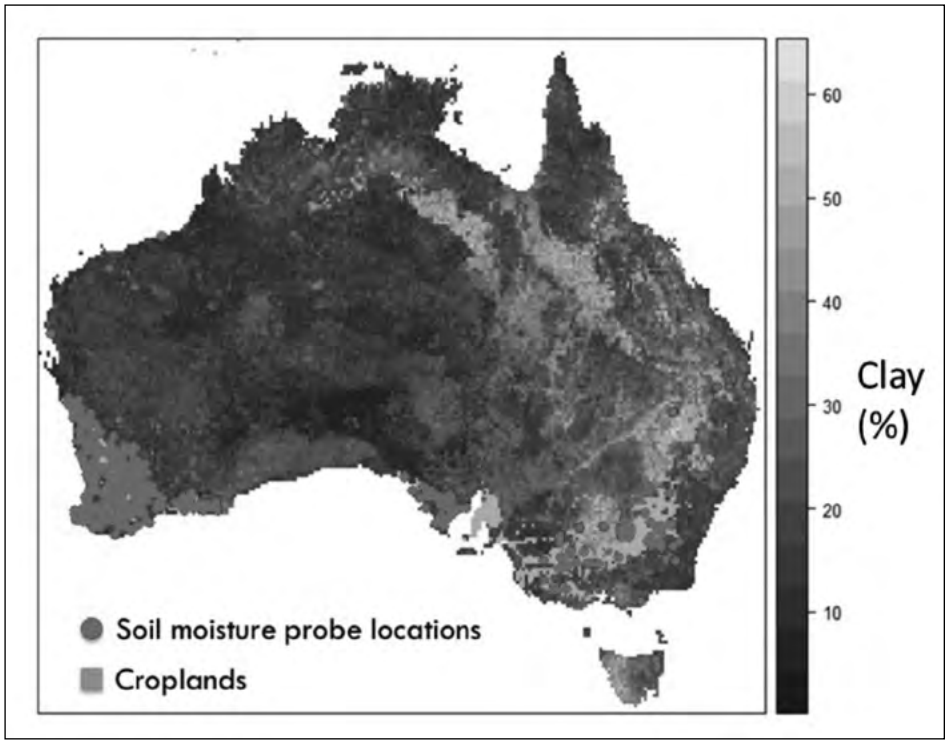


Figure 10. Current soil moisture probe locations overlaying cropland and topsoil clay maps.

data set (the data extracted at the moisture probe network locations) can be made based on the same input parameters. The DI is based on calculating the distance in the multidimensional data space between data outside the training data to the data used in the training model.

The method was implemented using the 'AOA' function from the 'CAST' R package (Meyer and Pebesma, 2020) that uses a Random Forest approach to build the training model using the multidimensional input (probe location data), calculates the DI as comparison with the whole data set (Australia-wide data set) and determines the area of applicability.

Reliable predictions are defined as predictions that can be made with an error that is, on average, comparable to the cross-validation error of the model computed using the training data. This concept is embedded in the use of DI where, if the result of the comparison between a new prediction location and the training model parameters is 0, then the new data point is identical in its values of predictors to the values of the training data set predictors. In this case we can believe our model can be used to predict at the new location. If the value of DI is equal to, or greater than 1, the difference between the new data point and the training model parameters is equal to or larger than the average dissimilarity in the data in the training data set. At this point the prediction error using the model at the new point would be equal or greater than the cross-validation error of the original model, and therefore the point is not suitable for application of the model. A maximum threshold DI value of 0.95 was set to define the AOA in this work.

Figure 11 shows the dissimilarity index calculated for the whole of Australia and Figure 12 shows the AOA for Australia based on the current soil moisture probe networks. As expected, much of Central and Northern Australia sits outside the AOA. The east coast also sits outside the AOA. Figure 13 shows the grain cropping regions overlain on the AOA map.

Future work will explore the use of state land use mapping products which have better spatial resolution and apply this approach at a finer resolution (90 m) as compared to the current approach which was performed at 1km.

Table 4. Percentage of cropland covered by the AOA calculated for individual Australian states.

State	NSW	VIC	SA	WA	QLD
AOA%	97.16	99.43	98.03	99.95	46.84

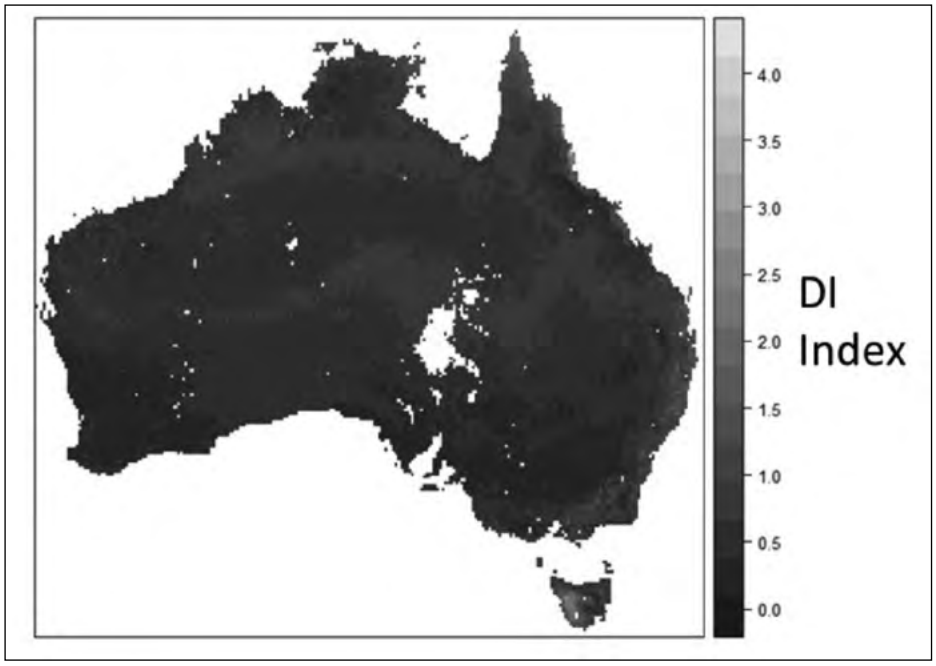


Figure 11. Map of dissimilarity Index: lower values show the minimum distance to training data in the multidimensional predictor space. Areas where there is no data are water bodies.

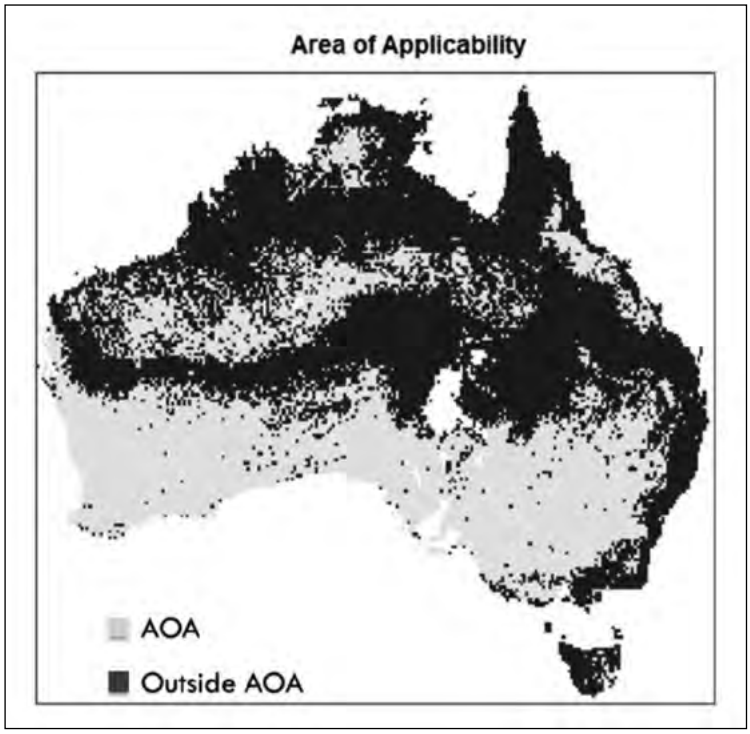


Figure 12. Area of Applicability (AOA) for the model built using the soil moisture probe network data.

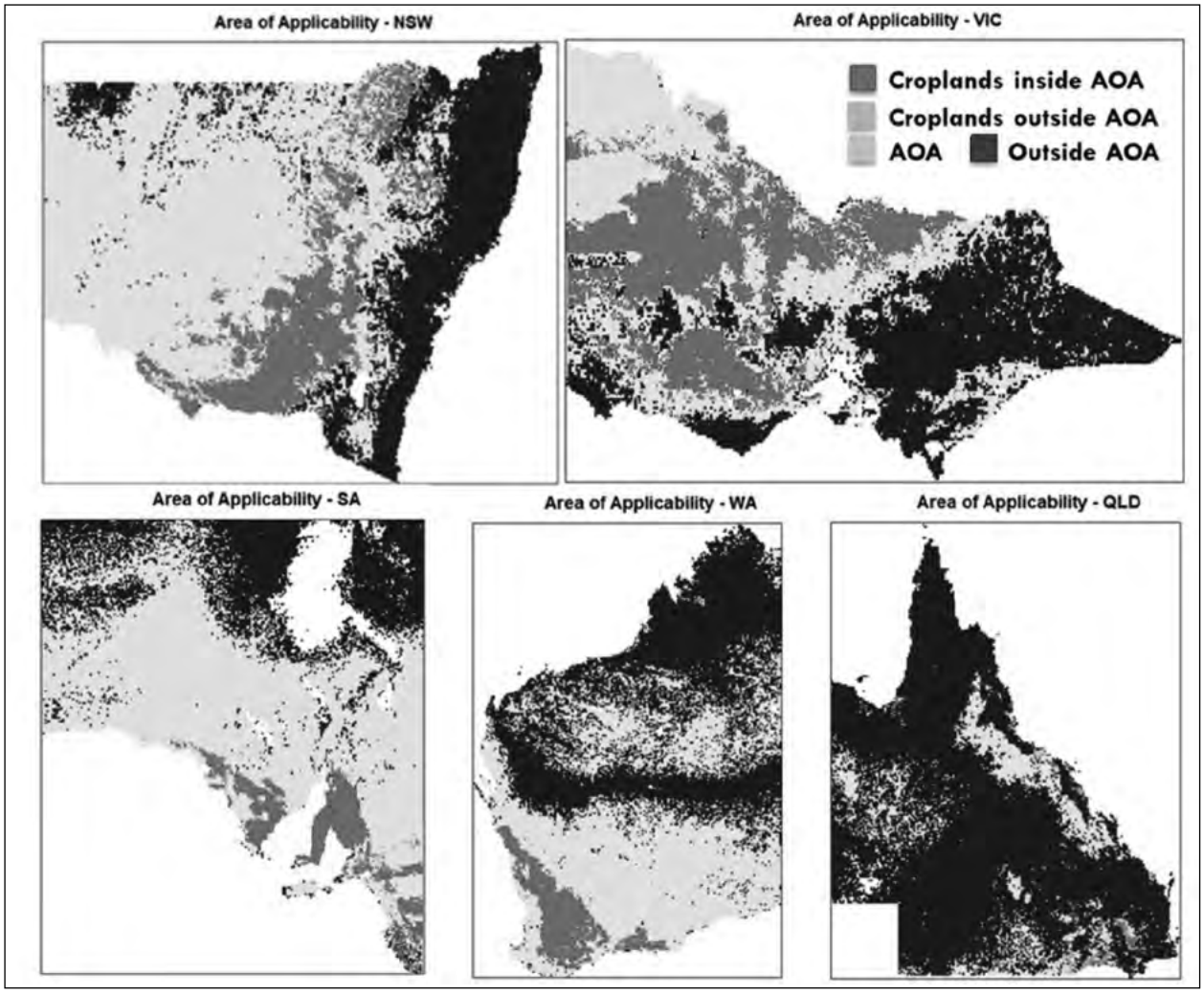


Figure 13. Croplands overlain on the Area of Applicability map.

A prototype of the PAW product

The first series of prototype soil moisture products has been launched on an R Shiny platform, which uses the water balance model introduced by Wimalathunge and Bishop (2019). The predictions are at 90m for multiple depths in the soil profile. Growers, consultants and other industry representatives will be invited to provide feedback on the prototype PAW products via the R Shiny Platform as the project develops. The following links present the prototype PAW product for a few time points at some test locations in NSW. The 1st link presents results for 2 of USYD's university farms. The 2nd link is for the Muttama Creek catchment near Cootamundra in southern NSW. Figure 14 provides an example of a soil water estimate for the USYD Nowley property at a 90m resolution for 30-100 cm.

Nowley/Llara - https://januarharianto.shinyapps.io/nowley/llara/

Muttama - https://januarharianto.shinyapps.io/muttama/

The number of locations will be expanded over the life of the project. Growers with an interest in providing feedback on the PAW products which can be applied on their farms should contact thomas.bishop@sydney.edu.au.

Moving forward

- Downscaling of MODIS ET is being undertaken to reduce the resolution of models and therefore predictions to below 1km.
- A process to use the data and models to 'semi-calibrate' soil moisture probes is being developed.
- Improvements are being made to the water balance model and we are comparing prediction quality via the use of different precipitation and ET products.

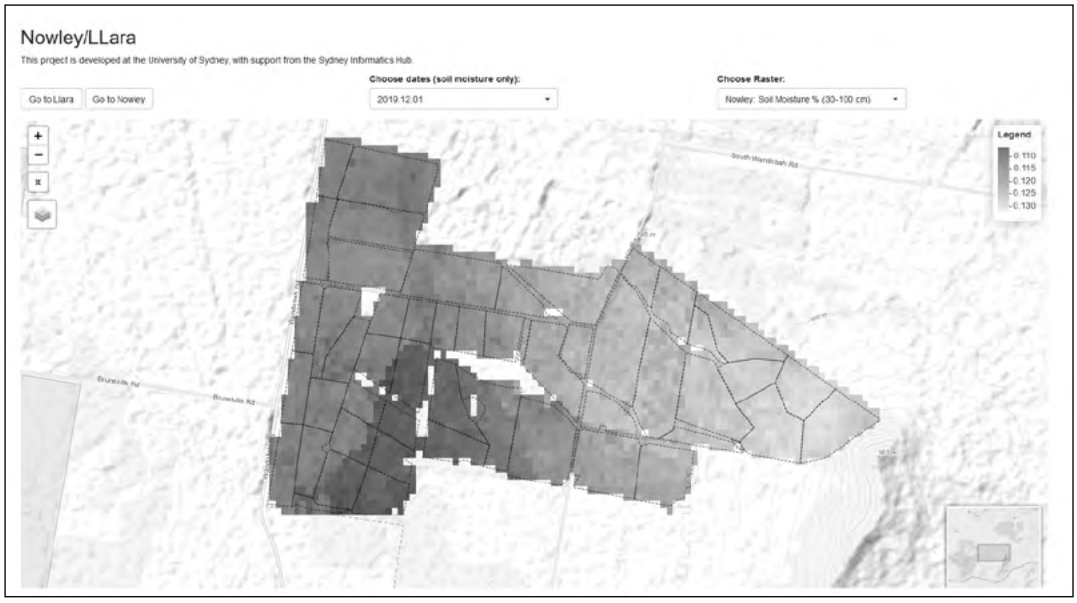


Figure 14. PAW estimates for the USYD property, 'Nowley'.

- Field measurement of soil moisture will be collected using CSIRO's mobile cosmic-ray probe platform (CosmOz Rover) to measure soil moisture in real-time on-the-go and validate our predictions

Conclusions

Future work will consider combining outputs from both projects so that the depth to constraint maps can be used to identify what soil moisture is in the unconstrained part of the soil profile. It is this accessible soil moisture that should be used to guide yield potential estimates and management decisions. Finally, while the quality of our predictions for depth to constraint or soil moisture with field observations can be tested the true test is whether these data products can improve management decisions. This can be achieved with on-farm experimentation which is possible with variable-rate technology.

References

Meyer, H. and Pebesma, E., 2020. Predicting into unknown space? Estimating the area of applicability of spatial prediction models.

Wimalathunge, N. and Bishop, T., 2019. A space-time observation system for soil moisture in agricultural landscapes. Geoderma, 344, pp.1-13.

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.

Contact details

Tom Bishop
Precision Agriculture Laboratory, Sydney Institute of Agriculture, The University of Sydney
Biomedical Building, Australian Technology Park, Eveleigh NSW 2015
02 8627 1132
thomas.bishop@sydney.edu.au

Return to contents

Notes

GRDC™

GRAINS RESEARCH
& DEVELOPMENT
CORPORATION

Concurrent session Day 2

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION
STORED GRAIN PROJECT

storedgrain information hub

Get the latest stored grain information online

storedgrain.com.au

The complete manual for on-farm grain storage

Call the National Grain Storage Information Hotline **1800 WEEVIL** (1800 933 845) to speak to your local grain storage specialist for advice or to arrange a workshop.

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION
STORED GRAIN PROJECT

www.grdc.com.au | **www.storedgrain.com.au** | **02 6166 4500**

Hyper Yielding Crops – are there learnings outside of the high rainfall zone?

Nick Poole[1], Tracey Wylie[1], Darcy Warren[1], Kat Fuhrmann[1], Aaron Vague[1], Ben Morris[1], Tom Price[1], Kenton Porker[2], Amanda Pearce[2], Ian Ludwig[2], Greta Duff[3], Brett Davey[3] and Rohan Brill[4].

[1]Field Applied Research (FAR) Australia, [2]South Australian Research and Development Institute (SARDI), [3]Southern Farming Systems (SFS) and 4Brill Ag.

GRDC project codes: FAR2004-002SAX, FAR00003

Keywords

- disease management strategies, integrated disease management, fungicide resistance, Group 11 Quinone Outside Inhibitors - QoI (Strobilurins), Group 7 Succinate Dehydrogenase Inhibitors (SDHIs).

Take home messages

- The Hyper Yielding Crops (HYC) project is a GRDC national investment which aims to push the economically attainable yield boundaries of wheat, barley and canola across five states.
- **Hyper yielding cereal crops cannot be produced with artificial fertiliser alone;** rotations which lead to high levels of inherent fertility are essential to underpin high yields and the large N offtakes associated with bigger crop canopies.
- The world record for wheat set in 2020 in New Zealand showed **wetter soils (irrigated) improved nitrogen use efficiency** and illustrated the importance of good soil nitrogen (N) supply in supporting high yields.
- **Disease management is one of the most important management components of growing high yielding** cereal crops in seasons that favour higher yield potential.
- Where genetic resistance in a wheat cultivar is not sufficient to delay fungicide decisions until flag leaf emergence (GS37-39), look to target the following three key timings for fungicide intervention; first node GS31, **flag leaf emergence GS39 with an optional third application at head emergence GS59.**
- **Avoiding repeated use of the same fungicide active ingredients,** and in the case of the newer Group 11 QoI (strobilurins) and Group 7 SDHIs, where possible, restrict strategies to just one application per season to slow down and help prevent the selection of resistant strains of the fungus.

Hyper Yielding Crops research and adoption

Led by Field Applied Research (FAR) Australia, the Hyper Yielding Crops (HYC) project is a GRDC national investment that commenced 1 April 2020, which aims to push the economically attainable yield boundaries of wheat, barley and canola in those regions with higher yield potential. Hyper Yielding Crops project builds on the success of the GRDC's four-year HYC project in Tasmania, which demonstrated that it is possible to significantly increase yields through sowing the right cultivars and effective implementation of appropriately tailored management strategies. While the project team is clearly aware that Tasmania is not mainland

Australia, it is believed that there are some common threads to the research that could benefit this mainland HYC initiative and for growers in regions that experience high yielding conditions in some seasons.

The first learning is the ability to operate a research centre that can look at all the latest developments in germplasm and agronomy in one location. This has already been established in the first two years of research delivered at FAR Australia's South Australia Crop Technology Centre (SACTC) Millicent, located in the state's South East; here winter wheat germplasm such as Anapurna and RGT Accroc wheat cultivars have performed well, mirroring results from Tasmania. The ability to research all the agronomic levers and new germplasm on the same site may not appear unique but when combined with results from other HYC research sites, it can be powerful. The second point is that across Australia, sowing dates are moving forward irrespective of region, and as a consequence, our germplasm requirements are changing. Moving sowing dates forward comes with its challenges, particularly in higher yielding long season scenarios where we need to be mindful of cultivar suitability and phenology and increased disease pressure and lodging risk. As a result, the HYC project is screening both winter and spring germplasm to determine if long season germplasm has high potential in mainland HRZ environments. At the HYC research sites, we are looking to determine if overseas bred material can offer any steps forward in the same way that cultivar RGT Planet[1] (barley) did in 2016. There is a strong focus on nutrition and disease control, since fungicide technology has developed considerably over the last decade, as has the increased risk of fungicide resistance in the pathogens.

As well as the five HYC research sites across the higher yielding regions of New South Wales (NSW), Western Australia (WA), SA, Victoria (Vic) and Tasmania (Tas), the project wants to engage with growers and advisers to scale up the results and create a community network aiming to lift productivity (see details at the end of this paper).

Results from the first year of HYC research trials are currently being harvested and processed at the time of writing, however there are some early learnings and results from the previous project that have applicability in other high rainfall regions when seasonal conditions favour high yields.

Nutrition and rotation for hyper yielding wheat –farming system fertility

The current world record wheat crop produced by Eric and Maxine Watson in New Zealand holds important lessons for us all, even if we don't farm in a region where 17.39t/ha is possible! **The first is that simply applying more and more fertiliser is not the route to achieving big yields.** This is clearly seen when one considers the overall N fertiliser input applied to achieve the record yield. A simple look at a commonly used N budget here in Australia makes clear the importance of farming system fertility in achieving big yields of cereals and canola. For example, it is widely assumed that:

- For every tonne/ha of wheat yield the crop needs to be supplied with 40kg N/ha.
- For every tonne/ha of canola yield the crop needs to be supplied with 80kg N/ha.

The key word here is 'supplied' rather than 'applied'. Using 40kg N/ha to achieve a crop of 17.39t/ha, the world record wheat crop would have required (from soil reserves and fertiliser) approximately 695kg N/ha based on our commonly used N budgets. In fact, the record crop received a total of 301kg N/ha applied N, begging the question where did the other 394kg N/ha come from? Improved nitrogen use efficiency (NUE) with irrigation clearly reduces the overall N requirement, **but the reality was that a wheat crop yielding 17.39t/ha removed more N in the grain alone than could be accounted for with the N applied.** Once the N in the crop canopy (straw and chaff) rather than the grain is considered, it is clear that the contribution of soil N supply as opposed to N fertiliser is vitally important in achieving big crops. The world record crop did not have a dry matter sample taken at harvest but with a typical harvest index of 55% the final harvest biomass is likely to have been in the region of nearly 32t/ha. If it's assumed that 25% N at harvest is in the straw and chaff rather than the grain, total crop N removal assuming all stubble was removed from the paddock (baled or burnt) would have been closer to 420kg N/ha.

Nitrogen input and offtake calculation assumptions – 2020 NZ World Record

- Yield – 17.398t/ha with a grain protein content of 10.26% equivalent to grain N content of 1.8% N.

Offtakes

- N removed in grain = 17,398kg/ha at 1.8% N = 313 kg N/ha in grain*.
- In the crop canopy at harvest, if it is assumed that on average 75% of the N is in the harvested grain, there would be an additional 25% N content in the straw and chaff, therefore in total 313 kg N/ha (grain) x 1.333 = 417kg N/ha removed in crop (grain and straw).

N inputs

- The crop received 301kg/ha N (Flofert liquid Urea 18% N).
- Soil mineral N reserve (0-60 cm) at start of spring 46kg N/ha.
- Soil mineralisation under irrigation *assumed* to make up the residual 70kg N/ha.

(*Assumptions based on grain at 15% moisture).

At the beginning of spring 46kg N/ha was available in the soil based on a 0-60cm soil mineral N test with the assumption that the residual 70kg N/ha was supplied by the soil through soil mineralisation.

Therefore, while achieving the world record required more fertiliser than that typically applied to crops in lower yielding scenarios, the record yield was still dependent on the farming system and soil organic matter to supply the N to support such a large yield and crop canopy.

Similar findings have been observed in the GRDC Hyper Yielding Cereal project in Tasmania where high wheat yields were achieved in the absence of excessive N fertiliser applications (Figure 1). The results indicated that high yields were dependent on the fertility of the rotation and farming system. In effect, the soil fertility was being 'mined' to produce the high yields, rather than the additional applied fertiliser N in that growing season. In the research conducted from 2016 to 2019, attempting to apply all the N required for a 'hyper yield' resulted in failure.

Attempts to apply over 250kg N/ha as urea fertiliser have been unsuccessful in generating the highest yields in the Tasmanian project. In fact, since 2016 in the Tasmanian trial work optimum applied fertiliser N levels have rarely exceeded 200kg N/ha for the highest yielding crops, even though the crop canopies that these yields are dependent on are observed to remove far more than 250 – 370kg N at harvest.

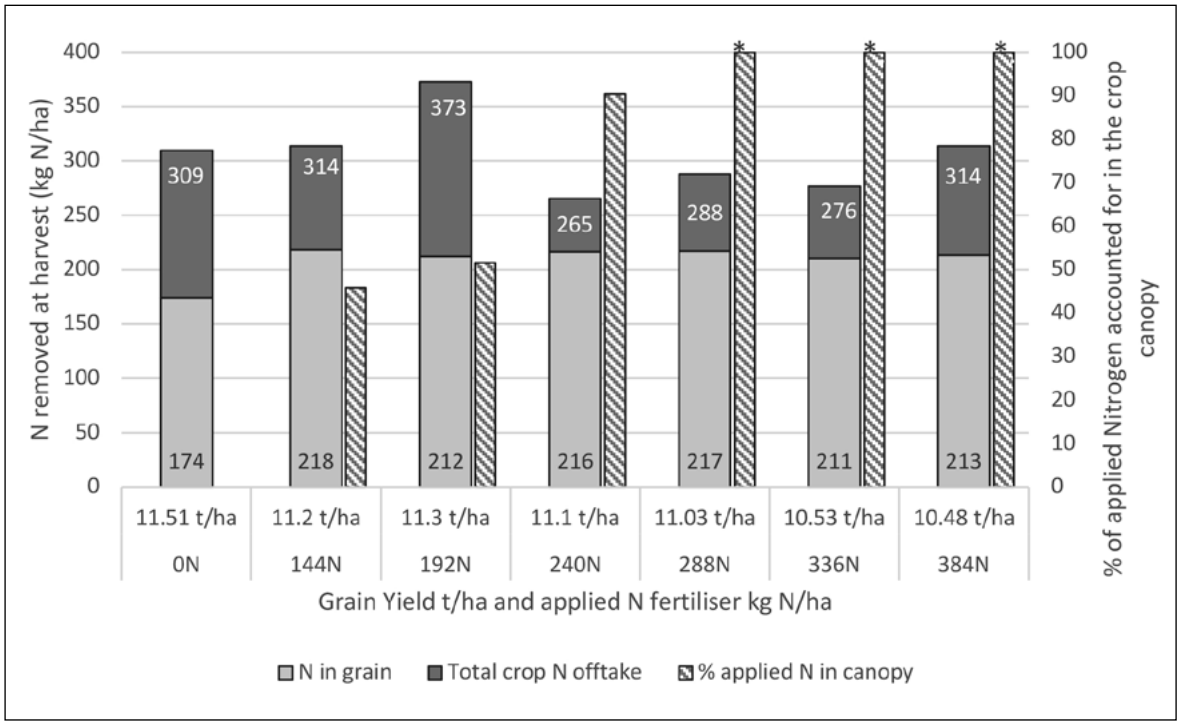


Figure 1. Nitrogen removed at harvest in both grain and total crop (kg/ha) and percentage of applied nitrogen accounted for in the final crop canopy at harvest – Hagley, Tasmania, Irrigated wheat RGT Relay 2019. Previous crop was poppies with a long history of lucerne a decade before.

n.b. * More nitrogen was applied to the crop than the total recovered in the canopy indicating that a proportion of the applied fertiliser N has been lost or left in the soil. Yields expressed at 12.5% moisture and N removal at 0% moisture.

In HYC nutrition trials just harvested in southern Victoria, attempts to push yields with N applications above 150kg N/ha have led to an increase in grain protein but not yield (Table 1). Again, N recovered in the grain would indicate that more N has been removed (grain and straw) than the crop would respond to in terms of applied N and its effect on yield.

An analysis of NIAB TAG trials on wheat from the UK suggested that high yielding crops were produced in paddock scenarios where if the crop in that paddock had been farmed with no nitrogen fertiliser it would have still produced a good yield. This was put forward to explain 'why the additional amounts of N required for very high yields in field trials is less than would logically be expected' (NIAB TAG 2018).

Nitrogen deficiency remains the single biggest factor contributing to the sizeable exploitable yield gap in Australian wheat production (Hochman and Horan 2018) yet applying more N has not necessarily removed this constraint even in leading farmers and favourable seasons (van Rees *et al.* 2014). Clearly, the fertility of farming systems and soil organic matter contents are lower in Australia than in the UK, however the HYC results show the fertility of the whole farming system is a key component to achieving high yields.

Disease management protects high yield potential

Disease management is one of the most important components of growing high yielding cereal crops in seasons with high yield potential. This is primarily a result of the growing season being typically longer, wetter and more disease prone than normal.

In HYC research in wheat it was found that three key timings for fungicide intervention were essential to protect the upper leaves of the canopy, capture the highest yields, and provide the highest economic returns; these were first node growth stage (GS) 31, flag leaf emergence GS39 and head emergence GS59. In barley two timings were essential; GS31 and awn tipping GS49. The introduction of new fungicides over the last five years has lifted our ability to secure a greater proportion of our yield potential in wet seasons conducive to foliar diseases.

Early harvested results in 2020 are already showing this in HYC. This also comes with a responsibility to protect our fungicides from the development of fungicide resistance and reduced sensitivity. One of the key measures we can adopt to slow down the development of fungicide resistance is to reduce the number of fungicide applications.

In HYC 2020 research trials, the objective has been to examine whether newer resistant or tolerant cultivars suitable for high yielding regions might allow us to delay fungicide intervention, and therefore, use less fungicide. If a cultivar has sufficient genetic resistance to suppress disease development it may be possible to delay fungicide application until flag leaf emergence. This will have two primary benefits; firstly, it will allow a much better appraisal of whether the seasonal conditions had the potential to support fungicide expenditure, and secondly, it may mean that a fungicide could be applied to all of the upper canopy leaves at the same time. In those seasons with a dry spring, it

Table 1. Detailed treatment list, grain yield (t/ha), % site mean and grain quality, protein (%), test weight (kg/HL) & screenings (%). Cv RGT Accroc$^{\phi}$, Gnarwarre, Victoria (HRZ region)

Trt.	Nutrition (kg/ha)	Yield (t/ha)		Protein %		Test Weight Kg/hl		Screenings %	
1	148 N kg/ha	10.14	ab	9.7	c	78.4	-	1.3	b
2	183 N kg/ha,								
	30 S kg/ha	10.29	a	10.2	b	78.4	-	1.4	b
3	183 N kg/ha	9.92	ab	10.4	b	78.0	-	1.4	b
4	217 N kg/ha,								
	45 S kg/ha	9.73	b	10.4	b	78.0	-	1.7	a
5	217 N kg/ha	9.91	ab	11.0	a	77.4	-	1.7	a
Mean		9.99		10.3		78.0		1.5	
LSD (p=0.05)		0.49		0.5		ns		0.2	
P Val		0.179		<0.001		0.829		0.005	

n.b. 22kg/ha of phosphorus applied to all treatments.
GSR - (April-November) 479mm (29mm above the long-term average).
Organic carbon 0 -10cm – 2.37%

means the flag leaf spray expenditure is cut back or removed altogether. However, the industry requires robust genetic resistance in our high yielding cultivars to make this a reality.

Results processed so far in HYC research in southern NSW (Table 2) and southern Victoria (Table 3) not only show the significant influence of disease management, but also the large differences in genetic resistance to disease. In a season with high yield potential and high disease pressure all cultivars produced a significant yield response to fungicide, but where cultivars had greater genetic resistance there was no additional benefit for the extra units of fungicide applied (where the flag leaf spray was based on a full rate azoxystrobin/epoxiconazole mixture (Radial® 840 ml/ha).

Table 2. Influence of fungicide strategy and cultivar on grain yield (t/ha) – HYC Wallendbeen, NSW.

	Disease management level					
	Untreated		1 Fungicide Unit (GS39)		4 Fungicide Units S.trt, GS31,39, 61	
Cultivar	Yield t/ha		Yield t/ha		Yield t/ha	
Trojan$^{\Phi}$ (spring)	2.28	n	7.55	hij	8.13	efg
Scepter$^{\Phi}$ (spring)*	7.07	kl	8.60	d	8.55	de
Nighthawk$^{\Phi}$ (facultative)	7.98	gh	8.47	def	8.54	de
Anapurna (winter)	9.69	c	10.22	b	10.46	ab
RGT Accroc (winter)	9.72	c	10.86	a	10.83	a
Beckom$^{\Phi}$ (spring)	7.75	ghi	8.46	def	8.66	d
Catapult$^{\Phi}$ (spring)	6.06	m	7.84	ghi	8.46	def
Gregory$^{\Phi}$ (spring)	6.75	l	7.15	jkl	7.40	ijk
Coolah$^{\Phi}$ (Spring)	7.26	jk	8.07	fg	8.75	d
DS Bennett$^{\Phi}$ (Winter)	5.68	m	8.75	d	9.48	c
LSD Cultivar p=0.05			0.26 t/ha		P val <0.001	
LSD Management p=0.05			0.28 t/ha		P val <0.001	
LSD Cultivar x Man. p=0.05			0.45 t/ha		P val <0.001	

**Scepter$^{\Phi}$ was unaffected by wheat powdery mildew at this site. Winter – winter wheat, Facultative – facultative wheat, Spring – spring wheat. Yield figures followed by the same letter are not considered to be statistically different (p=0.05). Plot yields: To compensate for edge effect a full row width (22.5cm) has been added to either side of the plot area (equal to plot centre to plot centre measurement in this case). All provisional results have been analysed through ARM software with further analysis when the final results are released.*

Table 3. Influence of fungicide strategy and cultivar on grain yield (t/ha) – HYC Gnarwarre, Vic.

	Disease management level					
	Untreated		1 Fungicide Unit (GS39)		4 Fungicide Units S.trt, GS31,39, 61	
Cultivar	Yield t/ha		Yield t/ha		Yield t/ha	
Trojan$^{\Phi}$ (spring)	2.14	p	2.90	o	8.97	d-g
Scepter$^{\Phi}$ (spring)	5.82	n	7.87	jkl	8.78	efg
Nighthawk$^{\Phi}$ (facultative)	7.21	m	7.60	lm	8.11	jk
Anapurna (winter)	8.30	hij	8.97	d-g	9.23	b-e
RGT Accroc (winter)	7.85	jkl	9.13	c-f	9.58	abc
RGT Calabro (winter)	7.67	klm	8.63	gh	8.95	efg
SFR 86-090 (winter)	5.94	n	9.15	c-f	9.82	a
Tabasco (winter)	7.67	klm	7.81	kl	8.11	ijk
SF Adagio (winter)	8.71	fgh	9.67	ab	9.44	a-d
Revenue$^{\Phi}$ (winter)	5.71	n	7.92	jkl	8.58	ghi
LSD Cultivar p = 0.05			0.27 t/ha		P val >0.001	
LSD Management p=0.05			0.18 t/ha		P val >0.001	
LSD Cultivar x Man. P=0.05			0.47 t/ha		P val >0.001	

Winter – winter wheat, Facultative – facultative wheat, Spring – spring wheat. Yield figures followed by the same letter are not considered to be statistically different (p=0.05). Plot yields: To compensate for edge effect a full row width (22.5cm) has been added to either side of the plot area (equal to plot centre to plot centre measurement in this case). All provisional results have been analysed through ARM software with further analysis when the final results are released.

Where susceptible cultivars require early fungicide application (e.g., early in stem elongation), it's imperative to adhere to sound practices to avoid the development of fungicide resistance. These include avoiding repeated use of the same active ingredients, and in the case of the newer Group 11 QoI (strobilurins) and Group 7 SDHIs, restricting fungicide strategies to just one application per season to slow down and prevent the selection of resistant strains.

Interested in hyper yielding crops?

If you are interested in getting involved in the project in south east SA then please get in touch with Jen Lillecrapp, your regional HYC Project Officer (Jen Lillecrapp <jen@brackenlea.com).

Acknowledgement

The research undertaken as part of these projects 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. FAR Australia gratefully acknowledges the support of all of its research and extension partners in the Hyper Yielding Crops project. These are CSIRO, the Department of Primary Industries and Regional Development (DPIRD) in WA, SA Research and Development Institute (SARDI), Brill Ag, Southern Farming Systems (SFS), Techcrop, the Centre for eResearch and Digital Innovation (CeRDI) at Federation University Australia, MacKillop Farm Management Group (MFMG), Riverine Plains Inc and Stirling to Coast Farmers.

Contact details

Nick Poole
Shed 2/63 Holder Rd, Bannockburn, Victoria 3331
03 5265 1290; 0499 888 066
nick.poole@faraustralia.com.au

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

Return to contents

Notes

Notes

Foliar pulse disease seasonal update for 2020 in South Australia

Sara Blake[1], Mohsen Khani[1], Penny Roberts[2], Sarah Day[2], Margaret Evans[1], Amanda Pearce[3] and Jenny Davidson[1].

[1]South Australian Research and Development Institute (SARDI), Plant Research Centre, Urrbrae, SA; [2]South Australian Research and Development Institute (SARDI), Clare, SA; 3South Australian Research and Development Institute (SARDI), Struan, SA.

GRDC project codes: CUR00023, UA2007-006RTX, UA2007-002RTX, DAV00150.

Keywords

- lentil, faba bean, chickpea, field pea, disease, fungicide, resistance changes.

Take home messages

- Two new chickpea varieties were released in 2020; CBA Captain$^{\phi}$ and PBA Magnus$^{\phi}$, they are rated susceptible (S) and moderately susceptible (MS) to ascochyta blight (AB), respectively.
- There were no changes to AB for lentil or faba bean for 2020. Two pathotypes of each pathogen are recognised and growers are advised to monitor closely for infection and manage disease proactively.
- Two new lentil varieties are available for 2021. GIA Leader$^{\phi}$ has provisional ratings of resistant to moderately resistant (RMR) to both AB pathotypes and moderately resistant (MR) to botrytis grey mould (BGM). PBA Kelpie XT$^{\phi}$ has a moderately resistant to moderately susceptible (MRMS) rating to both AB pathotypes and a RMR rating to BGM.
- SARDI annual testing of *Ascochyta lentis* isolates in 2020 included the highly resistant newly released variety PBA Highland XT$^{\phi}$ for the first time. Of the 20 isolates tested, that were collected in 2019, 25% of these were able to infect PBA Highland XT$^{\phi}$ indicating that there are isolates present in the pathogen population that can overcome the variety's resistance. All (100%) of the tested isolates infected PBA Hurricane XT$^{\phi}$.
- In a trial at Bool Lagoon, PBA Amberley$^{\phi}$ had less chocolate spot (CS) than both PBA Kareema$^{\phi}$ and PBA Bendoc$^{\phi}$. Multiple fungicide applications significantly reduced disease severity particularly in PBA Bendoc$^{\phi}$ and PBA Kareema$^{\phi}$.

Pulse disease seasonal update for 2020 - diagnostics and surveillance

Despite generally good opening rains and average spring rainfall for most South Australian regions, the dry conditions in June and July contributed to low levels of disease across most regions and crops.

SARDI Pulse Pathology received 78 plant samples for disease diagnosis from lentil, faba bean, chickpea, field pea, lupin, vetch and canola crops. Over 40% (33 of 78) had no disease and symptoms were attributed to abiotic causes (for example, weather or chemical damage). The main disease diagnosis was AB in seven (9%) samples. Other primary foliar diseases diagnosed included chocolate spot (CS) and cercospora leaf spot (CLS) in faba bean, and sclerotinia in lupin. Twenty-two specimens (28%) were also assessed for root disease (refer Blake Gontar's 2021 Adelaide GRDC

Grains Research Update paper included within proceedings). Virus testing in some of the pulse specimens also identified cucumber mosaic virus (CMV) in lentil and lupin, alfafa mosaic virus (AMV) and bean leaf roll virus (BLRV) in lentil as well as turnip yellows virus (TuYV) in lentil, faba bean and chickpea.

Disease surveillance

A survey of 40 pulse crops across the major growing regions in South Australia (SA) for endemic and notifiable exotic diseases was conducted in spring 2020. Crops were selected with assistance from regional agronomists and represent proportional crop type per region. One hundred plants per paddock were sampled and whole plant percent disease severity rated. Results reflect the fungicide regimes and seasonal conditions. Overall, there was a low level of disease in all crop types, with some regional differences, likely due to the 2020 winter being drier than average for most regions. No sclerotinia or notifiable exotic diseases were found in the paddocks surveyed.

In the 11 **chickpea** paddocks surveyed, 55% of crops were infected with AB but at very low severity (2% or less) and the number of plants per crop with AB lesions (i.e. disease incidence per crop) ranged between 1-44%. Botrytis grey mould was identified in only one crop, which was on the Yorke Peninsula, but severity was almost zero (0.002%) and the disease incidence was also very low (1%).

Of the **lentil** crops surveyed on the Yorke Peninsula, 30% of crops were infected with AB but at very low severity (less than 1% plant area diseased) and the disease incidence per crop was also very low (ranging from 3-4%). Two crops showed BGM symptoms at a very low severity (4.3-5.7%), although disease incidence was high at 83-88% in those two crops.

In the nine **faba bean** paddocks surveyed, 56% were infected with AB but at very low severity (2% or less) and the disease incidence, ranging from 3-12%, was also low. Forty-four per cent of crops were infected with CS, ranging in severity between 0.6 to 53.9%, and disease incidence was high at 49-100% in those crops. All surveyed crops in the South East region of SA were infected with CS. No CLS was detected, possibly due to the timing of survey.

In the 10 **field pea** paddocks surveyed, 100% were infected with AB with plant severity ranging between 15-58%. Severe downy mildew had been reported widely across the state in seedling crops early in the season, and in the spring survey, 4 of 10 crops were infected but at a very low severity (0.02-1.6%) with 1-50% disease incidence. Warm spring conditions likely restrained downy mildew. No bacterial blight, BGM or sclerotinia were detected in these crops.

Ascochyta blight in chickpea, lentil and faba bean - fungicide trials, variety trials, and pathogenicity testing

Chickpea

All current commercial varieties of chickpea are rated MS or S to AB. This includes two new releases in 2020; CBA Captain$^{\phi}$ rated S to AB, and PBA Magnus$^{\phi}$ rated MS to AB.

Economic management strategies in chickpea to control ascochyta blight and maximise yield

Ascochyta blight in chickpea causes large grain yield loss and therefore economic losses due to cost of treatment and reduced yield. Two replicated split plot trials at Kingsford were sown on the 6 June with the aim of measuring yield loss from AB in commercial varieties and advanced breeding lines of chickpea in order to determine fungicide management strategies. A variety trial was sown to six varieties and three advanced breeding lines and received three fungicide treatments (Table 1). A separate fungicide trial was sown to two varieties (Howzat, Genesis™090) and one advanced breeding line (CICA1454) and received five fungicide treatments (Table 2). A fungicide program to maximise disease control to ensure no disease developed commenced on 14 July. Trials were inoculated with AB infested stubble six weeks after sowing. Disease was assessed on 15 October as % plot severity during podding. Grain yield was not available at the time of publication.

The maximise disease control treatment achieved disease freedom in all varieties at both trials to provide a yield loss comparison (Table 1 and 2). In the unsprayed plots of the variety trial, the lowest disease scores were in CICA1454, Genesis™090 and PBA Royal$^{\phi}$ (11.3 – 13.8% plot severity). CBA Captain$^{\phi}$ (22.5% plot severity) had statistically similar disease levels to Genesis™090 and PBA Royal$^{\phi}$, but more than CICA1454. Highest disease scores were in Howzat, PBA Monarch$^{\phi}$ and PBA Magnus$^{\phi}$ ranging from 58.5 to 81.3% plot severity (Table 1). Veritas® fungicide sprays reduced disease to one or two thirds of that in unsprayed plots so that plot disease severity ranged from 3.3% in the less susceptible lines up to 45-50% in the more susceptible lines (Table 1). Unsprayed plots of each variety had significantly less yield than disease free plots except for CICA 1454 in which yields were similar for the three different treatments. Most of the varieties

had less than 14% plot severity when treated with 4 sprays of Veritas® and achieved similar yield to the disease free plots. However, two susceptible varieties, PBA Monarch and Howzat, had 45-50% plot severity when treated with Veritas® and yields were significantly lower than the disease free plots.

In the fungicide trial, all treatments reduced disease to less than 4% plot severity in the moderately susceptible Genesis™090 and in CICA1454 (Table 2). However, in the very susceptible Howzat, disease severity was significantly lower in the plots treated with Miravis Star® (registration pending) (5.5% plot severity) compared to those treated with Veritas® or Aviator XPro® (20.8 and 24.3% plot severity respectively). While Miravis Star® treated plots showed an increase in yield compared to the other strategic fungicides, the increase was not significant in this trial. Nevertheless, there was a strong correlation (r2 = 0.9) between disease severity and yield for Howzat and Genesis090

Faba bean and lentil

Ascochyta blight disease management trials were established in low, medium and high rainfall zones at Port Broughton, Maitland and Riverton, respectively. The aim was to determine the potential yield loss in faba bean and lentil associated with the new resistance breaking isolates of each pathogen, *Ascochyta fabae* and *A. lentis*, respectively. Maitland and Riverton were sown on 26 May and Port Broughton was sown on 14 May. Varieties and their AB resistance categories included in the trial are shown in Tables 3 and 4. Ratings were current at the time of trial inoculation but may have since changed subsequent to the NVT Pulse Disease project ratings review. The trials were sown as a replicated split block, with fungicide as the main block and varieties randomised within each block. Two treatments were included in the trials *viz*. (1) Fungicide program to maximise disease control to ensure no disease developed or (2) no fungicide.

Table 1. Mean ascochyta blight disease (% plot severity) in Kingsford chickpea variety trial.

Variety	Rating	Disease free*		Strategic Veritas®		Nil fungicide	
		% plot severity	Yield (t/ha)	% plot severity	Yield (t/ha)	% plot severity	Yield (t/ha)
Howzat	S	0.0 a	2.42	50 hi	1.19	81.3 k	0.30
PBA Monarch(Ф)	S	0.0 a	1.99	45 h	1.11	72.5 jk	0.25
CICA1352 (PBA Magnus(Ф))	MS	0.0 a	1.69	10.8 de	1.42	58.8 ij	0.55
PBA Striker(Ф)	S	0.0 a	2.38	13.8 ef	2.03	42.5 hi	0.78
PBA Slasher(Ф)	S	0.0 a	2.38	9.3 cde	2.28	26.3 g	0.93
CICA1521 (CBA Captain(Ф))	S	0.0 a	2.26	6.3 bcd	2.17	22.5 fg	1.33
Genesis™090	MS	0.0 a	1.93	4.3 bc	2.04	13.8 ef	0.84
PBA Royal(Ф)	MS	0.0 a	1.62	3.3 b	1.67	13.8 ef	0.73
CICA 1454	-	0.0 a	1.92	3.8 bc	1.96	11.3 de	1.45

Different letters represent significant difference (p<0.001)

** Fungicide program to maximise disease control to ensure no disease developed.*

Table 2. Mean ascochyta blight disease (% plot severity) in Kingsford chickpea fungicide trial.

Treatment	Rate of fungicide application (l/ha)	Howzat		Genesis™090		CICA1454	
		% plot severity	Yield (t/ha)	% plot severity	Yield (t/ha)	% plot severity	Yield (t/ha)
Nil	0	67.5 h	0.26	14.3 ef	0.86	7.5 de	1.51
Strategic Veritas®	1L/ha	20.8 fg	1.56	3.8 bcd	1.47	1.8 bc	1.57
Strategic Aviator XPro®	600 mL/ha	24.3 g	1.49	3.8 bcd	1.61	3 bcd	1.87
Strategic Miravis Star®#	600 mL/ha	5.5 cd	1.91	2.5 bcd	1.71	1 ab	1.85
Disease free*	-	0 a	2.40	0 a	1.88	0 ab	2.23

Different letters represent significant difference (p<0.001)

#registration pending for June 2021.

** Fungicide program to maximise disease control to ensure no disease developed.*

Unsprayed plots were inoculated with a mixed spore suspension of six different pathotype 2 isolates of *A. fabae* and nine different pathotype 2 isolates of *A. lentis*, all collected from SA. Pathotype 2 of *A. fabae* is widespread in the southern growing region and is virulent on the faba bean, Farah$^{\Phi}$ and a range of other varieties. Pathotype 2 of *A. lentis* is common in lentil growing areas of SA and is virulent on previously resistant varieties including PBA Hurricane XT$^{\Phi}$ and a range of other varieties. Plants were inoculated on three separate occasions (2 July, 22 July and 18 August) in overcast conditions ahead of a rain front to be conducive to infection. Percent disease per plot of each trial was rated on 1 September. All trials were harvested at maturity. Grain yield was not available at the time of publication.

Low to average rainfall conditions occurred in May and June, and July was extremely dry, limiting disease infection and spread. Rainfall was average in August and September allowing a low to moderate level of disease to establish at Maitland and Riverton trials. Higher than average rainfall occurred in October when plants were maturing but seed infection levels were not available at the time of publication.

Results for faba bean trials

Moderate levels of disease established in the Maitland and Riverton trials but very little in the low rainfall trial at Port Broughton. The three-way interaction between site x fungicide x variety for disease severity assessed on 1 September was not significant but there were significant differences (P<0.001) between varieties for disease severity which was consistent across sites (Table 3). The two-way interaction for site x fungicide treatment was also significant (P<0.001). The maximum control treatment across the three sites had zero disease (data not shown) while disease severity in untreated plots ranged from an average of 2.4% plot severity at the low rainfall site to an average of 8.3% plot severity at the high rainfall site. Highest disease severity was recorded in untreated plots of the S variety Farah$^{\Phi}$ (16.7% plot severity) and the MRMS variety PBA Marne$^{\Phi}$ (11.7% plot severity) at Riverton. In the other varieties the disease severity averaged across sites and fungicide treatments ranged from 2.7% to 1.3% plot severity. The sites and varieties significantly differed in yield, but fungicide treatments did not affect yield at any of the sites.

Ascochyta blight resistance ratings and pathogenicity testing on faba bean

There are no changes to AB disease ratings for faba bean varieties for 2020 however isolate pathogenicity testing in controlled environment conditions on a differential host set was not conducted for faba bean this season. The last examination of the *A. fabae* population in 2019 of 2018-collected isolates indicated a possible third pathotype emerging in the population that is aggressive on PBA Samira$^{\Phi}$ (Blake *et al.* 2020). PBA Amberley$^{\Phi}$, PBA Bendoc$^{\Phi}$ and PBA Marne$^{\Phi}$ have not been assessed against a suite of current isolates in this manner. Continued monitoring will be critical to confirm if any further shifts are occurring in the pathogen population.

Results for lentil trials

A moderate level of AB disease established in the trials at Maitland and Riverton but very little in the low rainfall site at Port Broughton. The three-way interaction for site x variety x fungicide treatment was significant (P=0.03) for disease severity. All plots treated for maximum control across the three sites had zero disease (data not shown). In the plots with no fungicide, most disease (18.3% plot severity) was recorded at the high rainfall site (Riverton) on the

Table 3. Ascochyta blight disease severity (% plot disease severity) and yield (tonnes/ha) in untreated (nil fungicide) faba bean plots trials at three sites in South Australia 2020 incorporating six varieties.

Variety	Pathotype 2 AB rating	Site					
		Port Broughton		Maitland		Riverton	
		% plot severity	Yield (t/ha)	% plot severity	Yield (t/ha)	% plot severity	Yield (t/ha)
Farah$^{\Phi}$	(S)	5.00 f	0.47 ab	8.30 i	4.14 de	16.70 k	3.60 c
PBA Marne$^{\Phi}$	(MRMS)	3.30 e	0.35 a	7.70 h	3.96 cd	11.70 j	4.16 de
PBA Samira$^{\Phi}$	(MR-R)	2.30 c	0.50 ab	5.00 f	4.39 ef	6.00 g	4.63 fg
Nura$^{\Phi}$	(MR-R)	1.00 b	0.45 ab	2.70 d	4.59 fg	7.70 h	4.19 de
PBA Amberley$^{\Phi}$	(MR-R)	0.30 a	0.75 b	2.00 c	4.65 fg	5.30 f	4.39 ef
PBA Zahra$^{\Phi}$	(MRMS)	2.70 d	0.55 ab	1.30 b	4.81 gh	2.70 d	5.08 h
Average per site		2.40 a	0.51 a	4.50 b	4.42 b	8.35 c	4.34 b

Different letters represent significant difference (P<0.001) for site x variety.

Table 4. Ascochyta blight disease severity (% plot disease severity) and yield (tonnes/ha) in untreated (nil fungicide) plots in lentil trials at three sites in South Australia 2020 incorporating six varieties.

Variety	Pathotype 2 AB rating	Site					
		Port Broughton		Maitland		Riverton	
		% plot severity	Yield (t/ha)	% plot severity	Yield (t/ha)	% plot severity	Yield (t/ha)
PBA Flash$^{\phi}$	(MS)	5.30 def	0.65 a	8.70 ef	3.76 b	18.30 g	3.35 b
PBA Hallmark XT$^{\phi}$	(MRMS)	5.00 def	0.72 a	7.70 ef	3.47 ab	9.30 ef	2.92 a
PBA Hurricane XT$^{\phi}$	(MRMS)	4.00cde	0.68 a	3.30 cde	3.57 abc	7.00 ef	3.60 b
PBA Highland XT$^{\phi}$	(MR)	1.70 bc	0.85 a	0.00 a	3.74 b	3.70 cde	3.97 c
PBA Ace$^{\phi}$	(R)	2.70 cde	0.66 a	1.00 ab	3.44 a	1.70 bc	3.97 c
PBA Jumbo2$^{\phi}$	(R)	0.30 ab	0.79 a	0.30 ab	3.98 bc	2.00 bc	4.07 c
Average per site		3.17 a	0.73 a	3.50 b	3.66 b	7.00 c	3.65 b

Different letters represent significant difference (p<0.001) for site x treatment x variety.

MS variety PBA Flash$^{\phi}$. Medium levels of disease (5 - 9.3% plot severity) were recorded at the medium (Maitland) and high (Riverton) rainfall sites on the MRMS varieties viz. PBA Hurricane XT$^{\phi}$ and PBA Hallmark XT$^{\phi}$, and on PBA Flash$^{\phi}$ at the low rainfall site (Port Broughton). The moderately resistant and resistant varieties (PBA Ace$^{\phi}$, PBA Highland XT$^{\phi}$ and PBA Jumbo2$^{\phi}$) had zero to low disease levels (3.7% plot severity) at all three sites (Table 4). The sites and varieties significantly differed in yield, but fungicide treatments did not affect yield at any of the sites.

Annual pathogenicity testing of Ascochyta lentis on lentil

SARDI's annual testing of A. lentis isolates on lentil hosts included the 2019-released lentil variety PBA Highland XT$^{\phi}$ for the first time, in place of elite line Indianhead. PBA Highland XT$^{\phi}$ is rated MR to both pathotype 1 and 2 of AB and is likely to be widely sown across SA in 2021. Due to the dry season and lower AB disease pressure in 2019, fewer isolates were collected in the 2019 season thus less isolates were available for controlled environment testing in 2020.

In 2020, twenty isolates of *A. lentis* collected each in 2018 and in 2019 from lentil field trials and commercial crops (36 from SA, 4 from Victoria; n=40) were tested in controlled environment conditions on a differential host set that included Nipper$^{\phi}$, PBA Hurricane XT$^{\phi}$ and PBA Highland XT$^{\phi}$ (Tables 5a and 5b). Of the isolates tested, 5 of 20 (25%) collected in 2018 and 7 of 20 (35%) collected in 2019, were capable of infecting PBA Highland XT$^{\phi}$ at a low level. This indicates that isolates exist that can overcome the resistance in PBA Highland XT$^{\phi}$. These isolates may become selected for over time in intensive lentil cropping systems and presents a risk of resistance ratings being downgraded in the future. PBA Hurricane XT$^{\phi}$ was infected by all 2019-collected isolates at a low to high level in this test, confirming that the MRMS rating in SA is under threat. The number of isolates capable of infecting PBA Hurricane XT$^{\phi}$ has steadily increased since first tested from 28% in 2016, 50% in 2018 and 67.5% in 2019 (Blake *et al.* 2020; Blake *et al.* 2019a, Blake *et al.* 2019b, Blake *et al.* 2017). The elite line ILL7537, a source of resistance used in the breeding program, remains resistant to all isolates tested.

Table 5a. Twenty *Ascochyta lentis* isolates collected in 2018 were inoculated onto a lentil host differential set in controlled environment conditions in 2020. Entries in the table are the number of isolates per category.

Test reaction	Cumra (susceptible check)	Nipper$^{\phi}$	PBA Hurricane XT$^{\phi}$	PBA Highland XT$^{\phi}$	ILL7537 (resistant line)
R	0	4	7	15	20
MR	0	9	2	3	0
MRMS	4	3	7	2	0
MS	8	2	3	0	0
S	8	2	1	0	0

Note: R = resistant, MR=moderately resistant, MRMS = moderately resistant-moderately susceptible, MS = moderately susceptible; S = susceptible

Table 5b. Twenty *Ascochyta lentis* isolates collected in 2019 were inoculated onto a lentil host differential set in controlled environment conditions in 2020. Entries in the table are the number of isolates per category.

Test reaction	Cumra (susceptible check)	Nipper$^{\phi}$	PBA Hurricane XT$^{\phi}$	PBA Highland XT$^{\phi}$	ILL7537 (resistant line)
R	0	5	0	13	20
MR	0	10	2	7	0
MRMS	3	5	7	0	0
MS	8	0	10	0	0
S	9	0	1	0	0

Note: R = resistant, MR=moderately resistant, MRMS = moderately resistant-moderately susceptible, MS = moderately susceptible; S = susceptible

The newly released lentil variety, GIA Leader$^{\phi}$, has been released with a provisional rating of RMR to foliar AB in SA and has shown excellent resistance to both the Nipper-virulent (pathotype 1) and Hurricane-virulent (pathotype 2) strains in controlled environment testing (tested as GIA1701L). The other new lentil release, PBA Kelpie XT$^{\phi}$, has been released with a provisional rating of MRMS to both pathotypes of foliar AB in SA. However, ratings for both varieties may be subject to change when more data becomes available. Growers should monitor for AB and if infection is present, plan to spray ahead of rain fronts at podding to protect the developing seed.

Faba bean foliar disease - chocolate spot (CS) and cercospora leaf spot (CLS)

Chocolate spot management to maximise yield in PBA Amberley$^{\phi}$

Chocolate spot (causal pathogen *Botrytis fabae*) in faba and broad beans can cause large grain yield loss. PBA Amberley$^{\phi}$, released in 2019, is recognised as having some level of resistance to CS and fewer fungicide applications may be required than currently used. To quantify the grain yield losses caused by CS and CLS in PBA Amberley$^{\phi}$ compared to other varieties, and to develop an economic fungicide regime for this variety, a trial was conducted at both Bool Lagoon and Yeelanna. Each replicated block trial was sown to three varieties with different reactions to CS and received four fungicide treatments as follows; (1) nil, (2) minimum = tebuconazole (350mL/ha) six weeks after sowing (WAS), (3) low cost = tebuconazole six WAS and at early flowering, and (4) standard = tebuconazole six WAS plus carbendazim (500mL/ha) at early flowering plus additional sprays of carbendazim or procymidone (500mL/ha) ahead of spring rain fronts (four additional sprays at Bool Lagoon and two additional sprays at Yeelanna). Disease was assessed three times at Bool Lagoon as % plot severity and analysed using Repeated Measures ANOVA (Table 6). The trial was harvested at maturity and grain yield of each plot calculated.

Extensive CS developed at Bool Lagoon, but no disease developed at Yeelanna, most likely due to higher rainfall at the former site, which enabled disease infection and spread. In the nil fungicide treatment, PBA Amberley$^{\phi}$ has less disease than both PBA Kareema$^{\phi}$ and PBA Bendoc$^{\phi}$ in the first two assessments (Table 6). By the third disease assessment, the standard fungicide treatment had significantly reduced disease severity in PBA Amberley$^{\phi}$ compared to the nil fungicide. No other treatments reduced disease severity in this variety. The standard treatment significantly reduced disease severity in PBA Kareema$^{\phi}$ compared to nil fungicide in all three assessments, while the low-cost treatment (two tebuconazole sprays) also reduced disease below the nil treatment but only in the first assessment. In PBA Bendoc$^{\phi}$ all three fungicide treatments reduced disease compared to nil fungicide in the first assessment, while in the second assessment the standard and low-cost treatments significantly reduced disease but the minimum treatment (tebuconazole at six WAS) was ineffective at this stage. By the third assessment there were no significant differences in disease across the treatments for PBA Bendoc$^{\phi}$. In the repeated measures analysis, averaged across the three assessments, the standard treatment significantly reduced disease severity below the nil treatment in all three varieties. The low-cost treatment also significantly reduced disease in PBA Bendoc$^{\phi}$. PBA Amberley$^{\phi}$ grain yield was higher than other two varieties; PBA Bendoc$^{\phi}$ and PBA Kareema$^{\phi}$. The grain yield of PBA Amberley treated with the standard fungicide treatment was significantly greater than nil or minimum treatments. PBA Amberley benefits from fungicide sprays despite having less chocolate spot disease

Table 6. Chocolate spot disease severity assessed at Bool Lagoon 2020*

Variety	CS disease rating	Treatment	% plot severity Individual Analysis of Variance per assessment			% plot severity Repeated Measures ANOVA	Yield (t/ha)
			23 Sept	13 Oct	27 Oct	3 assessments	
PBA Amberley$^{\Phi}$	MR#	Standard	1.70 a	4.20 a	28.30 a	11.40 a	4.64 f
		Low cost	2.00 ab	9.30 ab	46.70 bcd	19.30 bc	5.06 g
		Minimum	2.30 ab	8.00 ab	38.30 abc	16.20 ab	4.05 de
		Nil fungicide	3.30 abc	10.50 ab	47.30 bcd	20.40 bc	4.13 e
PBA Kareema$^{\Phi}$	MS	Standard	3.70 abc	10.80 ab	34.00 ab	16.20 ab	3.69 bcd
		Low cost	4.00 bc	13.80 bc	46.70 bcd	21.50 bcd	3.47 bc
		Minimum	6.50 de	13.30 bc	45.00 bcd	21.60 bcd	3.74 cde
		Nil fungicide	7.70 e	20.80 cd	50.00 cd	26.20 de	3.80 cde
PBA Bendoc$^{\Phi}$	S	Standard	3.30 abc	15.00 bc	50.00 cd	22.80 cde	3.28 ab
		Low cost	5.20 cd	20.00 cd	55.00 d	26.70 de	3.43 bc
		Minimum	5.00 cd	25.80 de	51.70 d	27.50 ef	2.98 a
		Nil fungicide	10.00 f	30.80 e	56.70 d	32.50 f	3.48 bc
Lsd (p<0.001)			2.20	8.10	13.40	5.60	0.43

 # provisional rating

**Different letters represent significant differences.*

Cercospora leaf spot in faba bean

All current commercial varieties of faba bean are susceptible to CLS and this disease developed in the CS trial at Bool Lagoon. Disease severity of CLS was assessed in late September. In the unsprayed plots PBA Kareema$^{\Phi}$ had significantly more CLS than the other two varieties. The low cost and standard treatments in PBA Kareema$^{\Phi}$ and PBA Amberley$^{\Phi}$ had less CLS than the untreated and minimum treatments, while CLS severity did not vary in the PBA Bendoc$^{\Phi}$ plots (Table 7).

A helpful guide for growers and agronomists to identify common faba bean diseases can be found here: http://communities.grdc.com.au/field-crop-diseases/spot-the-difference-identifying-faba-bean-diseases/. Correct identification is important as different fungicides are used to manage different fungal disease.

Concluding remarks and recommendations

Foliar disease control in pulses is determined by varietal responses, seasonal conditions and inoculum load. In a dry season, AB in lentil and faba bean may not be yield limiting and fungicides may not be required. For AB in chickpea, fungicide products are best chosen based on their efficacy with application timed ahead of rain fronts. For CS in faba bean, PBA Amberley is less susceptible than other commercially available cultivars but fungicide sprays may still be required to control the disease. To prevent loss of cultivar resistance and avoid the selection of more aggressive or virulent isolates, growers are recommended to follow integrated disease management best practice. This includes observing a minimum of 3 years between crops of the same type, to rotate cultivars where possible, and to be judicious with fungicide use. Growers and advisors are encouraged to monitor crops closely

Table 7. Cercospora leaf spot severity assessed at Bool Lagoon

Variety	Treatment			
	Standard	Low cost	Minimum	Nil
PBA Amberley$^{\Phi}$	4.3 a	4.3 a	9.3 bc	10.0 bc
PBA Kareema$^{\Phi}$	5.0 a	8.3 ab	6.5 c	13.3 d
PBA Bendoc$^{\Phi}$	6.0 ab	6.0 ab	8.3 ab	9.3 bc
Lsd (p<0.007) = 4.1				

**Different letters represent significant difference*

Note: Tebuconazole is registered for the control of cercospora leaf spot in faba bean at 145 mL/ha.

for signs of disease and to report observations to pathologists.

Disease samples of ascochyta blight and sclerotinia sought

Diseased samples of pulses with ascochyta blight or sclerotinia are sought by SARDI for GRDC-investment projects monitoring pathogen populations and changes in variety resistance. If you can help, please contact Sara Blake (email: sara.blake@sa.gov.au) for a collection kit that includes sample envelopes and a return Express Post envelope.

Diagnostic plant samples can be sent by Express Post to Pulse Pathology Plant Diagnostics SARDI, Locked Bag 100, Glen Osmond, 5064. Dig up whole symptomatic and asymptomatic plants and send with roots wrapped in damp (not wet) paper towel. Send at the beginning of the week, so the parcel does not get held up in the post. Send an email to PIRSA.SARDIPulsepathology@sa.gov.au to notify team that the plants are coming.

Crop protection products

There are often changes to permits for the use of fungicides in pulse crops. See Pulse Australia's website (www.pulseaus.com.au) or APVMA's website (www.apvma.gov.au) for current information on Crop Protection Products including Minor Use Permits,

Acknowledgements

The research undertaken as part of these projects 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 continued assistance in trial management from SARDI Agronomy groups at Clare, Struan and Port Lincoln is gratefully acknowledged and appreciated as is the assistance from SARDI Pulse and Cereal Plant Pathology groups. The assistance of regional agronomists and growers in conducting the crop survey is gratefully acknowledged.

Useful resources

Seasonal disease reports Subscribe to SA CropWatch e-newsletter http://pir.sa.gov.au/research/services/reports_and_newsletters/crop_watch

GRDC GrowNotes:

- Chickpea: https://grdc.com.au/resources-and-publications/grownotes/crop-agronomy/chickpea-southern-region-grownotes
- Faba bean: https://grdc.com.au/resources-and-publications/grownotes/crop-agronomy/faba-bean-southern-region-grownotes
- Field Pea: https://grdc.com.au/resources-and-publications/grownotes/crop-agronomy/field-pea-southern-region-grownotes
- Lentil: https://grdc.com.au/resources-and-publications/grownotes/crop-agronomy/lentil-southern-region-grownotes

2021 SA sowing guide: https://grdc.com.au/resources-and-publications/all-publications/publications/2020/2021-south-australian-crop-sowing-guide

New pulse variety releases:

CBA Captain$^{\phi}$ chickpea:

https://www.pbseeds.com.au/docs/CBA%20Captain%20key%20advantages%20Victoria.pdf

PBA Magnus$^{\phi}$ chickpea:

https://www.pbseeds.com.au/docs/PBA%20Magnus%20kabuli%20chickpea%20brochure.pdf

PBA Kelpie XT$^{\phi}$ lentil:

https://www.seednet.com.au/sites/seednet/files/2020-11/documents/PBA-KelpieXT-lentil-Nov2020.pdf

GIA Leader$^{\phi}$ lentil: http://grainsinnovation.com/

GIA Ourstar$^{\phi}$ field pea:

http://grainsinnovation.com/wp-content/uploads/2020/12/OURSTAR-AND-KASTAR-brochure-AUG-21.pdf

GIA Kastar$^{\phi}$ field pea:

http://grainsinnovation.com/wp-content/uploads/2020/12/OURSTAR-AND-KASTAR-brochure-AUG-21.pdf

References

Blake S, Kimber R, Day S, McMurray L, Brand J, Paull J, Davidson J (2017) Pulse diseases 2016. GRDC Update, Adelaide, 7-8 February 2017. pp89-95 https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2017/02/pulse-diseases-2016

Blake S, Farqharson L, Walela C, Hobson K, Kimber R, Davidson J (2019a) Ascochyta blight in intensive cropping of pulses, GRDC Update, Adelaide, 12-13 February 2019 https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2019/02/ascochyta-blight-in-intensive-cropping-of-pulses

Blake S, Rose J, Roberts P, Day S, Hobson K, Davidson J (2019b) In-Season Pulse Disease Update, Hart Field Day Guide, 17 September 2019, pp70-78

Blake S, Fanning J, Roberts P, Pearce A, Khani M, Davidson J (2020) The pulse health report -2019 pulse disease seasonal update and National Variety Trial (NVT) disease ratings. GRDC Update, Adelaide, 11-12 February 2020 https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2020/02/the-pulse-health-report-2019-pulse-disease-seasonal-update-and-national-variety-trial-nvt-disease-ratings

Contact details

Sara Blake
GPO Box 397, Adelaide SA 5001
08 8429 2248
sara.blake@sa.gov.au
@Sara_N_Blake

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

Return to contents

Notes

Root disease in pulses – cause of poor performance?

Blake Gontar, Tara Garrard, Kelly Hill, Steve Barnett, Entesar Abood and Alan Mckay.

South Australian Research and Development Institute, Adelaide..

GRDC project code: DJP1907-002RMX

Keywords

- pulse root disease, *Fusarium, Phytophthora, Phoma, Pythium, Aphanomyces*, lentil, faba bean.

Take home messages

- Root disease is common in pulses and appears to be causing varying levels of yield loss.
- Five hundred and thirty-three pulse root survey samples were assessed in 2020, building on previous work. *Pythium* spp., root lesion nematode, *Phoma pinodella* and *Rhizoctonia solani* AG8 are common across a range of pulses.
- Less common but potentially more damaging *Aphanomyces* and *Phytophthora* spp. continue to be detected; these are found across Australia but only infrequently at this stage.
- Partial control of root disease in field trials in 2020 corresponded with yield increases of up to 0.62t/ha. Pulse root diseases are likely to be having significant yield impacts across Australia.

Introduction

Australian growers are increasingly incorporating legumes into rotations for benefits such as nitrogen fixation, broadleaf weed control and disease break effects. More recently, high prices for food legumes such as lentil and faba bean have driven high frequency (e.g., wheat-lentil rotation) pulse cropping. However, despite an eagerness to grow more legumes, growers remain wary, with poor performance and occasional crop failure a concern.

Poor performance of pulses is likely due to multiple factors. Many obvious above-ground issues have been resolved through resistance breeding and the development of insecticide and fungicide strategies and products. However, unexplained poor performance continues to be a frequently reported issue. Increasingly, soil abiotic and biotic constraints are being investigated as the cause of poor performance.

International experience, particularly in North America and Europe, indicates that as pulse cropping frequency increases, soilborne pathogens build up and can cause substantial reductions in yield. Priority targets for international research include *Aphanomyces euteiches, Fusarium* spp., *Phoma pinodella* and *Phytophthora* spp.

This paper summarises the findings of surveys of pulse roots diseases (three years in South Australia (SA) and two years nationally) and preliminary results of yield loss trials conducted in 2020.

Detecting pathogens in pulse roots

Methods

Root samples of poor performing legume crops in SA were sent to SARDI by growers and agronomists. From 2019, the survey was expanded to include AgVic, NSW DPI, DPIRD and USQ to provide national coverage of legume crops. The surveys focused on the roots and lower stems.

In 2020, 533 samples were processed, root health was scored and photographed, then DNA was extracted by the SARDI Molecular Diagnostic Centre. The extracted DNA was tested using a suite of quantitative polymerase chain reaction (qPCR) tests to quantify known pulse pathogens, and by next generation sequencing (NGS) (Illumina® MiSeq®) to identify potentially important pathogens

for which SARDI does not have qPCR tests. Three DNA libraries were prepared using primer pairs that target oomycetes (e.g., *Aphanomyces, Phytophthora* and *Pythium* spp.) and fungal species (e.g., *Fusarium* and *Sclerotinia*). The 2020 samples are currently being sequenced and the results will be reported at a later date.

Results

The survey is providing insight into crop symptoms which were previously unexplained (e.g., poor establishment, reduced vigour or early/uneven senescence (as seen in Figure 1)).

The most common pathogens detected using qPCR were *Pythium* spp., *Pratylenchus* spp. (root lesion nematodes), *Rhizoctonia solani* AG8, and *Phoma pinodella*.

Pythium and *Pratylenchus* spp. are known to have broad host ranges, *R. solani* AG8 prefers cereals but will infect a broad range of plants. *Phoma pinodella* along with *Didymella pinodes* causes blackspot of field pea, but it has a much broader host range.

There were also infrequent detections of *Aphanomyces* and *Phytophthora genera*. These genera have been reported to cause severe and widespread yield losses in pulses in Europe and North America.

Aphanomyces euteiches was detected in six faba/broad bean samples from SA and New South Wales (NSW) and one lentil sample from Victoria (Vic); the collecting agronomists reported large yield loss in many of these paddocks.

Phytophthora medicaginis, a known problem in northern NSW, was detected in 26 (25 chickpea, 1 faba bean) samples from northern NSW; *P. megasperma* was detected in 33 samples (multiple crop types) across Australia, and *P. drechsleri* (tentative identification), was detected in 14 samples, mostly lupin from Western Australia (WA); this species was also detected in SA, Vic and southern NSW. SARDI is currently undertaking work to confirm the identity of this species.

Next generation sequencing has been a valuable research tool to identify pathogens not covered by existing qPCR tests. Three primer pairs were developed to amplify gene regions selected to identify different pathogen groups.

It was the NGS technology that first identified *P. megasperma* and *P. "drechsleri"*. It also detected a range of *Aphanomyces* and *Fusarium* species,

Figure 1. Yellowing, poor vigour and patches of premature senescence are symptoms of root disease in this chickpea crop grown in the South-East of SA in 2017. The roots were assessed as part of the National Pulse Root Disease Survey and contained multiple pathogens, including *Phytophthora megasperma*, a likely cause of the observed rapid die-back.

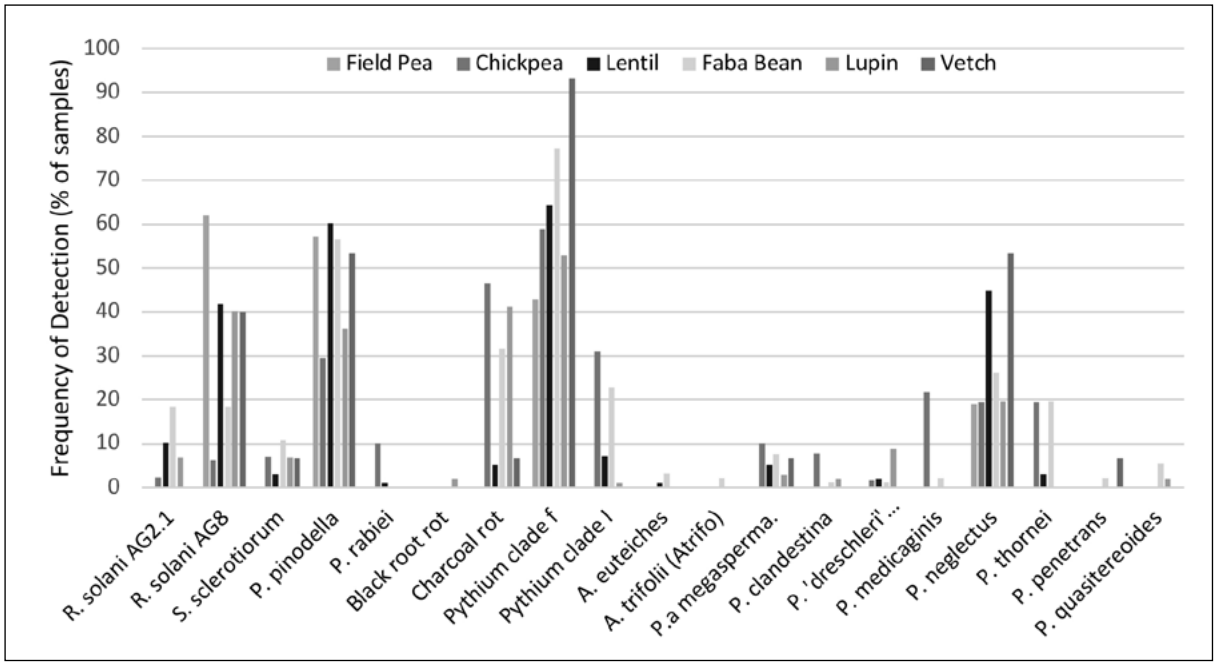


Figure 2. Frequency of detection over threshold levels of pathogens using qPCR in pulse samples received nationally in 2020.

Sclerotinia trifolorium and *Thielaviopsis basicola. Fusarium* spp. such as *F. avenaceum*, while not likely to cause total crop loss, are increasingly being viewed as important internationally due to their ability to affect a wide host range (including cereals) and cause considerable reduction in root mass, and thereby reduce yields under tough conditions.

Confirming pathogenicity of fungal isolates

To confirm the role of specific organisms in causing root disease, fungi and oomycete species were isolated from the diseased pulse samples. An isolate collection of 200+ suspected pathogens have been put in long-term storage for future investigations.

Methods

Preliminary pathogenicity and host range tests have been conducted for *Fusarium, Phytophthora* and *Phoma* isolates in replicated controlled growth room bioassays (pot tests). Isolates were evaluated on lentil, faba bean, chickpea, field pea and lupin seedlings grown in sand/vermiculite soil mix inoculated with agar plugs of growing culture. Disease symptoms were evaluated visually after 4-6 weeks growth in controlled environment rooms.

Results

Fusarium avenaceum isolates were highly pathogenic on all crops tested, with just one strain appearing non-pathogenic (Table 1). Infection was characterised by the development of black lesions on the stem base and roots and yellowing and early senescence of above ground plant parts (Figure 3).

Fusarium oxysporum and *F. redolens* isolates' pathogenicity varied between crops, but all isolates of both species were highly pathogenic on chickpea.

Fusarium tricinctum isolates were highly pathogenic on chickpea and moderately pathogenic on faba bean, lentil and lupin.

P. pinodella isolates were highly pathogenic on chickpea, field pea and lentil, but less so on faba bean and lupin (Table 2).

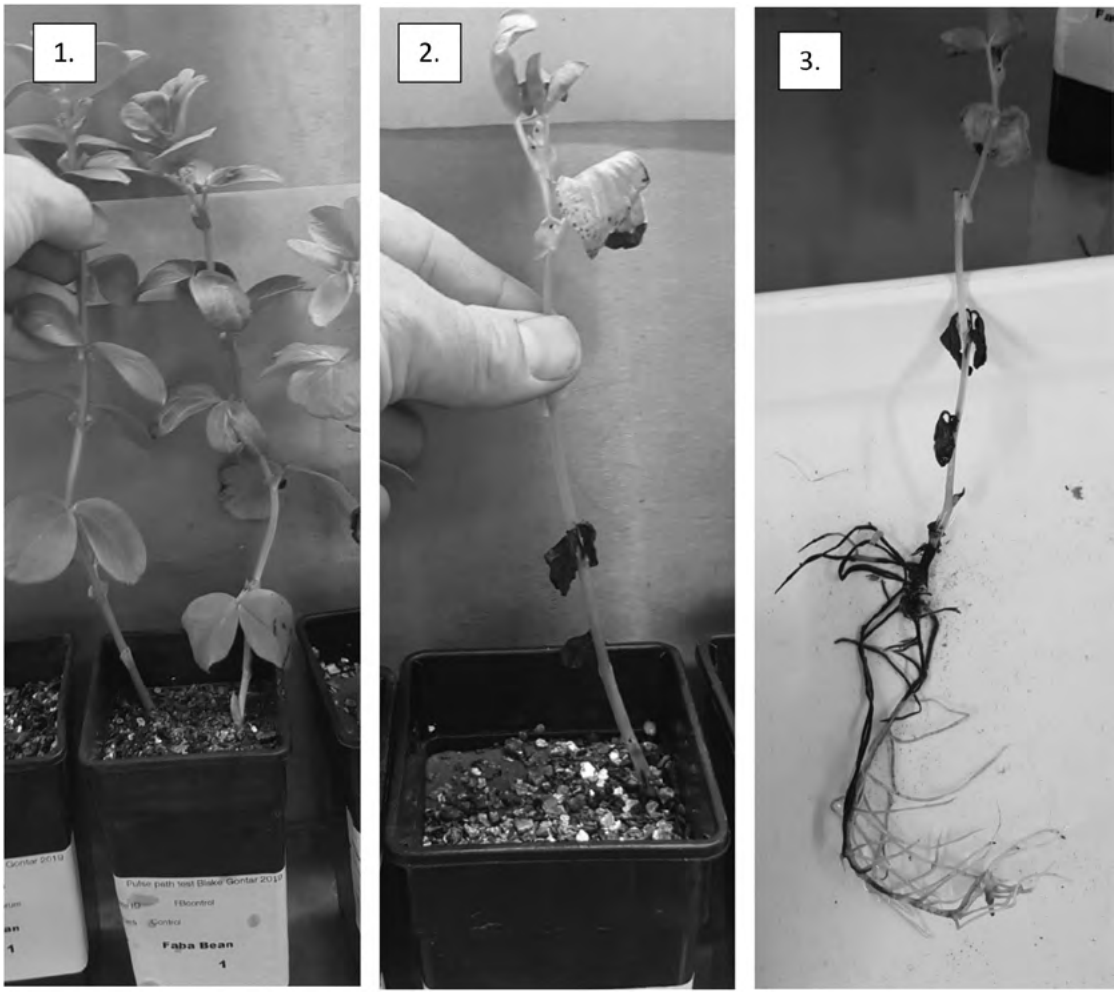


Figure 3. 1) Faba bean seedlings grown in controlled environment without pathogen, **2)** Symptoms exhibited by seedling inoculated with *Fusarium avenaceum* from faba bean grown in South-East SA, 2019. **3)** Root symptoms of inoculated seedling.

Table 1. Frequency of detection of *Fusarium* spp. in 2019 survey samples using next generation sequencing and pathogenicity of representative isolates collected from 2018-2019 crop samples. Pathogenicity on each crop is indicated as '-' non-pathogenic, '+' weakly pathogenic, '++' moderately pathogenic or '+++' highly pathogenic.

Species	Isolates Collected	Isolates Tested	Chickpea	Field pea	Faba bean	Lupin	Lentil
F. acuminatum	12	5	56%	77%	84%	71%	89%
			-/+	-/+	-/+	-/+	-/+
F. avenaceum	6	5	6%	31%	63%	29%	27%
			-/+++	-/+++	+/+++	-/+++	-/+++
F. culmorum	1	1	6%	8%	21%	7%	6%
			++/+++	+/+++	+/+++	+/+++	-/+
F. equiseti	4	4	48%	69%	72%	55%	49%
			-/++	-/+	-/++	-/+	-
F. oxysporum	17	14	91%	100%	91%	80%	73%
			++/+++	-/+	-/+	-/++	-/++
F. redolens	2	2	31%	0%	16%	9%	29%
			++/+++	-/+	-/++	-/++	-/+
F. solani	4	4	70%	0%	19%	36%	13%
			-/+	-/+	-/+	-/+	-/+
F. tricinctum	4	4	5%	31%	37%	30%	2%
			+++	-/+	-/++	+/++	+/++

Table 2. Frequency of detection of *Phoma* spp. in 2019 survey samples using next generation sequencing and pathogenicity of *P. pinodella* isolates collected from samples 2018-2019 toward common pulse crops in controlled environment assay. Pathogenicity is indicated as either non-pathogenic '-' non-pathogenic, '+' weakly pathogenic, '++' moderately pathogenic or '+++' highly pathogenic.

Species	Unique Isolates	Isolates Tested	Chickpea	Field pea	Faba bean	Lupin	Lentil
Phoma/Didymella spp.	20	16	53.13%	100.00%	90.70%	67.86%	75.00%
			++/+++	++/+++	+/++	-/++	++/+++

Yield effects of pulse root diseases

In 2020, SAGIT project SUA920 investigated yield losses caused by soilborne diseases of pulses using a mixture of fungicides at 20 sites associated with the GRDC investment Southern Pulse Agronomy program.

Methods

At each site, two suitable legume crops were sown with seed and soil fungicides to control multiple fungal/oomycete/nematode targets.

Plant samples (approximately 15 per plot) were visually assessed and DNA tested using the same 'Pulse Research' test panel as for the survey. Trials were harvested to determine any yield response.

Preliminary results are presented in this paper, data analysis is progressing. For simplicity, only lentil and faba bean data are presented.

Results

Table 3 summarises the pathogens present at each site. Other pathogens, including *Fusarium* spp., for which a PREDICTA®B test has not been developed, could not be quantified but are likely to have been present and possibly played a role in disease development and response. Plant samples will be processed through NGS to detect the presence of *Fusarium* and other species.

These sites were selected without prior knowledge of disease risk and potentially are representative of the pulse producing areas. Bool

Table 3. Initial density of pathogens detected in soil samples from 2020 field sites. Fungi results are reported as pgDNA/g soil. *Pratylenchus neglectus* and *P. thornei* are reported as nematodes/g soil.

Site	*Rhizoctonia solani AG2.1*	*Rhizoctonia solani AG8*	*Phoma pinodella*	*Macrophomina phaseolina*	*Pratylenchus neglectus*	*Pythium clade f*	*Pythium clade I*
Booleroo	21	62	2	3	0	36	0
Eudunda	1	43	279	2	1	3	5
Farrell Flat	248	48	9	15	1	16	2
Hart	0	0	342	1	1	19	5
Pinery	0	101	0	1	3	28	4
Riverton	0	20	186	2	2	28	13
Tarlee	2	141	104	1	1	36	4
Turretfield	36	4	54	75	2	71	1
Warnertown	4	6	89	15	0	46	7
Pt. Broughton	0	0	11	89	1	13	5
Maitland	18	0	3	1	35	21	57
Kimba	8	60	35	10	2	12	5
Stokes	29	49	103	1	2	239	0
Tooligie 1	0	0	167	6	9	17	0
Tooligie 2	56	75	75	12	1	28	2
Wudinna	0	128	150	1	12	10	3
Yeelanna	0	0	84	20	20	50	19
Bool Lagoon	0	0	1775	222	2	271	28
Coomandook	0	10	25	131	7	36	2
Sherwood	29	4	2373	71	0	67	0

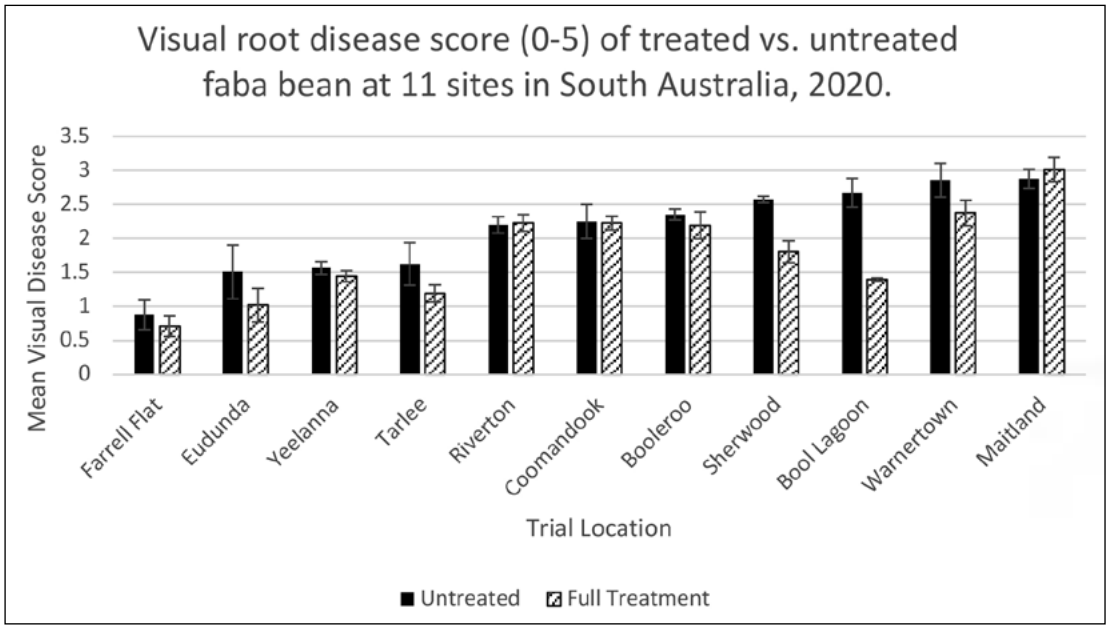


Figure 4. Mean root disease score (0-5 scale where 0 = no disease and 5 = plant death) of faba bean either untreated or treated with a combination of fungicides/nematicides targeting oomycetes, fungi and nematodes at replicated (n=3) field trials at SA sites in 2020. Approximately 10-15 plants per plot were assessed for each replicate of each treatment.

Lagoon, Sherwood, Riverton, Tarlee, Eudunda, Hart, Maitland, Wudinna, Pinery, Stokes and Tooligie 1 all had relatively high levels of one or more pathogens detected by the existing qPCR tests.

Root disease developed at all sites, however severity varied. For example, at Farrell Flat, mean root disease score in untreated lentil was less than 1. This level of disease is unlikely to affect crop growth or yield. At Maitland and Warnertown root disease scores exceeded 3 (Figure 4). Most sites root disease scores were greater than 2 across a range of crop types.

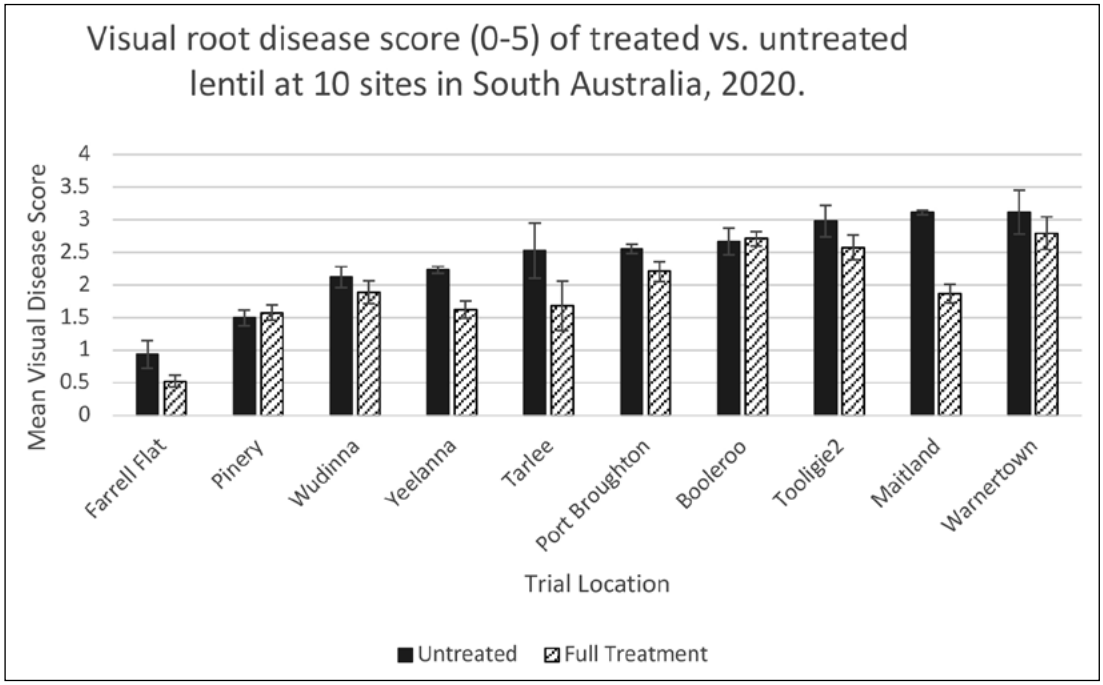


Figure 5. Mean root disease score (0-5 scale where 0 = no disease and 5 = plant death) of lentil either untreated or treated with a combination of fungicides/nematicides targeting oomycetes, fungi and nematodes at replicated (n=3) field trials at SA sites in 2020. Approximately 10-15 plants per plot were assessed for each replicate of each treatment.

Full treatment with a combination of pesticides appeared to reduce root disease compared with the untreated control at several sites (Figure 4 and 5). There were noticeable root disease responses in lentil at Yeelanna, Tarlee, Maitland and Tooligie 2, and in faba bean at Tarlee, Sherwood, Bool Lagoon and possibly Warnertown.

Complete disease control was not achieved at any site, despite the number of products applied in combination at robust rates, indicating the necessary combination of products is currently unavailable. For example, the difference at Sherwood was less than one unit of a 0-5 scale.

Despite only partial disease control, significant yield effects were observed at four of the eight lentil sites and five of the 11 faba bean sites (Tables 4 and 5). The yield responses mostly align with observed reductions in root disease (Figures 4 and 5) and pathogen DNA in roots (data not shown). However, the yield responses to various treatments did not follow the same trend across sites. For example, at Tarlee, the oomycete treatment alone improved yield over the untreated treatment by 0.42t/ha, whereas the addition of other chemistry limited yield response to equal or less than the untreated. Pre-sowing *Pythium* levels at this site were not particularly high, yet the pathogen levels in the lentil roots sampled during the season were high and clearly reduced by fungicides. The same effect was not evident in the faba bean crop grown alongside. *Pythium* is known to rapidly increase under favourable conditions.

At Bool Lagoon, the addition of the oomycete treatment alone did not improve yield, even though *Pythium* levels were high at this site. Addition of fungal and nematode treatments saw a 0.62t/ha

Table 4. Mean yields and standard error (SE) of treatments applied to lentil seed and soil at soilborne disease response sites 2020. All treatments are currently unregistered and have been coded: O = treatment selected to control oomycetes (*Pythium* & *Phytophthora*), F1 = selected to control Rhizoctonia, Phoma etc.., F2 = selected to control Fusarium, N = selected to control nematodes.

Site	Treatment Mean Yield (t/ha)							
	Nil	O	N	O + F1	O + F1 + N	O + F1 + N + F2	SE	*p-value*
Yeelanna	4.55	4.12	4.74	4.15	4.61	4.75	0.24	0.035
Tooligie 2	1.39	1.37	1.35	1.44	1.44	1.09	0.11	0.023
Booleroo	1.94	1.75	1.73	1.65	1.92	1.71	0.28	0.146
Farrell Flat	1.99	2.06	1.97	1.78	2.02	1.84	0.11	0.144
Maitland	2.86	2.99	2.94	2.99	3.07	3.00	0.10	0.007
Tarlee	3.11	3.53	3.17	2.82	3.15	2.86	0.21	<0.001
Pinery	2.72	2.83	2.82	2.71	2.73	2.67	0.05	0.062
Warnertown	2.19	2.27	2.17	2.17	2.18	2.19	0.07	0.577

Table 5. Mean yields and standard error (SE) of treatments applied to faba bean seed and soil at soilborne disease response sites 2020. All treatments are currently unregistered and have been coded: O = treatment selected to control oomycetes (*Pythium* & *Phytophthora*), F1 = selected to control Rhizoctonia, Phoma etc., F2 = selected to control Fusarium, N = selected to control nematodes.

Site	Treatment Mean Yield (t/ha)							
	Nil	O	N	O + F1	O + F1 + N	O + F1 + N + F2	SE	*p-value*
Yeelanna	5.36	5.22	5.29	5.55	5.32	5.38	0.08	<0.001
Sherwood	3.36	3.59	3.51	3.63	3.73	3.70	0.14	0.004
Coomandook	3.83	3.66	3.90	3.74	3.97	3.76	0.19	0.477
Bool Lagoon	4.70	4.64	5.10	5.12	5.32	4.98	0.32	0.005
Booleroo	2.59	2.21	2.36	2.32	2.16	2.32	0.32	0.931
Eudunda	3.97	3.89	3.77	3.74	3.62	3.82	0.09	0.058
Farrell Flat	4.86	4.94	5.07	4.83	5.01	4.84	0.10	0.288
Maitland	4.52	4.47	4.63	4.56	4.68	4.85	0.11	0.199
Riverton	4.37	4.48	4.35	4.08	4.51	4.43	0.14	0.015
Tarlee	3.59	3.72	3.56	3.79	3.58	3.68	0.09	<0.001
Warnertown	2.25	2.30	2.36	2.26	2.33	2.26	0.05	0.478

yield increase. This site had high *P. pinodella* and *Macrophomina phaseolina* levels, and therefore, controlling one pathogen only, in a pathogen complex, may not be sufficient to improve yield.

The addition of some fungicides appeared to reduce yield at some sites. The fungicides may have phytotoxic impacts on pulses and reduce yield when the target pathogen is not present. Indirect effects on Rhizobia may also be important.

Conclusion

Surveys undertaken by this project show root disease is common in Australian pulse crops. Pathogens are generally present in a pathogen complex. Some pathogens are very common across grain legume regions and crop types i.e., *P. pinodella, P. neglectus, Pythium* spp., *Fusarium* spp. and *Rhizoctonia solani* AG8. It is suspected that these have some effects on yield across many crops.

Yield losses up to 0.6t/ha yield in faba beans at Bool Lagoon, associated with partial control of moderate-high root disease, is an indication that soilborne diseases can be a substantial constraint to pulse yields.

Several pathogens were detected including *Aphanomyces euteiches* and *Phytophthora* spp. that caused substantial yield loss in isolated crops. These pathogens are favoured by wet conditions and could cause large losses in above average rainfall seasons.

Preliminary controlled environment studies have confirmed the pathogenicity of *Phoma* isolates on roots of chickpea, field pea and lentil, with weaker pathogenicity on faba bean and lupin. *Fusarium* isolates were more variable, with most isolates of *F. avenaceum* and *F. culmorum* highly pathogenic on all tested crops but isolates of *F. redolens* and *F. oxysporum* showing a preference for chickpea. Isolates of *F. solani* and *F. acuminatum* tested so far have been non-pathogenic or only weakly pathogenic. Several individual isolates appear highly pathogenic on at least one crop and likely caused the poor performance of the original crop from which they were obtained. Future studies will endeavour to prioritise pathogens that have the greatest impact on yield and seek to develop control strategies.

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 collaborators from DPIRD, AgVic, NSW DPI and USQ for their assistance with the national pulse survey. We also thanks staff in SARDI regional offices in Clare, Port Lincoln, Minnipa and Struan for their assistance in sowing the pulse root disease yield response trials, particularly Penny Roberts and Sarah Day of SARDI Clare for their contribution and collaboration.

Contact details

Blake Gontar
blake.gontar@sa.gov.au

Return to contents

Notes

Notes

Phosphorus application recommendations based on soil characterised zones – does it pay?

Sean Mason[1], Sam Trengove[2] and Stuart Sherriff[2].

[1]Agronomy Solutions; [2]Trengove Consulting.

GRDC project code: 9176604

Keywords

- phosphorus availability, phosphorus buffering index, precision phosphorus applications, replacement phosphorus.

Take home messages

- Optimal phosphorus (P) applications for maximising gross margins vary significantly within a paddock and have been linked to varying soil properties.
- Soil P status, phosphorus buffering index (PBI), normalized difference vegetation index (NDVI) images and in-season plant analysis have identified poor performing areas where higher than replacement P rates are required.
- P replacement strategies based on estimated P removal in grain only work on soils where P is not limiting growth i.e. those with high soil P and low PBI.
- Poor performing areas should be ground-truthed to ensure soil P is not limiting crop production before implementing a replacement P strategy.

Background

Most growers in the southern region use a P replacement strategy based on the amount of P removed in the grain (i.e., 3kg P/t grain) to determine fertiliser P application rates. Recent response trial work in the broad acre cropping regions of South Australia (SA) has highlighted that some soils with moderate to high PBI levels (>100) tend to be P deficient and require relatively high P rates (>20kg P/ha) to maximise both yields and gross margins. Phosphorus fixation at these selected locations is associated with the presence of low to moderate levels of calcium carbonate (5-20%) and is marked by high soil pH values. Data from these soils which often occur in areas within a paddock suggest that current P application rates are not sufficient at meeting crop P demands when soil characteristics are factored in. Through more extensive data measurements it has also been found that these areas are quite often marked by poor early growth and vigour of cereals and can be identified by in-season NDVI images. Where variable rate fertiliser technology is used, based on replacement P strategies determined by P removal in grain yield, these poor areas receive lower amounts of P fertiliser which amplifies the P deficiency.

Typically, P deficiency through replicated trials has been assessed on small, selected regions of a paddock with little data quantifying variations in P requirements across the whole paddock. With an aim to improve P applications determined by soil characteristics and in-season NDVI imagery (rather than the 'traditional' replacement P strategies), a SAGIT funded project (TC219) tested zonal strategies in five paddocks across the past two growing seasons. Broader approaches have been used in the current GRDC project to assess responses to different starter P applications across the length of a paddock utilising strip trial methodology.

Method

Intensive paddock sampling for soil pH limitations, combined with satellite imagery identified different production zones across five paddocks located in the Mid North of SA. These zones can also be linked to soil properties which drive P availability, including soil pH, soil carbonate levels and the P fixation potential (measured by PBI) which can change dramatically over short distances within a paddock. Through the SAGIT funded project (TC219), the implication of these soil attributes on economic P rates has been tested by running 21 replicated field P response trials in different soil pH, PBI and NDVI zones split across the five paddocks. Wheat or barley responses to P applications were assessed at each of the 21 sites and optimal P rates determined at: 1) maximum grain yield and 2) maximum partial gross margins. The maximum partial gross margins obtained were related back to the partial gross margins that would have been obtained if a variable rate P replacement strategy was used. The replacement P rate was determined retrospectively by using the maximum yield obtained at each site and multiplying by 3kg P/ha, which is the rule of thumb for P removal per tonne of grain exported. Partial gross margins were calculated by using the same price for monoammonium phosphate (MAP), urea and grain across both seasons which were $650/t, $500/t, and $300/t, respectively.

Results and discussion

Site soil characteristics

Site selection was based on NDVI imagery taken early in the growth season (< GS31) from the cereal phase during the previous season and soil pH mapping performed using a Veris® soil pH mapper by Trengove Consulting. In all five paddocks tested, areas of the paddock with low early vigour and biomass correlated to high pH (driven by the presence of calcium carbonate), higher P fixation potential (PBI) and lower soil P availability, identified through Colwell P with PBI interpretation and diffusive gradients in thin films (DGT) analysis (Table 1).

Table 1. Soil pH and P availability values for the 21 P trials performed in five paddocks across two growing seasons (2019-2020).

Paddock	Site	pH	Colwell P	PBI	DGT P	Response to P (grain)
		CaCl2	mg/kg		ug/L	
Koolunga	1	7.55	24	126	20	**
	2	7.58	28	141	25	**
	3	6.19	44	44	93	NS
	4	5.87	58	73	71	NS
Bute 19	5	4.94	36	25	150	NS
	6	5.96	33	61	51	NS
	7	7.67	25	90	20	**
	8	7.67	19	73	35	**
Brinkworth	9	6.65	50	105	92	NS
	10	7.63	96	64	198	NS
	11	7.69	44	120	21	**
	12	6.22	93	66	168	*
Bute 20	13	5.75	32	19	135	NS
	14	7.82	49	66	70	**
	15	6.11	67	85	71	*
	16	7.63	39	108	47	**
Kybunga	17	Tbc	27	53	69	NS
	18	Tbc	28	108	25	**
	19	Tbc	27	23	158	NS
	20	Tbc	31	50	58	NS
	21	Tbc	34	119	16	**

*The significance of grain yield response to P applications of each site is indicated by ** ($p < 0.01$), * ($p < 0.05$) and non-significant response (NS).*

Cereal response to P applications

From the 21 sites across the five paddocks, 11 sites had a significant grain response to P applications (Table 1). This highlights that previous P applications were enough to build soil P reserves and no significant reliance on P inputs was observed to increase grain yields at 48% of sites. The average soil PBI in the non-responsive sites was 52 with an average soil pH of 6.14. The highly significant ($p < 0.001$) responses to P were found on sites with an average PBI of 106 and soil pH of 7.66.

Identifying soil characterised zones for phosphorus management

The trial sites that were highly significant and responsive to P applications had P requirements of more than 30kg P/ha to maximise yields. This P input is a large investment, and its economic advantage needs to be tested before implementation at large scales. Comparing partial gross margin analysis for two categories (Maximum gross margin (Max GM) point with P rate versus gross margin (GM) at replacement P rate) indicates that there are

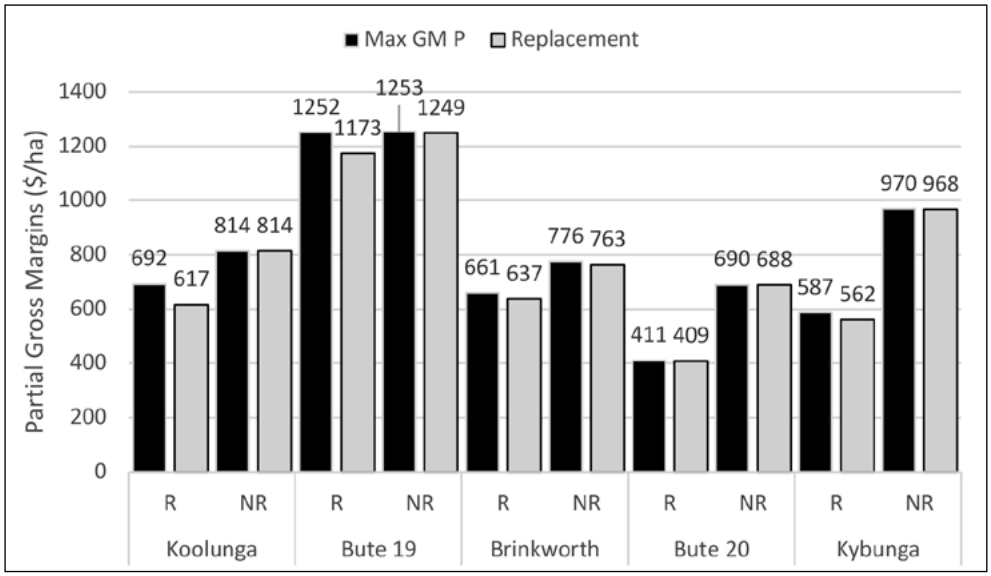


Figure 1. Comparison of partial gross margins if P response was optimised with identification of responsive sites (R (sites merged)) compared to partial gross margins obtained if replacement P rates were used for each paddock. Corresponding analysis for non-responsive sites (NR).

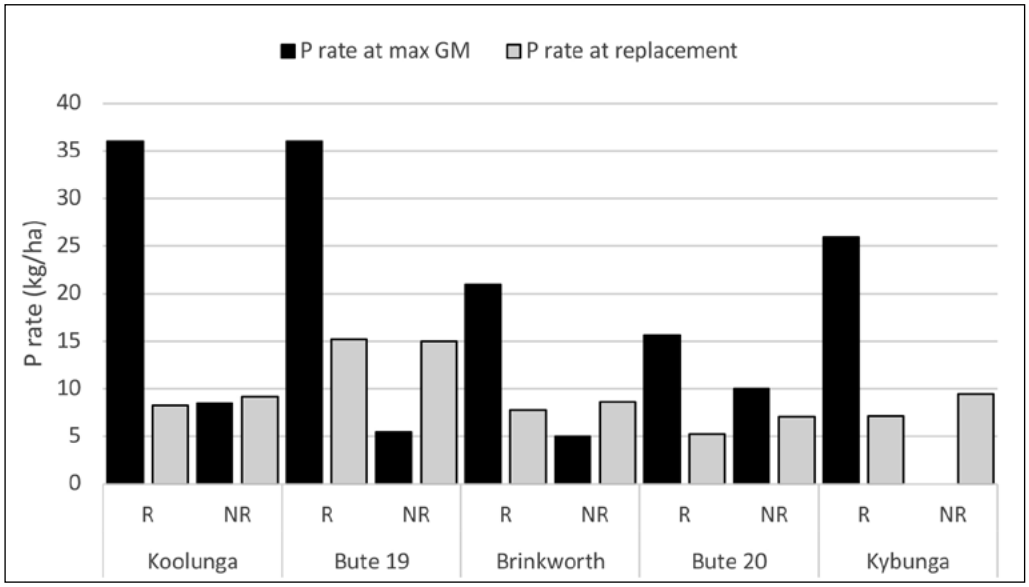


Figure 2. Phosphorus rates obtained at maximum GM for responsive and non-responsive zones in five paddocks compared to replacement P rates at each zone.

considerable improvements that can be made in productivity and GM by identifying soil zones prone to P deficiency and requiring higher P rates than recommended by replacement P calculators. The magnitude of the improvement in productivity will be determined by the proportion of the paddock that expresses these soil characteristics. Identification of responsive sites at Koolunga and Bute (during the 2019 season, Bute 19) improved partial gross margins (for those soil types) by $75 and $79/ha, respectively over replacement P scenarios (Figure 1). However, benefits of only $24/ha, $2/ha and $25/ha were obtained for Brinkworth, Bute 20 and Kybunga, respectively, highlighting the varying circumstance within each paddock (Figure 1). As expected, Max GM was obtained at near replacement P rates for non-responsive sections of each paddock. In theory, for non-responsive sites Max GM would be obtained at 0kg P/ha. As expected, the P rates which corresponded to Max GM were considerably higher for responsive areas compared to replacement P rates and apart from Bute 20, Max GM P rates were lower than replacement P for non-responsive sites (Figure 2).

The locations of the paddocks analysed in the SAGIT project) were targeted in the Mid North of SA while previous selected P trial work on similar soil zones occurred through the Yorke Peninsula. Through the GRDC investment project (9176604), similar paddock variation has been recorded through the northern Mallee of Victoria, parts of the Wimmera and on the Eyre Peninsula. Validation via the grower scale fertiliser strip treatments has shown very similar variation in P rates to maximise GM which have been associated with high soil pH and PBI, low P availability, and low NDVI. From 213 paddocks sampled in the southern region prior to the 2020 growing season, 51% of paddocks reported lower soil test P and higher PBI values in the low production zone compared to high production zones, as outlined by in-season NDVI and grain yield maps. Overall, 36% of paddocks had soil test values low enough to indicate that their yields would potentially improve from a boost in P input application within these zones.

Variation in grain yields and in-season NDVI images across a paddock can be driven by multiple soil constraints (e.g., acidity, low water holding capacity, high soil strength and poor structure) and climatic interactions. In some instances, production could be improved by targeting P inputs in lower production zones as identified through soil characterisation. It is important to ground-truth yield variability and constraints to production through soil testing and interpretation before moving to replacement P programs.

Conclusion

Phosphorus availability is controlled by inherent soil properties and often the variation across a paddock will impact the optimum P input application strategy. Increases in gross margins can be obtained by identifying zones that express high PBI, high soil pH, low early biomass, and low plant P tissue contents and increasing the P rates accordingly. In SA these poor zones within a paddock are often associated with high pH and calcium carbonate content. These zones can change quite quickly over a landscape within 100-200m. Classifying zones via soil analysis and characterisation will build confidence that current P management practice is providing maximum returns.

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 also like to acknowledge the growers involved in SAGIT funded project TC219 for allowing multiple trial sites within one paddock.

Contact details

Dr. Sean Mason
Research and Director of Agronomy
Solutions Pty. Ltd.
U3/11 Ridley Street, Hindmarsh SA 5007
0422 066 635
sean@agronomysolutions.com.au
@AgSolutionsOz

Return to contents

Notes

Notes

New approach needed for successful pulse management in low rainfall environments

Sarah Day[1], Penny Roberts[1] and Jenny Davidson[2].

[1]SARDI, Agronomy, Clare; [2]SARDI, Plant Health and Biosecurity, Urrbrae.

GRDC project codes: DAS00162A, DAV00150

Keywords

- pulses, break crop, lentil, vetch, disease, herbicides, plant density.

Take home messages

- Current recommendations for pulse management are based on medium and high rainfall zones and these strategies are not always economical for growers in low rainfall regions.
- Ability to control foliar diseases needs to be carefully considered prior to growing a pulse crop.
- It is important to follow an integrated disease management approach, monitor pulse crops for disease infection and apply fungicides at the first sign of disease prior to rain.
- Lentil is extremely sensitive to Group C herbicide use in dry conditions and herbicide choice, rate and application timing are critical in reducing risk of crop injury.
- Lentil crops are versatile, and hay can be cut to salvage a financial return where lentil is severely droughted or frost damaged.

Background

Pulse crop production has expanded into the low rainfall cropping regions of South Australia (SA) in the last decade, as adoption of direct drilling and continuous cereal cropping has increased the need to include break crops. The expansion is also a result of recent high grain prices for some pulse crops and the developments in pulse breeding, particularly the introduction of varieties with improved herbicide tolerance characteristics and varieties better adapted to low rainfall environments. Faba bean, chickpea, lentil, vetch and lupin production has increased since 2012, with the largest increases in area sown to chickpea, lentil and vetch (Figure 1). Field pea is the only pulse that has seen a reduction in production area, with the reduction in part due to the disease risk for field pea and higher grain prices for alternative pulse options. The Mid North region of SA has seen the largest reduction in field pea production area and has instead seen an increase in faba bean and lentil production. The western and eastern Eyre Peninsula has seen a small decrease in field pea production and an increase in lentil and vetch production, while the Lower Murray and the Murray Mallee regions have seen an increase in chickpea, lentil and vetch production area. While growers in low rainfall regions have increased their production area to pulses, the challenge of best management strategies for resource and economic efficiency remains.

The majority of pulse management research is conducted in medium and high rainfall zones and strategies developed in these environments are often not viable or economical for growers in low rainfall regions. To improve grower confidence in pulse production within the low rainfall region there is a need for pulse management strategies developed specifically for low rainfall environments. In particular, novel approaches and management strategies to reduce or diversify economic risk, as well as strategies to reduce input costs without

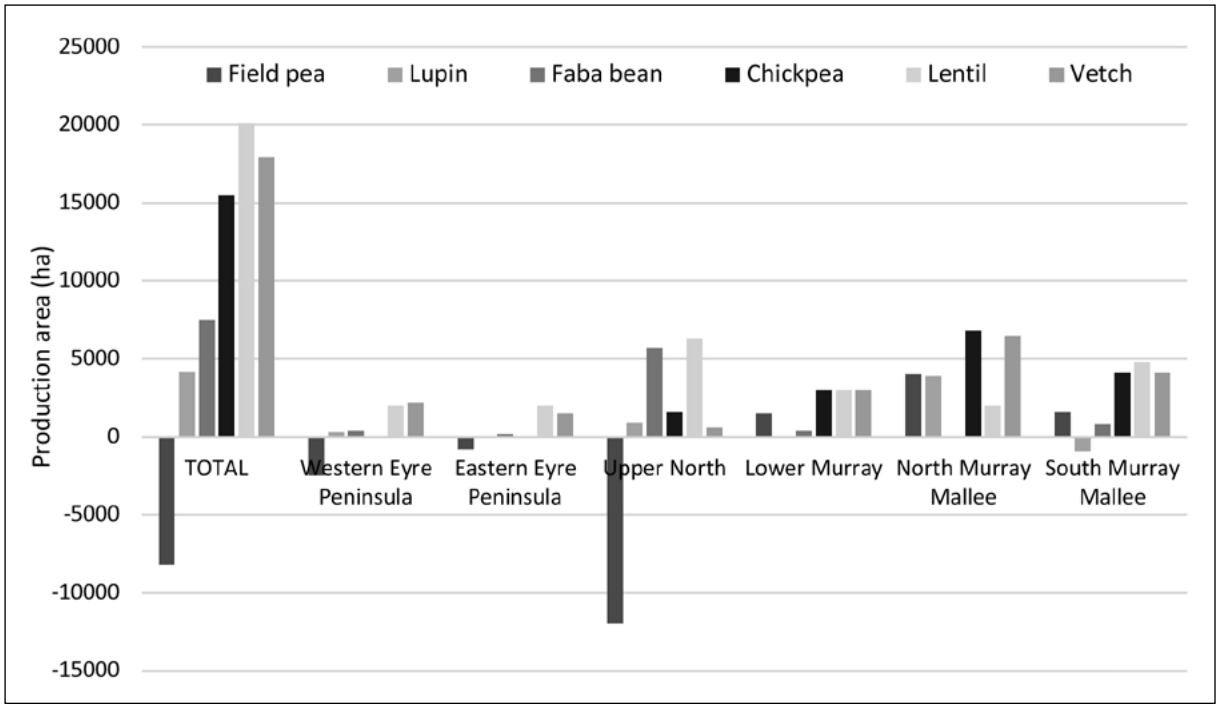


Figure 1. Change in production area (ha) of pulse crops in the South Australian low rainfall cropping regions, shows an increase in lentil, chickpea and vetch production, 2012 to 2020 (1).

compromising production potential. This paper highlights refined approaches to pulse management for low rainfall environments, including disease management and lentil herbicide management. A comparison between vetch and lentil production potential and optimum seeding rate is also discussed, in view of the expansion of these two crops and an increased interest in the potential of lentil production for grazing or hay.

Results and discussion

Disease management

The Australian pulse industry experiences a loss of $74 million per year from disease infection, with the highest disease losses occurring in field pea and chickpea (Murray and Brennan, 2012). Fungicide seed dressings and multiple foliar applications are highly recommended for field pea and chickpea as there is currently no varietal resistance to Ascochyta blight (AB). However, the cost of these applications is not economical in low rainfall environments where grain production is low. It is important to keep in mind the cost of fungicide products and ensure label directions for use are followed. Applications of newer fungicide products such as Aviator® Xpro® can cost almost double that of Mancozeb® ($17.66/ha) and cannot be applied after early flowering unlike the latter product.

Disease infection risk can be low in pulse crops in low rainfall environments. However, regular crop monitoring and disease management strategies are still important as severe disease infection can occur in higher rainfall seasons if left unmanaged. The best approach to disease management is an integrated approach, combining the selection of a resistant variety, use of clean seed, paddock hygiene and the application of fungicides. It is important to implement a three to four year break between crops of the same type, revise cultivar selections and avoid sowing in paddock(s) in close proximity to previous year's crops (Blake *et al.*, 2019). Crop sowing guides and GRDC Grow Notes provide key and up-to-date information on variety resistance characteristics and disease management approaches. The subsequent sections highlight the key considerations for disease management in low rainfall environments for the commonly grown pulse crops.

Field pea

For field pea, the control of blackspot with fungicides is not economically viable where grain production is less than 1.5t/ha. Where grain production potential is greater than 1.5t/ha, newer fungicide options have been effective in reducing disease and improving grain yield in early sown crops and high disease situations (Walela *et al.*, 2018). Blackspot can be reduced using a fungicide strategy of P-Pickel T® seed dressing combined with

two foliar fungicide sprays (four to nine weeks post sowing and again at early flowering). Predictions of blackspot risk and spore release times in each field pea growing district can be obtained through 'Blackspot Manager' online (https://agric.wa.gov.au/n/7658).

Vetch

An integrated disease management program is very important for vetch production as there are few fungicides registered for use in this crop. Some of these registered fungicides have long withholding periods, and therefore, these should be avoided if the vetch crop is being cut for silage or hay destined for the dairy industry or grazed (GRDC GrowNotes - Vetch, 2018). It is important to consider the ability to control AB in vetch, as well as botrytis grey mould (BGM) and rust in higher rainfall seasons or where crops grow large quantities of biomass. There are fungicides registered for the control of BGM but the need for multiple sprays in conducive seasons may not be economical (Davidson and Noack, 2018). Grazing vetch will open up the canopy allowing it to dry out and reduce any disease spread. Rust can impact vetch growth and yield and it is very important not to graze or cut infected vetch crops for hay or silage as it can induce abortions in pregnant stock (GRDC GrowNotes - Vetch, 2018; Davidson and Noack, 2018).

Lentil

Lentil crops should be monitored for AB, as well as BGM in higher rainfall seasons or where crops grow large canopies. Growers should monitor lentil crops for disease infection and plan to spray infected crops ahead of rain fronts during podding to protect the developing seed. Fungicides may be required in wet springs to control BGM. There are lentil varieties with high disease resistance ratings (e.g., PBA Jumbo2$^{\phi}$) that can be utilised to reduce the need for fungicide applications without compromising yield potential.

Faba bean

Faba bean crops also need to be monitored for AB and chocolate spot (CS) as well as rust. Growers should monitor faba bean crops for AB infection and plan to spray infected crops ahead of rain fronts during podding to protect the developing seed. There are faba bean varieties with high AB resistance (e.g., PBA Samira$^{\phi}$) that reduce the need for fungicide applications. Flowers are particularly susceptible to CS and fungicides may be required during wet springs to protect against this disease. Growers should monitor crops for rust and spray at the first sign of disease.

Chickpea

In recent years high levels of AB infection have been found in chickpea crops across SA, even in lower rainfall environments. This has seen a reduction in resistance ratings in commercial varieties, leading to all varieties being rated as either susceptible or moderately susceptible. Growers need to carefully consider their risk of AB infection and their ability to effectively control the disease prior to making the decision to grow chickpea in the southern region. It is essential that all chickpea seed is treated with a thiram-based fungicide seed dressing to prevent early infection on seedlings, as the disease will survive on stubble and organic matter for numerous years. It is important to monitor crops for signs of infection and apply fungicides ahead of rain, particularly during reproductive growth stages, to protect developing seeds.

Lentil herbicide management

Herbicide choice and application timing is important to reduce risk associated with lentil production, particularly as lentil is extremely sensitive to Group C herbicide use in dry conditions. Applying herbicide prior to sowing is considered a lower risk option than a post-sowing pre-emergent (PSPE) application. Herbicide application incorporated by sowing (IBS) will disperse the herbicide so that it does not sit close to the seed, thereby reducing risk of crop injury. Herbicides applied PSPE are at a higher risk in low rainfall environments as the first rainfall event post application can leach herbicide into the seed bed. Crop injury from herbicides can result in reduced grain yield, nitrogen fixation, and weed competition, and increase the risk of soil erosion over summer.

Preliminary research was undertaken at Minnipa on neutral to alkaline clay loam soil to assess the risk of commonly used Group C herbicides on lentil. Terbuthylazine expressed a lower safety level and higher economic risk than diuron and metribuzin, with lentil generally more sensitive to terbuthylazine than other pulse crops (Figure 2 and Figure 3). These trials were expanded to new locations and soil types in 2020 to assess the risk of stacking Group C and Group B herbicides on Group B tolerant lentil, PBA Hallmark XT$^{\phi}$. Two trials were sown on different soil types at Tooligie. Crop injury occurred from metribuzin, with minimal damage from IBS application and chlorosis from PSPE application (Table 1). Terbuthylazine caused minimal crop injury on lighter soil types at Tooligie, in the 2020 season.

Herbicide choice will differ depending on an individual grower's attitude towards risk and

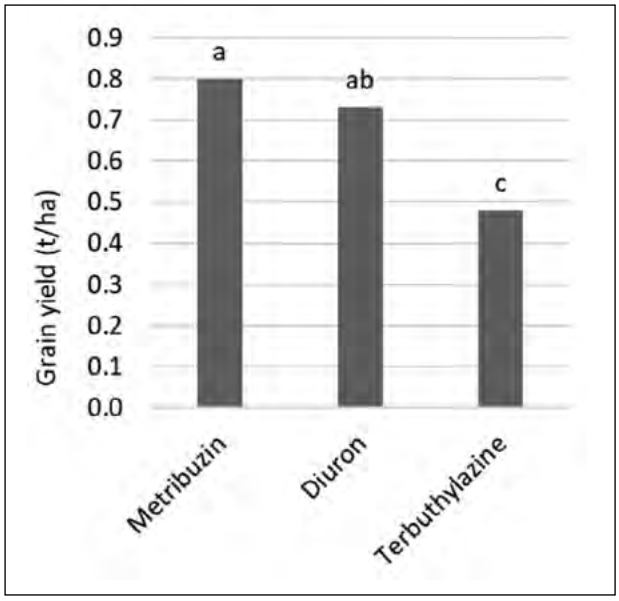


Figure 2. Reduced grain yield production in lentil where terbuthylazine was applied pre-emergent in clay loam soil at Minnipa, 2018. Bars labelled with the same letters are not significantly different (P<0.05).

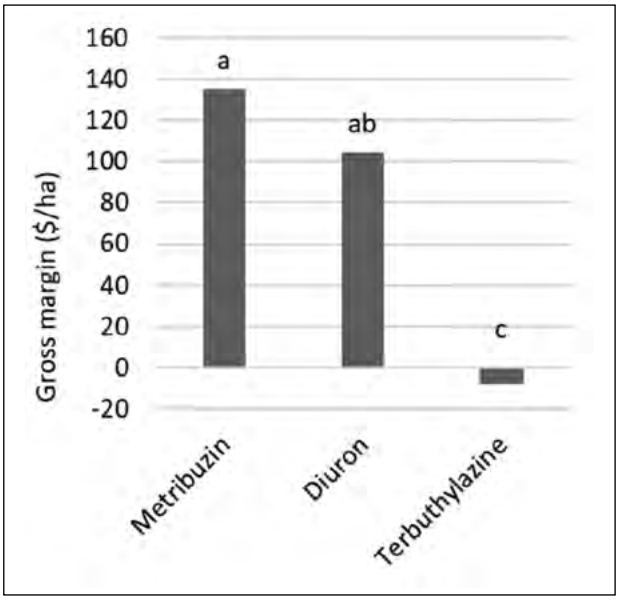


Figure 3. Reduced gross margin in lentil where terbuthylazine was applied pre-emergent in clay loam soil at Minnipa, 2018. Bars labelled with the same letters are not significantly different (P<0.05).

experience with products, soil type, target weed populations, environmental conditions, herbicide solubility, and leaching rate. Often a combination of herbicides with different solubility and leaching rates can be used to reduce the risk of damage while targeting a wider spectrum of weeds. The solubility and binding rates of Group C herbicides used in lentil vary between products (Table 2). The solubility of each herbicide influences how much rain is required for herbicide incorporation and the likelihood of the herbicide moving down the profile (Congreve and Cameron, 2019). Herbicides with low solubility (diuron and terbuthylazine) require good soil moisture and rainfall to achieve incorporation and are less available in the soil moisture than herbicides with high solubility (metribuzin). A herbicide with high solubility can move more readily within the soil and is more likely to cause off-target damage, as seen on sandy loam soil at Tooligie (Table 1). The binding or absorption ability of herbicides is affected by the soil texture and soil organic matter (Congreve, 2015). Heavy soils and soils with high levels of organic matter have greater binding ability and will absorb more herbicide. For this reason, higher application rates are required to achieve successful weed control as there is less herbicide available in the soil water for root uptake.

Table 1. Mean crop injury score (0 = no crop damage, 9 = crop death) for damage caused by Group C and/or Group B herbicides applied to PBA Hallmark XT(1) lentil at Tooligie, 2020. Scores with different associated letters are significantly different (P<0.05). IBS = incorporated by sowing, PSPE = post-sowing pre-emergent, POST = post emergent.

HERBICIDE	SITE 1 (Loam/clay loam)		SITE 2 (sandy loam)	
	Score		Score	
Nil	0.2	d	0.0	c
Diuron® 830 IBS	0.6	bcd	0.1	bc
Diuron 830 IBS + Intercept® 600 (POST)	0.8	bc	0.5	b
Terbyne® 860 IBS	0.4	cd	0.1	bc
Terbyne 860 IBS + Intercept 600 (POST)	1.0	ab	0.3	bc
Metribuzin® 280 IBS	0.5	bcd	0.3	bc
Metribuzin 280 IBS + Intercept 600 (POST)	0.8	bc	0.5	b
Metribuzin 280 PSPE	1.0	ab	2.3	a
Metribuzin 280 PSPE + Intercept 600 (POST)	1.4	a	2.1	a
LSD (P<0.05)	*0.58*		*0.46*	

Table 2. Label instructions, solubility rate and binding ability of commonly used Group C herbicides in lentil production. IBS = incorporated by sowing. PSPE = post-sowing pre-emergent.

Product	Diuron	Metribuzin	Terbuthylazine
Product cost	$13.25 per kg	$48 per kg	$21 per kg
Label rate	IBS: 0.83-1.1 kg/ha PSPE: 0.55-0.83 kg/ha	Light sandy soils: 180g/ha Medium soils: 280g/ha Heavy soils: 380g/ha	0.86-1.2 kg/ha
Label instructions	Apply the lower rate on light sandy soil	Only apply post-sowing pre-emergent to a crop sown at least 5cm deep.	Apply IBS only. Do not use on light soil types. Do not use rates higher than 0.86kg/ha on soils with pH 8.0 and above.
Solubility	Low	High	Low
Binding	Slightly mobile	Mobile	Moderately mobile

Vetch in comparison with lentil - reducing inputs and diversifying production

With a reduction in area sown to field pea, growers are choosing to grow vetch, a versatile break crop, and are considering the potential of other pulse break crop options for alternative end uses. There are many unfavourable aspects of vetch production, including poor early weed competition, limited herbicide options, hard seediness of some varieties, poor harvestability and market access. Using lentil for grazing or hay is growing in interest among low rainfall growers, which initiated research trials comparing biomass and grain production of vetch and lentil sown at multiple seeing rates, at four trials sites in 2020. The seeding rates compared recommended target plant density (120 plants/m2 for lentil and 60 plants/m2 for vetch) with a target density of half and three-quarters of the recommended rate to assess whether input costs could be reduced without compromising production potential. Higher than recommended rates were not included, as high plant density crops increase the risk of disease infection and lodging and reduce the resource efficiency due to larger canopies. At three of four sites seeding rate could be reduced by a quarter without compromising biomass or grain production in 2020 (Table 3). Reducing the seeding rate further to half of the target density did reduce production at some sites. A seeding rate that is too low exposes the crop to aphid infestation and weed establishment and the crop is more difficult to harvest. Previous preliminary trials on seeding rate in lentil at Melton and vetch at Willowie support these findings that seeding rate can be reduced without compromising production under some seasonal conditions. Additional trials are required in future seasons to further validate this research across a range of seasonal conditions and soil types.

Where vetch is not favoured as a break crop, lentil can be a versatile option. Lentil hay could be cut to salvage a financial return where the crop is severely affected by frost, heat or drought. For the 15 break crop trials in the southern region, lentil was better than (vetch < lentil) or equal to vetch (vetch = lentil) for biomass production in seven trials, for grain production in 10 trials and for profit in nine trials (Table 4). Lentil production and profit was greater than vetch at two sites and in these cases, crops were affected by frost or dry spring seasonal conditions. Lentil can be utilised as a lower risk and versatile crop option as an alternative to vetch, with greater market access for lentil grain and increasing interest in lentil hay. Feed analysis shows minimal difference in the feed quality of lentil and vetch hay

Table 3. Biomass and grain production (t/ha) responses to multiple seeding rates of lentil and vetch at four sites in 2020. LSD = least significant difference (P<0.05). n.s. = not significant.

Seeding rate	Eudunda		Booleroo		Kimba		Stokes	
	Biomass yield	Grain yield	Biomass yield	Grain yield	Biomass yield	Grain yield	Biomass yield	Grain yield
Recommended	5.2	3.0	5.2	2.6	1.7	0.8	2.6	1.7
Three-quarter	4.8	3.0	4.8	2.7	1.6	0.7	2.2	1.6
Half	4.4	2.8	4.5	2.6	1.5	0.7	2.0	1.5
LSD (P<0.05)	*0.5*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*0.36*	*n.s.*

Table 4. Frequency of break crop trials where vetch biomass and grain production and profit from grain production was equal, greater than, or less than lentil, 2017-2020.

	Biomass	Grain	Profit (grain)	TOTAL
Vetch = lentil	6	8	7	21
Vetch > lentil	7	4	1	12
Vetch < lentil	1	2	2	5
Unknown	1	1	5	7
TOTAL	15	15	15	45

Table 5. Feed analysis results of lentil and vetch cut for hay at early pod development growth stage.

	Lentil	Vetch
Crude Protein (% of dry matter)	19.2	21.2
Digestibility (% of dry matter)	77.6	78.2
Metabolisable Energy (MJ/kg dry matter)	11.7	11.8

(Table 5), and in recent years lentil crops have been profitable where hay was cut due to severe frost damage that would have resulted in no grain production.

Conclusion

The majority of pulse management recommendations have been developed for medium and high rainfall zones. These strategies are unlikely to be viable and economical for low rainfall regions or in low rainfall seasons and there is a need for specifically developed management strategies that reduce inputs costs without compromising on production potential.

The ability to control foliar disease in pulse crops needs to be carefully considered prior to growing these crops and an integrated approach is essential. For disease management it is important to follow recommendations on seed and paddock hygiene, select varieties with improved disease resistance where possible, monitor paddocks for disease infection and apply fungicides at first sign of disease prior to rain fronts.

Lentil is extremely sensitive to Group C herbicide in dry conditions and herbicide choice is important in reducing risk of crop injury. Herbicide choice will differ depending on an individual grower's attitude towards risk and experience with products, soil type, target weed populations, environmental conditions, herbicide solubility and leaching rate. It is important to remember that product label rates, plant-back periods and directions for use must be adhered to.

Lentil can be a versatile pulse option where vetch is not favoured or where lentil crops grown for grain are severely drought or frost effected. Seeding rate of lentil and vetch can be reduced without compromising on production potential but it is important to not reduce rates too low as this can reduce production and will leave crops exposed to weed and aphid infestations.

Acknowledgements

The research undertaken as part of these projects (GRDC project codes DAS00162A and DAV00150) 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.

Useful resources

https://grdc.com.au/NVT-south-australian-crop-sowing-guide

https://grdc.com.au/resources-and-publications/grownotes

References

1. PIRSA. Crop and Pasture Reports South Australia. 2012-2020.
2. Murray G, Brennan J. The current and potential costs from diseases of pulse crops in Australia. 2012.
3. Blake S, Farquharson L, Kimber R, Davidson J, Walela C, Hobson K. Ascochyta blight in intensive cropping of pulses. In: ORM, editor. GRDC Grains Research Updates; Adelaide2019.

4. Walela C, Roberts P, Mould R, Spriggs B, McMurray L, Davidson J. Ascochyta blight severity and yield response to fungicides in field pea. 2018.
5. GRDC. GRDC Grow Notes - Vetch. 2018. https://grdc.com.au/__data/assets/pdf_file/0023/293117/GRDC-GrowNotes-Vetch-Southern.pdf?utm_source=website&utm_medium=download_link&utm_campaign=pdf_download&utm_term=South&utm_content=Vetch%20Southern%20Region%20-%20GrowNotes%E2%84%A2
6. Davidson J, Noack S. Disease management of pulses in low to medium rainfall zones. In: ORM, editor. GRDC Grains Research Updates2018.
7. Congreve M, Cameron J. SOIL BEHAVIOUR OF PRE-EMERGENT HERBICIDES IN AUSTRALIAN FARMING SYSTEMS - a reference manual for agronomic advisers. October 2019 https://grdc.com.au/resources-and-publications/all-publications/publications/2018/soil-behaviour-of-pre-emergent-herbicides for agronomic advisers. GRDC publication, Australia; 2019.
8. Congreve M. Pre-emergent herbicides - fact sheet. 2015.

Contact details

Sarah Day
70 Farrell Flat Road, Clare SA 5453
08 8841 2404
Sarah.Day@sa.gov.au
@Sarah_Day

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

Return to contents

Notes

Russian wheat aphid thresholds - insect density, yield impact and control decision-making

Maarten van Helden [1,2], Thomas Heddle[1], Elia Pirtle[3], Jess Lye[3] and James Maino[3].

[1]South Australian Research & Development Institute; [2]University of Adelaide; [3]cesar Australia, Parkville.

GRDC project code: DAS00119

Keywords

- Russian wheat aphid, yield loss, action threshold.

Take home messages

- Natural Russian wheat aphid (RWA) risk was nonsignificant in all 28 trials in 2018 and 2019.
- RWA yield impact is 0.28% yield loss per percent of tillers with RWA (%TwRWA).
- After GS30 the %TwRWA doubles approximately every 35 days.
- The RWA action threshold calculator is now available on-line and allows for an integrated pest management (IPM) approach to controlling RWA.

Background

This project studied the risk of infestation by the Russian wheat aphid (RWA, *Diuraphis noxia* (Kurdjimov 1913)) and its effect on yield in order to develop best management practices for RWA in an Australian context of winter cropping of short cycle cereals. Risk of yield loss depends on aphid invasion, subsequent pest development and sensitivity of the crop to the pest.

Previously, there were no data available for quantitative and qualitative yield effects of RWA and for the development of intervention thresholds in Australian cereal growing conditions. Overseas data, from North America and South Africa, where RWA has been present for many decades (Archer and Bynum 1992; Du Toit and Walters 1984; Du Toit 1986; Bennett 1990a,b; Kieckhefer and Gellner 1992; Girma *et al.* 1990, 1993; Mirik *et al.* 2009; Legg and Archer 1998, Chander *et al.* 2009), report a wide range of potential damage levels (yield loss and qualitative losses) and derived economic injury levels. Yield losses of around 0.5% per percentage of RWA infested tillers during stem elongation and grain filling are most frequently reported (Archer and Bynum 1992).

These knowledge gaps were addressed through:

1. Twenty-eight natural RWA infestation field trials in 2018 (15) and 2019 (13) in South Australia (SA), Victoria (Vic), New South Wales (NSW) and Tasmania (Tas) (Table 1).
2. Fifteen RWA inoculated field trials in 2018 (5) and 2019 (10) where 50 RWA/m2 (500,000 RWA/ha) were applied at GS12-14 (2-4 leaf stage, Table 1)
3. Green bridge sampling of grasses during the non-cropping period in both years in all states and extensive continuous sampling of grasses in SA over 26 months (March 2018-May 2020).

Table 1. Location of trial sites in 2018 and 2019.

Site Name	State	Lat	Long	Inoculation	Irrigation
2018					
Birchip	Vic	-35.9666	142.8242	Y	N
Cummins	SA	-34.3050	135.7189	N	N
Griffith	NSW	-34.1902	146.0920	Y	N
Hillston	NSW	-33.5482	145.4408	N	Y
Inverleigh	Vic	-38.1805	144.0390	N	N
Keith	SA	-36.1299	140.3233	Y	N
Lockhart	NSW	-35.0837	147.3280	N	N
Longerenong	Vic	-36.7432	142.1135	N	N
Loxton	SA	-34.4871	140.5891	Y	N
Minnipa	SA	-32.8398	135.1642	N	N
Nile DRY	Tas	-41.6759	147.3140	N	N
Nile IRR	Tas	-41.6759	147.3140	N	Y
Piangil	SA	-35.0519	143.2758	N	N
Riverton	SA	-34.2193	138.7350	Y	N
Yarrawonga	NSW	-36.0484	145.9833	N	N
2019					
Birchip	Vic	-35.9666	142.8242	Y	N
Bundella	NSW	-31.5851	149.9064	N	N
Cressy	Tas	-41.7854	147.1134	Y	N
Eugowra	NSW	-33.4944	148.3192	N	N
Griffith	NSW	-34.1902	146.0920	Y	N
Horsham	Vic	-36.7432	142.1135	Y	N
Inverleigh	Vic	-38.0497	144.0104	Y	N
Loxton	SA	-34.4871	140.5891	Y	N
Minnipa	SA	-32.8398	135.1642	Y	N
Mildura	Vic	-34.2627	141.8535	Y	N
Pt Broughton	SA	-33.5757	137.9987	Y	N
Thule	NSW	-35.6491	144.3914	Y	N
Yarrawonga	NSW	-36.0484	145.9833	N	N

Results

Risk of RWA invasion of crops

Overall RWA risk was very low during these two (very dry) years with no significant RWA infestation occurring in any of the non-inoculated field trials. Therefore, the largely adopted use of prophylactic seed treatments against RWA was not justified.

Yield loss in inoculated trials

Regional and varietal differences were large (Figure 2). In some, but not all of the inoculated field trials RWA populations reached population levels (maximum observed between GS40 and 50) resulting in yield loss. Of the various aphid pressure metrics, the best predictor of yield loss was the maximum percentage of tillers with RWA present (%TwRWA) with a 0.28% yield loss observed for every %TwRWA. This simple relationship applied to wheat, barley and durum wheat cereal types, years and regions (through the adjustment of potential yield), but oat did not allow RWA development. This yield impact is substantially lower than described for the USA (0.46-0.48%, Archer and Bynum 1992).

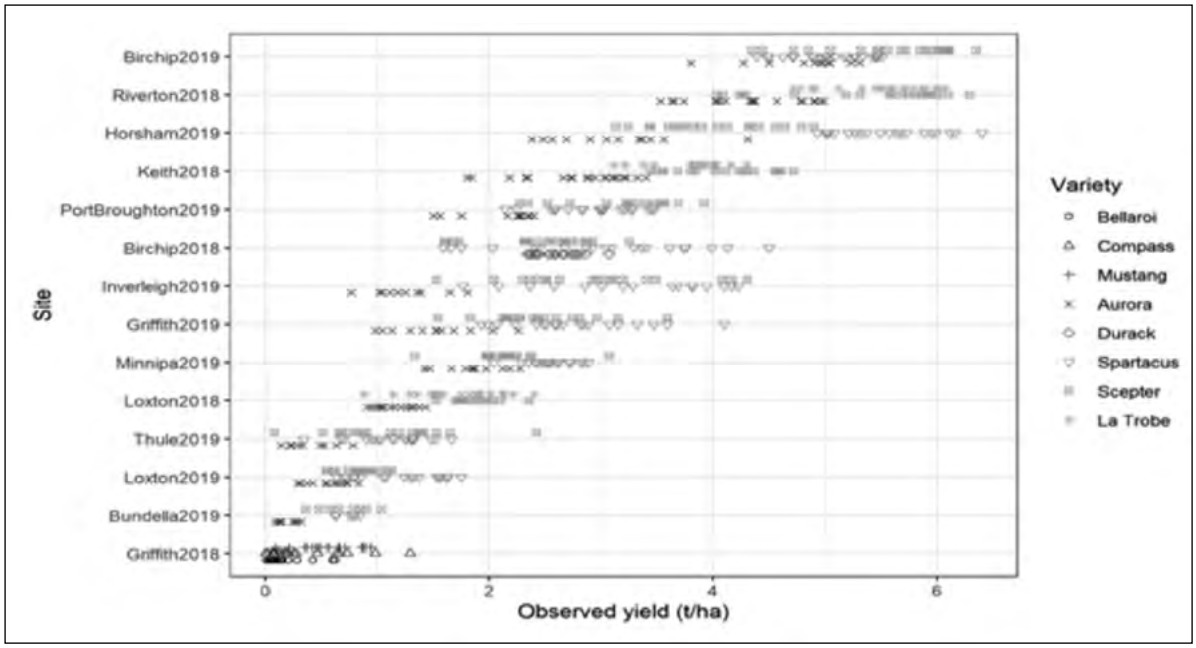


Figure 2. Yield across all trial sites and years with different cereal type/variety denoted by different markers. Barley varieties used were Compass[Φ], Spartacus CL[Φ] and La Trobe[Φ]. Durum wheat varieties used were EGA Bellaroi[Φ] and DBA Aurora[Φ]. Wheat varieties used were Scepter[Φ] and Mustang[Φ]. Oat variety used was Durack[Φ].

From this equation, the economic threshold (the break-even point of yield loss and control measures) can be calculated depending on the following parameters: cost of control (pesticide, applications costs), expected yield (region and year dependant) and the farm-gate price of the crop (Figure 3).

RWA population development

After inoculation, the highest RWA populations that developed were in the drier regions, through a combination of increased RWA establishment during inoculation and an increased population increase. Less tillering in dry areas also contributed to higher

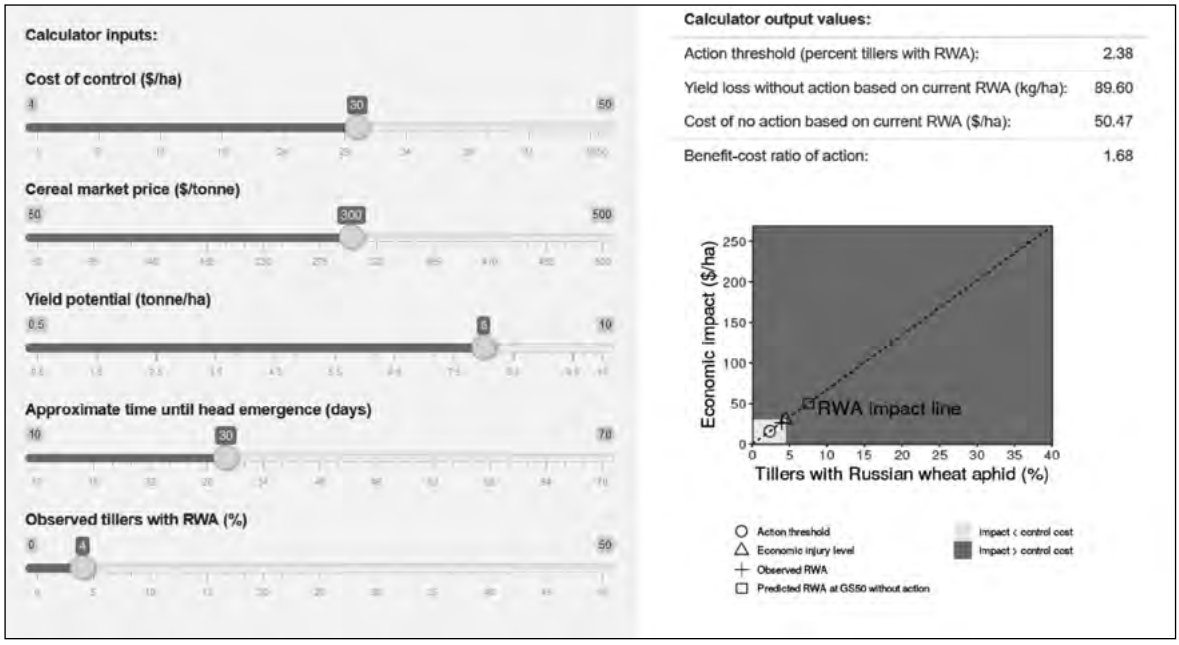


Figure 3. An example of output from the RWA Action Threshold calculator.

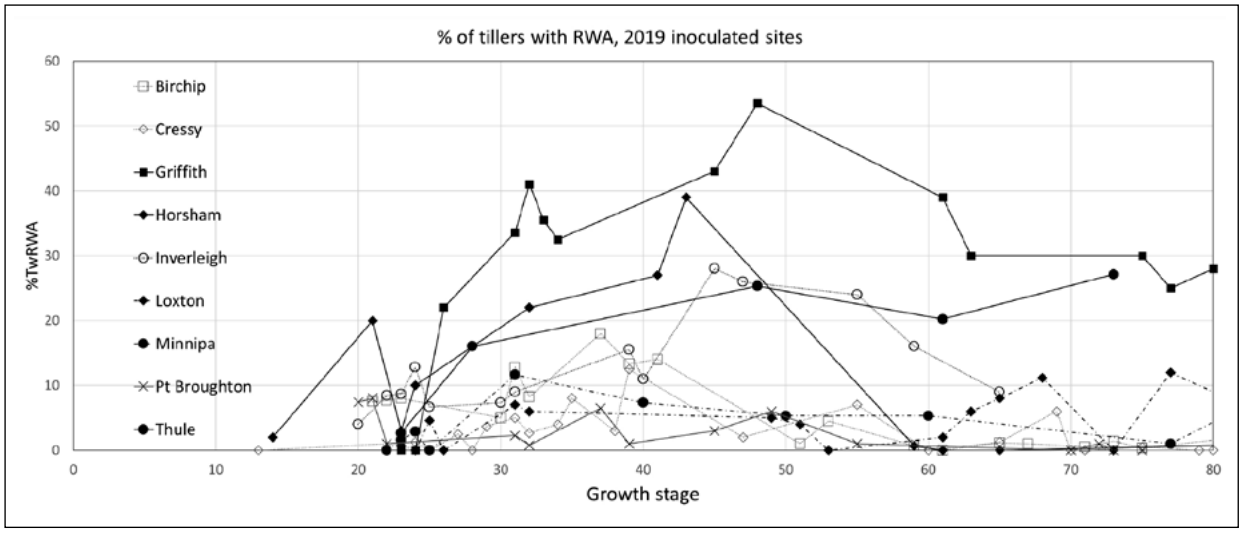


Figure 4. Percentage of tillers with RWA (%TwRWA) against growth stage for the inoculated untreated control plots (AI-UTC) in all inoculated trial sites in 2019.

%TwRWA. The maximum population of RWA and the maximum %TwRWA was reached between GS40 and 50 (Figure 4) followed by a decrease. Between the end of tillering (GS30) and GS50 an increase in the %TwRWA of 0.021%/%/day was observed. This would result in a doubling of the %TwRWA every 35 days.

Action threshold calculator

Based on these observations and equations, a decision rule (action threshold, Figure 3) was proposed for RWA management using an observation of the percentage of tillers with symptoms and the %TwRWA at GS30. This observation and the expected increase in %TwRWA (based on the expected time to ear emergence, GS50) inform the need for management action, which can (if needed) be combined with existing treatments at GS 32-35, reducing application costs. Growers and advisers are directed to the GRDC calculator (Useful resources) to calculate thresholds for their growing conditions.

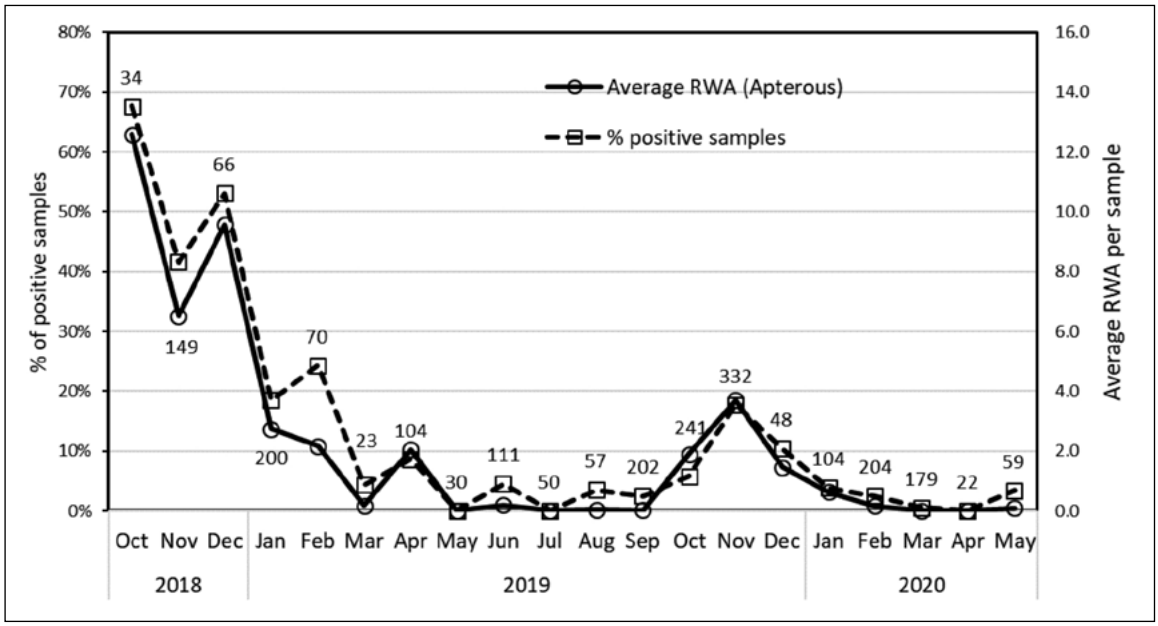


Figure 5. Dynamics of the percentage of positive samples (dotted line, left axis) and average RWA per sample (solid line, right axis) over time in South Australia. Numbers above markers show number of samples taken per month, n=2285.

Green bridge risk

The environmental conditions over summer that form a 'green bridge' of suitable (grass) habitat between winter crops were expected to determine the risk of early colonisation events.

RWA detections were particularly common in field surveys during the spring to autumn periods (when no crops were present in the field), with high populations during spring in the warm dry grain growing regions of northern Vic, southern NSW and SA. During the summer, green vegetation for most grass species disappeared and RWA populations declined (Figure 5). Apart from volunteer cereals (wheat and barley), the majority of RWA detections were on five grass genera (barley grass, Bromus sp, phalaris, ryegrass and wild oat.

Barley grass (*Hordeum leporinum*) and (to a lesser extent) brome grasses (*Bromus* sp.) are the host plants that showed the highest combination of abundance, positive RWA detection frequency and aphid numbers. These introduced species are not summer active in low rainfall areas, where the native bottlebrush (*Enneapogon nigricans*) is the most important summer refuge in low rainfall areas, because of its widespread distribution (207 samples collected from 135 sites) and summer growth pattern. Grazing and water availability (irrigation) can make some host grass populations, including prairie grass, couch grass, ryegrass and volunteer cereals, persist in summer. The presence of irrigated crops increased the likelihood of RWA detections 1.6-fold over the green bridge.

Early rainfall in late summer/autumn, two to three months before sowing, could cause RWA population to build up on grasses and cereal regrowth, potentially exacerbating early crop invasions. A 250mm high rainfall event in the Birchip area (Vic) in December 2018 did cause significant development of a green bridge but did not seem to result in an increased RWA risk. Reports in 2020 from the Port Augusta area (SA), where a significant summer rain occurred on 1 February suggested an increase in RWA pressure. This shows that observations, especially in early break years and a better understanding of aphid population dynamics and migration on the green bridge before and after sowing, are needed to obtain more precision on the impact of the green bridge and the risk and times of invasion of crops.

A 'wetter' year with a higher green bridge, or if immigration of aphids occurs at a higher level for some other reason, will not automatically result in a higher impact from RWA. Wetter and colder conditions and rainfall will be less favourable for RWA development in the crop (as can be seen from the Tasmanian trials) compared to the two experimental years (slowing down population development) and will also improve crop development which will better enable the crop to resist RWA.

Crop sensitivity

The project has shown similar yield impact and aphid population **development** for all crops tested except for oat, which is not an RWA host. However, crop and varietal differences in RWA **establishment** are likely to exist and have been reported. Also, the crop condition (growth stage, level of tillering, drought stress, nutritional stage) will play a role in RWA **development** and could result in a different risk for reaching population levels above thresholds.

Conclusion

RWA ecology and yield impact in Australia are now somewhat better understood. This allows growers and agronomists to manage RWA more sustainably and economically. Management based on observations and regionally adapted decision rules, rather than prophylactic seed treatments, will increase profitability, minimise chemical inputs and reduce off-target risks and resistance development.

The two years during which this study was conducted were very dry with hot summers and growing seasons. These conditions were unfavourable for RWA survival over summer, but favourable for the development of RWA in the inoculated trials (Baugh and Phillips 1991, De Farias *et al.* 1995). Some anecdotal observations in 2020, and in the few years that RWA has been known to be present in Australia (since 2016, Ward *et al.*2020, Yazdani *et al.*2018), do suggest that the population levels will be very different (but not necessarily more damaging) with different rainfall patterns. More experience and research are needed to better understand RWA ecology, and to improve the RWA management guidelines.

The geographical distribution of RWA is expected to increase further into northern NSW and Queensland (Avila *et al.* 2019), and RWA was detected in Western Australia in 2020. Different growing conditions (temperature, drought) and presence of other cereal crops, including summer cereals (rice, corn, sorghum, millet), and other grass hosts could alter the risk of RWA in those regions.

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. Trials were run through multiple contractors requiring long hours of careful observations. Special thanks to Courtney Proctor, Bonnie Wake and Millie Moore for data management and long trips required for aphid inoculation and scoring trials, and Farah Al-Jawahiri for aphid rearings.

Useful resources

GRDC publication. Russian wheat aphid (https://grdc.com.au/resources-and-publications/resources/russian-wheat-aphid)

References

Archer TL and Bynum EO 1992. Economic Injury Level for the Russian Wheat Aphid (Homoptera: Aphididae) on Dryland Winter Wheat. J Econ Entomol 85:987–992. (https://doi.org/10.1093/jee/85.3.987).

Avila GA, Davidson M, van Helden M and Fagan L 2019. The potential distribution of the Russian wheat aphid (*Diuraphis noxia*): an updated distribution model including irrigation improves model fit for predicting potential spread. Bulletin of Entomological Research 109, 90–101.

Baugh BA and Phillips SA 1991. Influence of population-density and plant water potential on Russian wheat aphid (Homoptera: Aphididae) alate production. Environmental Entomology 20, 1344-1348.

Bennett LE 1990a. Preliminary economic threshold level for Russian wheat aphid (RWA) *Diuraphis noxia* (Mordvilko), on dryland winter wheat in southeastern Wyoming. Final Report to the Wyoming Wheat Growers Association, 20 August 1990, Laramie, WY

Bennett LE 1990b. Economic damage, economic injury levels and economic threshold levels for Russian wheat aphid (RWA), *Diuraphis noxia* (Mordvilko), on winter barley in Wyoming. M.S. thesis, University of Wyoming, Laramie.

Chander S, Ahuja LR, Peairs FB, Aggarwal PK and Kalra N 2006. Modelling the effect of Russian wheat aphid *Diuraphis noxia* (Mordvilko) and weeds in winter wheat as guide to management, Agricultural Systems, vol. 88, pp. 494–513, 2006.

De Farias AMI, Hopper KR and Leclant F 1995. Damage symptoms and abundance of *Diuraphis noxia* (Homoptera: Aphididae) for four wheat cultivars at three irrigation levels. J. Econ. Entomol. 88: 169-174.

Du Toit F and Walters MC 1984. Damage assessment and economic threshold values for the chemical control of thr Russian wheat aphid, *Diuraphis noxia* (Mordvilko) on winter wheat. Tech Commun Dep Agric Repub South Africa 58–62

Du Toit F 1986. Economic thresholds for *Diuraphis noxia* (Hemiptera: Aphididae) on winter wheat in the eastern Orange Free State. Phytophylactica. 18, 107-109.

Girma M, Wilde G and Reese JC 1990. Influence of temperature and plant growth stage on development, reproduction, life span, and intrinsic rate of increase of the Russian wheat aphid (Homoptera: Aphididae). Environmental Entomology 19: 1438.

Girma M, Wilde GE and Harvey TL 1993. Russian wheat aphid (homoptera, aphididae) affects yield and quality of wheat. Journal of Economic Entomology. 86, 594-601.

Kieckhefer RW and Gellner JL 1992. Yield losses in winter wheat caused by low density cereal aphid populations. Agron. J. 84, 180–183.

Legg DE and Archer TL 1998. Sampling Methods, Economic Injury Levels, and Economic Thresholds for the Russian Wheat Aphid. In: Response Model for an Introduced Pest—The Russian Wheat Aphid. pp 313–336

Mirik M, Ansley J, Michels J and Elliott N 2009. Grain and vegetative biomass reduction by the Russian wheat aphid in winter wheat. Southwestern Entomologist 34, 131–139.

Ward S, van Helden M, Heddle T, Ridland PM, Pirtle E and Umina PA 2020. Biology, ecology and management of *Diuraphis noxia* (Hemiptera: Aphididae) in Australia. Austral Entomol. 59(2): 238-252 (https://doi.org/10.1111/aen.12453).

Yazdani M, Baker G, DeGraaf H, Henry K, Hill K, Kimber B, Malapatil M, Perry K, Valenzuela I and Nash, MA 2018. First detection of Russian wheat aphid *Diuraphis noxia* Kurdjumov (Hemiptera: Aphididae) in Australia: a major threat to cereal production. Austral Entomol. 2018; 57: 410–417. (https://doi.org/10.1111/aen.12292).

Contact details

Maarten van Helden
South Australian Research & Development Institute
GPO Box 397 Adelaide SA 5001
61 8 8429 0642
maarten.vanhelden@sa.gov.au

Return to contents

Notes

Frost mapping – a future management tool

Uday Bhaskar Nidumolu.

CSIRO, Adelaide.

Notes

Contact details

Uday Bhaskar Nidumolu
Uday.Nidumolu@csiro.au

Return to contents

Notes

Cereal Pathology Update 2021

Hugh Wallwork, Tara Garrard and Marg Evans.

South Australian Research and Development Institute; Affiliates of The University of Adelaide, School of Agriculture, Food and Wine.

GRDC project codes: UOA2003-008RTX, DAS1905-013SAX, CUR1905-001SAX

Keywords

- net form net blotch, crown rot, spot form net blotch, fungicide resistance, Systiva®, stripe rust, wheat powdery mildew.

Take home messages

- Resistance to Systiva® and tebuconazole in the net form net blotch (NFNB) pathogen population was readily found on the West Coast of the Eyre Peninsula and is present in much of South Australia (SA).
- Increased virulence on barley in the NFNB pathogen population has been identified on the Northern Yorke Peninsula and in isolates tested from across Western Australia (WA).
- Resistance to Systiva has been identified in the spot form net blotch (SFNB) pathogen population in WA. Growing barley on barley was again part of the problem.
- Powdery mildew in wheat was a problem across wide areas of SA in 2020 and fungicide resistance is a significant threat limiting our ability to manage it.
- Crown rot was severe in 2020 and inoculum levels will be high, going into 2021. An effective seed treatment is on the horizon.

Season summary

A reasonable start to the season with good early rains gave warning that foliar diseases could have been a problem in 2020. This was followed by a dry winter that delayed the development of most diseases and, in particular, ensured that Septoria, which requires more consistent rain periods, would not be a serious problem to most growers outside of the South-East. These early wet and then very dry conditions greatly favoured the development of crown rot in winter and many crops were seriously affected in 2020. Inoculum levels will be very high in stubbles from these crops for the 2021 season, so care should be taken in choosing what to grow in these paddocks in 2021.

The disease that resulted in the greatest number of enquiries to SARDI's cereal pathology team was powdery mildew in wheat. This has become a regular problem on the upper Yorke Peninsula, but in 2020 the disease was found to be a concern across a much wider area. The cooler, more humid conditions through spring favoured spread and development of the disease through the canopy and also onto the heads and many crops were given a spray to try to manage the problem. Apart from the favourable spring conditions, this disease has also been building up in recent years because of the widespread cultivation of very susceptible varieties that trace their pedigree back to Wyalkatchem$^{\Phi}$. Amongst these varieties are Scepter$^{\Phi}$ and Chief CL Plus$^{\Phi}$. Mace$^{\Phi}$ was the exception amongst

these varieties in that it is rated only moderately susceptible to susceptible (MSS) to powdery mildew and is therefore significantly better than the susceptible to very susceptible (SVS) ratings of the newer varieties that have replaced it. Stubbles from these infected crops will be hosting the survival fruiting bodies of the fungus so there will be a substantial carryover of inoculum across the state going into the new season.

Unfortunately, the pathogen causing powdery mildew in wheat is another that has developed resistance to some fungicides. In this case resistance to the strobilurins and some of the older demethylation inhibitors (DMI), or azole, fungicides is common on the upper Yorke Peninsula. It is highly likely that this resistance is now much more widespread. This will mean that where inoculum levels are likely to be high, growers should avoid the most susceptible varieties and try and manage any subsequent infection with a mixture of fungicides applied early to keep inoculum levels down.

Stripe rust made a reappearance and this season a mixture of the older, Scepter virulent strain and a new strain from the east was seen which has reduced virulence on Scepter$^{\phi}$ and related varieties but increased virulence on Trojan$^{\phi}$, DS Bennett$^{\phi}$ and many of the durums. Leaf and stem rust were again absent from wheat crops apart from some leaf rust in the South-East. Barley leaf rust was more common and was assessed in National Variety Trial (NVT) plots at Brentwood and Roseworthy.

Net form net blotch

Testing of samples of NFNB on adult plants of many barley varieties reveals their 'pathotype', that is their pattern of virulence which distinguishes them from each other. Repeating this testing each year reveals the selection that the pathogen population is under and this largely reflects the varieties that are grown in the areas the samples are collected from. This is not entirely the case because some varieties are released which have almost no resistance and other varieties have resistance which is more durable than others. Added to this is the somewhat random nature of mutations that determine which virulences arise, and therefore, can be selected for.

Table 1 shows the 2020 isolates tested so far, and indicates that Commander$^{\phi}$, Compass$^{\phi}$, Fathom$^{\phi}$ and Spartacus CL$^{\phi}$ are all susceptible (S) or very susceptible (VS) at multiple sites. In the case of Compass$^{\phi}$ and Spartacus CL$^{\phi}$ this situation has evolved since their release and widespread cultivation. Fleet$^{\phi}$ and Maritime$^{\phi}$, which were very susceptible in the past, now appear to be quite resistant at all sites bar one. This shows that in the absence of that variety being grown, the pathogen can quite rapidly lose virulence for that variety. One isolate collected from Maritime$^{\phi}$ in an NVT trial at Bute showed however, high virulence on both these varieties as well as on the older varieties; Clipper, Schooner and Sloop SA that had previously shown a high level of durable resistance to this disease. These data show how variable this pathogen is and how important it is to keep the level of disease in crops as low as possible. The more the disease is allowed to develop the more the variation and virulence will develop in the future.

Amongst the newer varieties, Banks$^{\phi}$, Bottler$^{\phi}$, Traveler and Kiwi$^{\phi}$ appear to have the best resistance. RGT Planet$^{\phi}$ continues to show moderate resistance (MR) in much of SA, although in the South-East this variety is VS and in previous years virulence on RGT Planet$^{\phi}$ has been recorded on the Lower Eyre Peninsula. Other varieties with notable resistance are Rosalind$^{\phi}$, Scope$^{\phi}$ and Vlamingh$^{\phi}$.

In 2020 for the first-time similar tests were conducted with NFNB isolates collected from other states. In Western Australian isolates, despite lower levels of reported disease, the level of virulence was surprisingly high and more so than in South Australian isolates (Table 2)

These pathotype tests have revealed that the most useful resistance was to be found in the varieties Banks$^{\phi}$, Fleet$^{\phi}$, Kiwi$^{\phi}$, Maritime$^{\phi}$, Scope$^{\phi}$ and Vlamingh$^{\phi}$. However, it is also known that, apart from Scope$^{\phi}$ and Kiwi$^{\phi}$, all these varieties have shown high susceptibility to at least one, and often many, isolates in tests carried out in previous years. Scope$^{\phi}$ appears to have the most durable resistance of all varieties tested, although it has rated S to one isolate in SA (Bute 2020) and one from NSW (Moree 2003).

The information from these tests can be used to help select varieties that have effective or different resistance patterns to NFNB in each region. Keeping a mix of varieties in an area helps to control the disease in a manner similar to mixing and rotating chemical control measures.

Table 1. Results of adult plant tests with net form net blotch isolates collected from SA in 2020.

	28/08/2020	9/10/2020	9/10/2020	9/10/2020	9/10/2020	29/09/2020	9/10/2020	28/08/2020	28/08/2020	29/09/2020	29/09/2020	9/10/2020	28/08/2020	9/10/2020
Isolate	9/20	41/20	52/20	55/20	42/20	51/20	54/20	10/20	11/20	19/20	33/20	69/20	14/20	68/20
Variety	Spartacus(D)	Compass(D)	Spartacus(D)	Spartacus(D)	Spartacus(D)	Compass(D)	Spartacus(D)	Barley	Rosalind(D)	Compass(D)	Spartacus(D)	Maritime(D)	Spartacus(D)	Commander(D)
Location	Pt Kenny	NE Pt Kenny	Mt Hall	Mt Cooper	Pt Kenny	Mortana	Elliston	Wauraltee	Minlaton	South Kilkerran	Warnertown	Bute	Reeves Plains	Beetaloo Valley
Alestar(D)	9	7	7	5	3	7	4	5	2	3	3	8	3	3
Banks(D)	3	3	2	2	1	2	3	2	2	1	2	4	2	2
Beast(D)	-	7	4	6	4	-	8	-	-	-	-	8	-	4
Bottler(D)	3	4	3	2	3	3	2	3	2	2	2	6	1	3
Clipper	4	4	4	5	2	6	4	4	3	2	3	8	3	3
Commander(D)	9	6	6	7	4	9	9	7	4	4	5	8	6	6
Compass(D)	7	6	7	5	3	8	7	7	3	2	4	7	6	4
Fathom(D)	9	7	7	6	5	9	8	9	4	7	5	9	7	5
Fleet(D)	3	2	3	2	1	2	2	3	1	2	4	9	2	2
KiwiA	3	2	3	2	1	3	3	1	2	2	2	5	1	3
Laperhouse	8	7	5	4	2	8	5	5	3	3	2	8	3	2
Leabrook(D)	8	7	6	7	4	8	9	6	3	5	3	8	6	5
Maritime(D)	3	3	3	2	2	3	3	3	2	3	2	9	3	2
Maximus CL(D)	6	5	4	5	5	7	7	7	4	5	2	7	5	4
RGT Planet(D)	4	4	4	5	4	5	2	4	2	2	2	5	3	3
Rosalind(D)	4	2	4	3	2	3	3	6	2	2	2	3	5	2
Schooner	6	7	3	2	3	7	7	5	4	3	3	8	4	5
Scope(D)	-	2	2	2	2	3	3	-	2	3	2	7	-	2
SloopSA	5	4	3	4	2	7	6	7	2	3	2	8	2	3
Spartacus CL(D)	9	4	5	4	4	5	7	8	6	4	2	8	7	4
Traveller	4	3	3	3	1	3	2	3	1	2	1	4	3	3
Westminster(D)	3	2	3	3	2	7	6	3	2	2	3	6	2	3
Vlamingh(D)	4	4	3	3	2	3	2	3	2	2	2	6	2	2

n.b. 1 = resistant (R), 3 = moderately resistant (MR), 5 = moderately susceptible, 7 = susceptible (S), 9 = very susceptible (VS)

Table 2. Results of adult plant tests with net form net blotch isolates collected from WA in recent years by Curtin University.

Isolate	NB2015-025	19PTT044	NB2016-47	NB2016-53	NB2016-54	NB2016-55	19PTT199A	NB2016-57	19Ptt48	NB2015-35	NB2015-33	NB2015-033	19PTT-026	19PTT-013	19PTT-016
Variety	Baudin(D)	Bass(D)	Barley	Barley	Oxford	Oxford	Bass(D)	Barley	RGT Planet(D)	Compass(D)	Compass(D)	Oxford	RGT Planet(D)	Bass(D)	RGT Planet
Location	Wickepin NVT	Boyup Brook	Kendenup Nth	Woogenell-up	Williams Nth	Williams	Tenterden	Toodyay	Mayanup	Frankland NVT	S. Stirling NVT	Frankland NVT	Qualeup	Arthur River	Kojonup
Alestar(D)	5	9	7	7	7	6	7	6	7	7	4	7	7	3	4
Banks(D)	2	4	2	2	3	2	3	4	3	2	1	2	3	1	1
Beast(D)	5	9	4	7	8	5	6	8	4	7	3	6	3	4	3
Bottler(D)	2	9	4	8	7	8	7	7	8	9	6	9	7	6	4
Clipper	5	8	4	2	5	2	7	7	7	7	3	7	4	2	2
Commander(D)	9	9	8	8	9	8	9	9	9	9	7	8	4	4	3
Compass(D)	6	9	8	9	5	7	9	9	8	8	6	7	6	6	3
Fathom(D)	5	9	7	7	8	6	7	8	8	8	7	8	5	6	1
Fleet(D)	2	4	2	2	2	2	2	3	2	3	1	2	1	1	1
Kiwi(D)	3	5	2	2	3	2	3	5	2	2	2	5	3	2	1
Laperhouse	4	9	5	6	9	5	8	8	7	8	2	6	2	3	3
Leabrook(D)	8	9	9	9	7	8	9	9	7	9	7	9	6	7	4
Maritime(D)	2	3	2	3	3	2	2	2	2	3	2	2	2	2	1
Maximus CL(D)	5	9	5	7	7	7	7	8	8	8	3	7	4	6	4
RGT Planet(D)	2	8	5	7	6	5	7	7	7	8	5	8	8	6	2
Rosalind(D)	3	7	5	5	4	3	5	7	6	7	2	5	3	1	1
Schooner	7	8	5	8	9	4	8	8	7	7	2	7	4	3	3
Scope(D)	2	5	2	2	2	2	3	4	3	2	2	3	3	3	2
SloopSA	6	9	7	3	7	7	8	-	8	8	3	8	4	4	3
Spartacus(D)	6	7	4	6	4	5	7	7	5	7	3	6	3	4	2
Traveller	2	7	7	8	8	6	8	7	6	8	3	8	4	5	2
Westminster(D)	2	6	4	4	5	4	6	7	2	7	3	7	2	3	3
Vlamingh(D)	2	8	2	3	4	3	3	5	2	2	2	2	2	2	2

n.b. 1 = resistant (R), 3 = moderately resistant (MR), 5 = moderately susceptible, 7 = susceptible (S), 9 = very susceptible (VS)

Fungicide resistance testing of the SA isolates by Fran Lopez of Curtin University has revealed that resistance to Systiva and tebuconazole is now very common along the stretch of country from Streaky Bay down to Elliston on the west coast of the Eyre Peninsula as well as across the Yorke Peninsula. Resistance to Systiva has also been confirmed from Lock and Kybybolite in 2019 and at Avon in 2020. Where resistance has been detected, growers are advised to avoid using Systiva for the following year at least and are advised to use alternative fungicides for early season control, where required. For further advice and up to date information on fungicide resistance, go the Australian Fungicide Resistance Extension Network (AFREN) website (https://afren.com.au/).

Spot form net blotch

In 2020 Curtin University researchers detected resistance to Systiva in the spot form net blotch (SFNB) pathogen population in WA. The resistance was detected in three paddocks near Cunderdin that had grown barley in successive seasons with Systiva applied to the seed each time. This is precisely the scenario where resistance to NFNB was first detected in SA in 2019. Growing barley on barley is not a good idea but if a grower does so despite this advice, then it is advisable to ensure that different chemical treatments are rotated, more resistant varieties are used, and any control is applied early to keep inoculum levels low.

Acknowledgements

The studies undertaken to enable this information to be provided is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would therefore like to thank them for their continued support. The NFNB isolates were also kindly contributed by Simon Ellwood from Curtin University.

Useful resources

https://pir.sa.gov.au/__data/assets/pdf_file/0011/356429/Cereal_Variety_Disease_Guide_Feb_2020.pdf

https://www.pir.sa.gov.au/__data/assets/pdf_file/0005/237920/Cereal_Seed_Treatments_2021.pdf

https://afren.com.au/understanding/#grower-advice

Contact details

Dr. Tara Garrard,
Research Scientist Cereal Pathology
SARDI
08 8429 2247
tara.garrard@sa.gov.au
@TaraGarrard

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

Return to contents

Notes

Management of powdery mildew on fungicide resistant wheat

Sam Trengove[1], Stuart Sherriff[1], Jordan Bruce[1] and Fran Lopez Ruiz[2].

[1]Trengove Consulting; [2]Centre for Crop and Disease Management.

Keywords

- wheat powdery mildew, fungicide resistance.

Take home messages

- Improving varietal resistance from susceptible to very susceptible (SVS) to moderately susceptible (MS) had a greater impact on reducing powdery mildew infection than use of any registered fungicide.
- In furrow and seed treatments provided early powdery mildew control, however this effect dissipated as the growing season progressed.
- Demethylation inhibitors (DMI) and quinone outside inhibitors (QoI) fungicides provided powdery mildew control, despite reduced sensitivity and resistance being detected within the population to these modes of action.
- Yield loss related to powdery mildew stem infection assessed at mid booting (GS45) ranged from 4-9.4kg grain/ha/stem pustule across three trials, resulting in yield loss of up to 17%.
- Cost of control and likely return on investment (ROI) should take into consideration the spatially variable nature of powdery mildew.

Background

Wheat powdery mildew (WPM) has been documented to cause up to 25% yield loss in Australia (https://grdc.com.au/news-and-media/newsletters/paddock-practices/protecting-cereal-crops-from-powdery-mildew). Common wheat varieties that are currently being grown have poor varietal resistance, with many having ratings of susceptible to very susceptible (SVS), and only a few varieties rated as moderately susceptible to susceptible (MSS) or moderately susceptible (MS). There has been a large shift in area sown to SVS varieties in the last four years, with the dominant variety Mace(Φ) that is MSS being superseded by Scepter(Φ) that is SVS. Consequently, there is a heavy reliance on fungicides for WPM control. Fungicide options have relied heavily on the DMI group 3 (triazole) products such as tebuconazole and epoxiconazole, and these are the basis of many fungicide mixes. In more recent years, there has also been increasing use of the QoI group 11 (strobilurin) actives in mixtures with DMI fungicides in products such as Amistar Xtra® (azoxystrobin + cyproconazole). Often the fungicide strategy has been targeting other pathogens, such as stripe rust and Septoria, with application timing and product selection targeted to these pathogens. The use of these products has also been providing some control of susceptible populations of WPM provided suitable application coverage is achieved. However, by its nature, WPM often infects low down in the canopy covering lower leaves, leaf sheathes and stem where good spray coverage can be difficult with late application timings.

Fungicide resistance in WPM was identified in the northern Yorke Peninsula region in 2019, with testing performed by the Centre for Crop and Disease Management (CCDM). DMI and QoI groups were both implicated. With reduced efficacy expected from these modes of action, currently the registered

alternative mode of action options are limited to the succinate dehydrogenase inhibitors (SDHI) (group 7) products such as Aviator® Xpro® (bixafen + prothioconazole) or ElatusTM Ace (benzovindiflupyr + propiconazole), which are mixtures of group 7 (SDHI) and group 3 (DMI) active ingredients.

Trials were initiated in 2020 as part of a SAGIT project to better understand the best practice management of WPM given emerging fungicide resistance issues.

Method

In 2020 five trials were implemented near Bute, northern Yorke Peninsula. Each of the five trials had a particular focus, these were:

1. Varietal resistance and post emergent fungicides (Sown 11 May).
    - Four varieties with disease ratings for WPM ranging from MS to SVS and four fungicide strategies.
2. Pre-emergent fungicides (sown to Chief CL Plus$^{\phi}$, 11 May).
    - Seven pre-emergent fungicides +/– post emergent fungicide.
3. Post emergent fungicides (sown to Scepter$^{\phi}$, 4 May).
    - A range of post emergent fungicide treatments applied twice at GS32 and GS45.
4. Fungicide timing (sown to Scepter$^{\phi}$, 4 May).
    - Fungicide applied at four timings (GS14, 32, 45 and/or 65) in 10 timing combinations.
5. Fungicide sequencing (sown to Chief CL Plus$^{\phi}$, 11 May).
    - A trial focused on controlling resistant powdery mildew using 15 combinations of pre-emergent and post emergent fungicides from a range of fungicide groups.

The trials were located at a site where fungicide resistant WPM was detected in a survey during 2019. At this site in 2019, 64% of the powdery mildew population had reduced sensitivity to the DMI (Group 3) fungicides and 1.5% of the population was resistant to the strobilurin (Group 11) fungicides.

Powdery mildew assessments were made on three occasions for each trial targeting early infection, mid-season infection and late infection in the head. For the first two assessment timings, individual pustules were counted on the stem and each leaf. Where pustules merged, an individual pustule was counted as an area of 2mm^2. For the head infection a 0 – 9 score was used where 0 = no powdery mildew, 5 = 50% coverage of powdery mildew, 9 = 90% coverage, etc.

Wheat powdery mildew was first identified at the site on 22 June 2020 at GS14, with a single pustule being observed. Rainfall at Bute in 2020 was characterised by periods of wet and dry throughout the growing season, with a dry early mid-winter and dry early spring (Figure 1). In particular, the trials appeared moisture stressed in mid-September, losing significant green leaf area as a result, and potentially limiting disease progression. These results should be interpreted in that context.

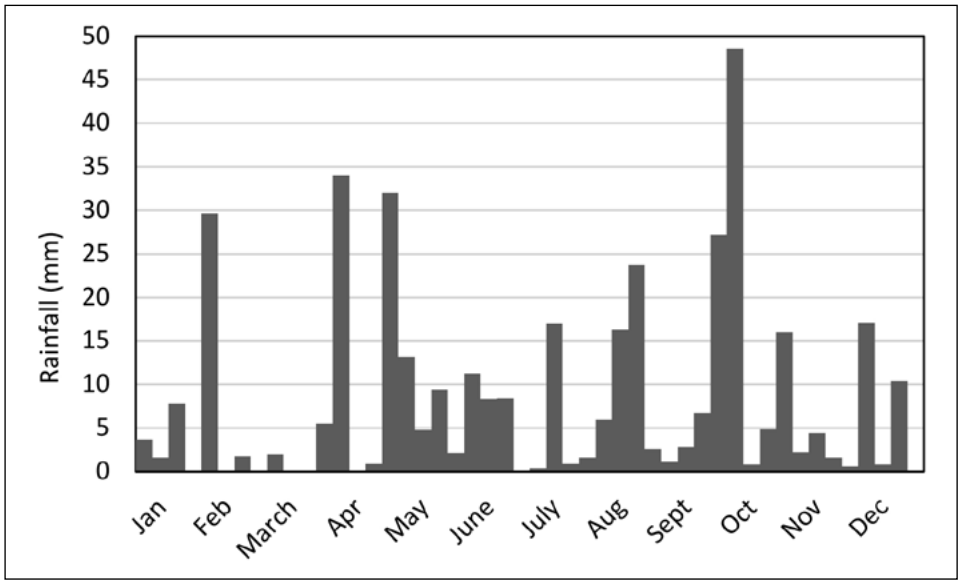


Figure 1. Weekly rainfall at Bute in 2020. April to October rainfall 301mm, 2020 annual rainfall 390mm.

Results and discussion

Varietal resistance to wheat powdery mildew

Four varieties were selected for this trial with a range of resistance levels to determine the benefit of varietal resistance and its interaction with fungicide use. The varieties were Kord CL Plus$^{\phi}$ (MS), Mace$^{\phi}$ (MSS), Scepter$^{\phi}$ (SVS) and Chief CL Plus$^{\phi}$ (SVS). Scepter$^{\phi}$ and Chief CL Plus$^{\phi}$ were both chosen as they have commonly been grown in the area and field observations indicated that Chief CL Plus$^{\phi}$ may be more susceptible, despite both being rated SVS in 2019. Kord CL Plus$^{\phi}$ was chosen despite being lower yielding, as it is one of the only MS rated main season varieties available for this area.

Wheat powdery mildew pustule counts showed that varietal resistance had a much greater impact on infection level than the application of epoxiconazole at GS32 (Figure 2). Epoxiconazole use reduced pustule number by 22-51%, whereas changing from an SVS variety (Chief CL Plus$^{\phi}$ or Scepter$^{\phi}$) to an MS variety (Kord CL Plus$^{\phi}$) reduced pustule number by 74-82%.

Comparing yields of untreated with yields of best performing fungicide treatment for each variety indicates yield gain from fungicide use of up to 17%, 9%, 8% and 1% for Chief CL Plus$^{\phi}$, Scepter$^{\phi}$, Mace$^{\phi}$ and Kord CL Plus$^{\phi}$, respectively (Figure 3). The scale of yield increase in response to fungicide treatment is reasonably consistent with varietal resistance rating, where the yield response to fungicide declines with improved varietal resistance.

Pre-emergent fungicides

Several in furrow fungicide treatments reduced WPM infection early in the season (Figure 4a). Flutriafol treatments appeared to be the best of these, reducing pustule number by up to 76%, whereas Uniform® treatments were similar to the untreated control. However, all treatments were ineffective as the season progressed and were not able to provide a long-term benefit in this instance (Figure 4b), despite the application of benzovindiflupyr + propiconazole (Elatus Ace) at 500ml/ha at GS32 and azoxystrobin + cyproconazole (Amistar Xtra) at 400ml/ha at GS45. The change in pustule number from 22 July (Figure 4a) to 24 August (Figure 4b) indicates the large increase in disease pressure over that time frame. No yield benefit was observed in response to in furrow fungicide treatment, however a 6.7% (0.26t/ha) increase was observed in response to post emergent fungicide application of Elatus Ace followed by Amistar Xtra (data not shown).

It is important to put these results in the context of a small-scale plot trial where airborne spores from adjacent plots with poorer control will increase infection load on treatments with better control that were kept clean early. In the case of a highly effective pre-emergent fungicide in a broad scale situation, such as a large paddock, the response to the pre-emergent fungicide may last longer than reported here, as there will be less inoculum

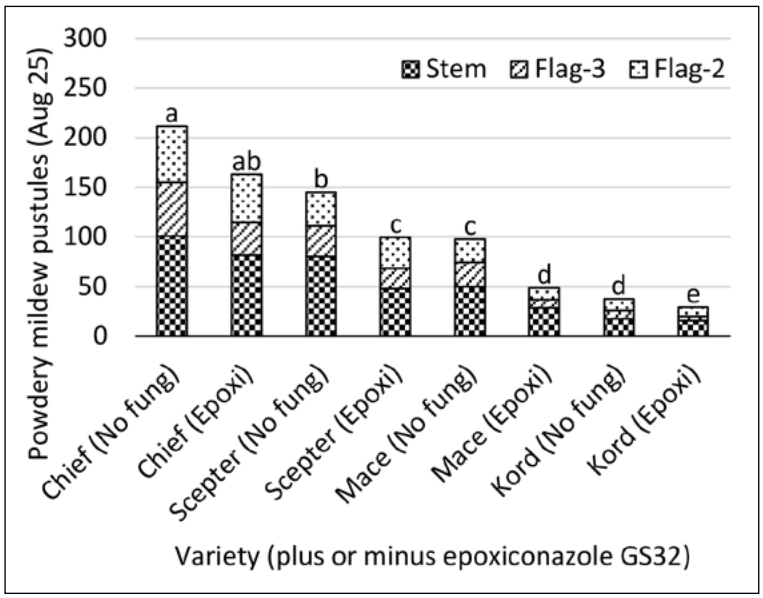


Figure 2. Variety and epoxiconazole fungicide effect on pustule number at GS45 (August 25) on the stem and leaves flag – 3 and flag – 2. Epoxiconazole (125g/L) applied at 500ml/ha at GS32 (July 16). Pr (>F) value = 0.027. Letters denote significant differences between pustule totals.

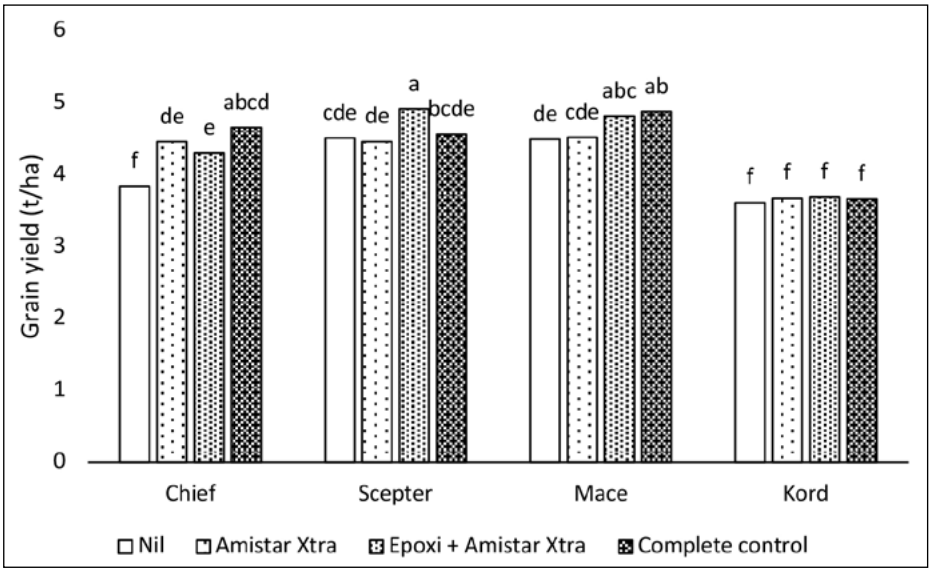


Figure 3. Variety and fungicide effect on grain yield. Epoxiconazole (125g/L) applied at 500ml/ha at GS32 (July 16). Amistar Xtra® (azoxystrobin + cyproconazole) applied at 400ml/ha at GS45 (August 25). Variety*fungicide Pr (>F) = 0.057, LSD (0.1) = 0.41t/ha, variety Pr (>F) = <0.001, LSD (0.05) = 0.19 t/ha, fungicide Pr (>F) = 0.004, LSD (0.05) = 0.19.

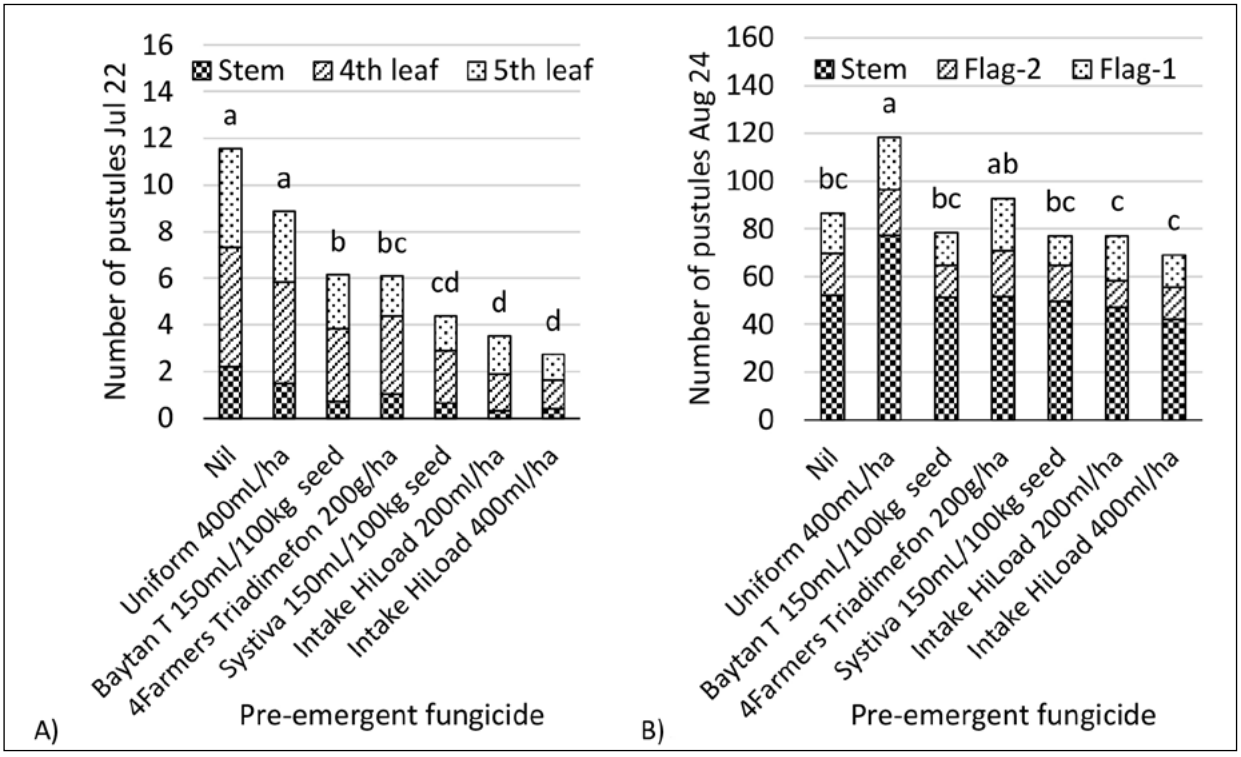


Figure 4. a) Number of pustules on the stem, 4th leaf and 5th leaf on 22 July, Pr (>F) = <0.001, LSD (0.05) = 0.11, **b)** Number of pustules on the stem, flag -2 and flag -1 on 24 August, Pr (>F) = 0.002, LSD (0.05) = 0.13, averaged across plus and minus post emergent Elatus™ Ace fungicide treatments. Letters denote significant differences between pustule totals.

load present as a result of good early control. This impediment is a common problem in plot trials where different treatment times are being compared and airborne pathogens are involved.

Post emergent fungicides

Demethylation inhibitors (Group 3) and strobilurin (Group 11) fungicides applied individually provided 56-76% pustule reduction at 13 August and 28-76% pustule reduction at 11 September (Figure 5 and 6), despite reduced sensitivity (64%) and fungicide resistance (1.5%) being detected in WPM at this site in 2019, respectively. There was a difference within the group 3 fungicides, with the commonly used fungicide, epoxiconazole performing poorer than both the tebuconazole and tebuconazole + prothioconazole (Prosaro®) fungicides. This could suggest a better performance of particular DMI fungicides when reduced sensitivity has developed due to the emergence of specific mutations at the DMI target site. The combination of group 3 and group 11 fungicides was better than either applied alone at the earlier assessment and that continued at the 11 September assessment, where epoxiconazole + azoxystrobin (Tazer Xpert™) was one of the best treatments. However, cyproconazole + azoxystrobin (Amistar Xtra) did not provide a significant advantage over the better DMIs such as tebuconazole or Prosaro. While the QoI treatments worked reasonably well, the continuous use of this group of fungicides will inevitably lead to the accumulation of resistant individuals and disease control problems in the future.

New SDHI plus DMI fungicide mixtures, bixafen + prothioconazole (Aviator Xpro) and benzovindiflupyr + propiconazole (Elatus Ace) provided 58 and 67% pustule reduction, respectively at the earlier assessment and 59 and 84% reduction at the later assessment (Figure 5 and 6). These provide little or no improvement compared with the better DMI actives, posing the question 'do the SDHI actives provide much WPM control, or is it the DMI mix partner doing most of the work?' A standalone SDHI fungicide (A (7)), not registered in wheat, performed poorly, suggesting that the group 3 DMI mix partner in the SDHI products were providing a significant level of the control.

Linear regression between stem pustules assessed at mid booting (GS45) and grain yield indicates yield loss in the range of 4-9.4kg/ha/stem pustule across three trials (Figure 7). This may provide a guide to predicting yield loss in season but requires further validation across multiple sites and seasons.

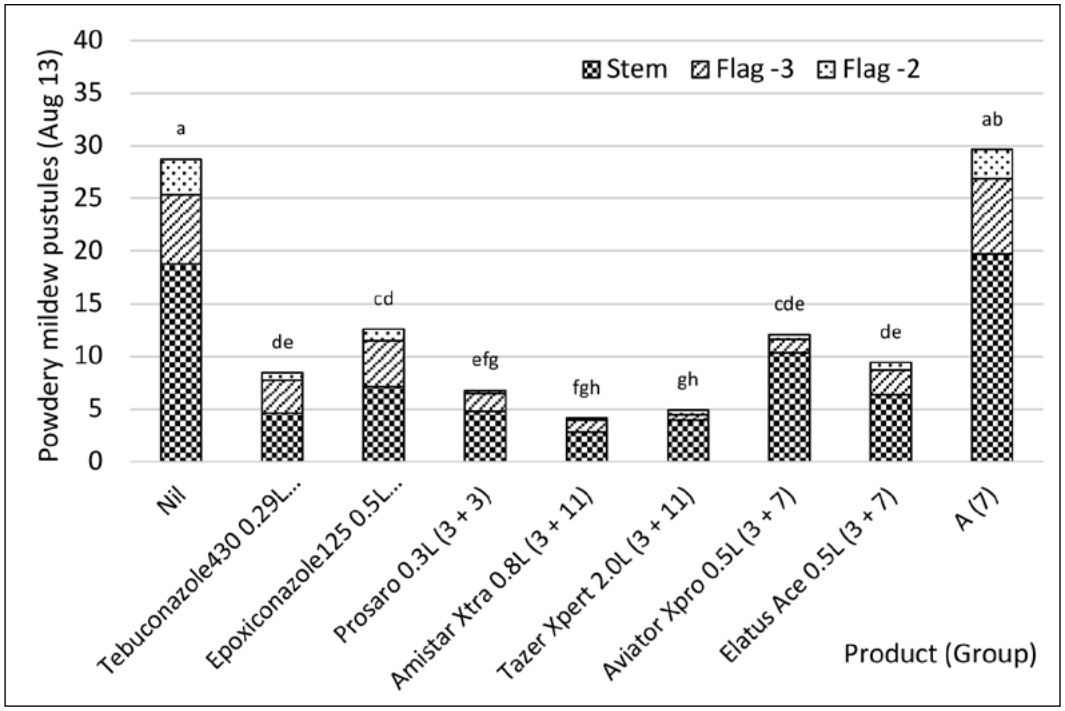


Figure 5. Number of powdery mildew pustules for selected treatments on the stem and flag leaf minus 3 and 2 counted 13 August 2020. Post emergent fungicides applied 16 July. Letters denote significant differences between log transformed totals Pr (>F) = <0.001.

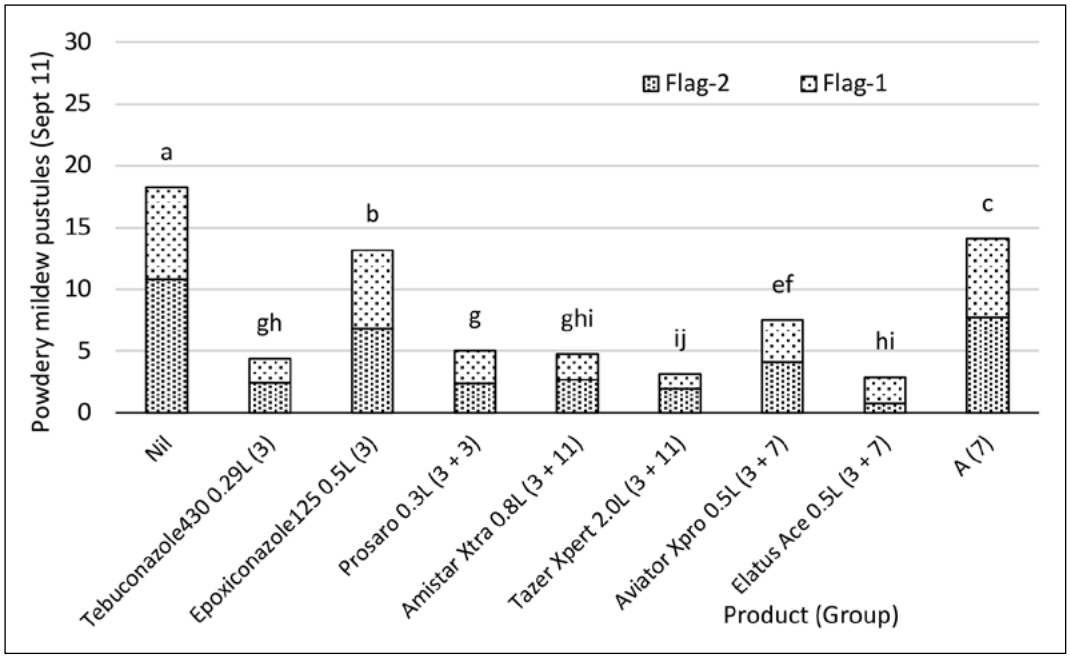


Figure 6. Number of powdery mildew pustules for selected treatments on flag leaf minus 2 and 1 counted 11 September 2020. Post emergent fungicides applied 16 July and 25 August. Letters denote significant differences between log transformed totals Pr (>F) = <0.001.

Sensitivity analysis of fungicide costs versus potential yield loss

Wheat powdery mildew incidence and severity has been observed to be highly variable spatially, particularly in the northern Yorke Peninsula region where this work has been undertaken. Typically, the disease is worst where the crop is growing on the lighter textured sands and dunes, whereas on the heavier textured soils in the swales, disease incidence tends to be much lower. The basis for these differences is not well understood. The area at high risk of severe WPM infection will have an impact on the likely returns from investment in fungicide.

Partial gross margin (PGM) sensitivity analysis indicates that with a $23/ha fungicide cost, 14% of the area or greater would need to be at high risk from severe WPM infection to generate a positive return on fungicide investment across the whole paddock, given the assumptions listed in Table 1. Where fungicide resistance increases and alternative modes of action are required, fungicide

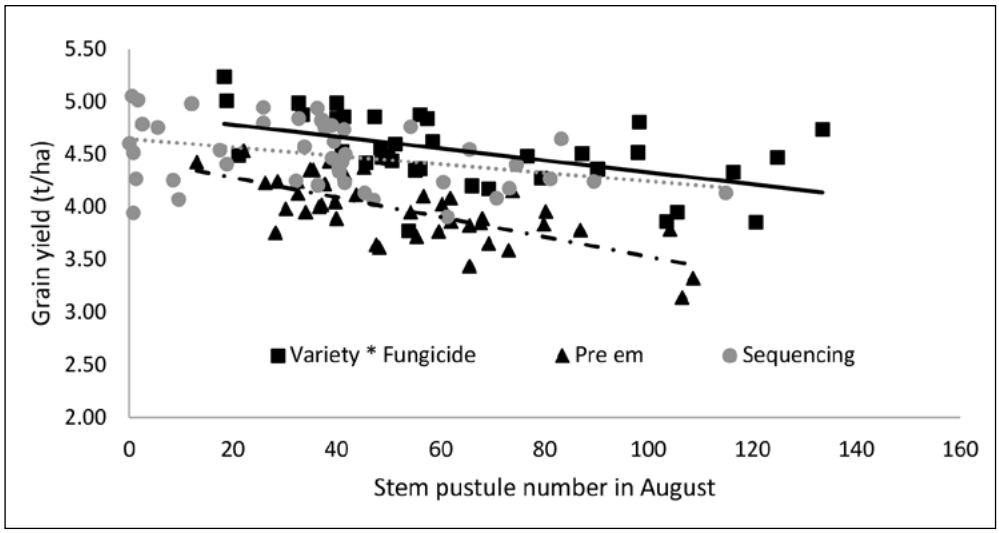


Figure 7. Linear regression of stem pustule numbers in August and wheat grain yield (t/ha) for the variety * fungicide (y = -0.0057x + 4.8967, R^2 = 0.2572), pre-emergent fungicide (y = -0.004 + 4.6494, R^2 = 0.1239) and sequencing fungicide trials (y = -0.0094x + 4.4692, R^2 = 0.4938).

Table 1. Partial gross margin sensitivity analysis for varying areas of soil type more susceptible to wheat powdery mildew (WPM). Analysis uses the following assumptions: farm gate wheat price $250/t, additional fungicide cost including application $23/ha, potential wheat yield 4t/ha, yield loss associated with WPM in more susceptible areas 17%.

Paddock area with high WPM	Paddock area with low WPM	Paddock average yield with no additional fungicide (t/ha)	Farm gate gross income without additional fungicide ($/ha)	Farm gate gross income with additional fungicide ($/ha)	Partial gross margin (PGM) ($/ha)
0%	100%	4.00	1000	977	*-23*
10%	90%	3.93	983	977	*-6*
20%	80%	3.86	966	977	11
30%	70%	3.80	949	977	28
40%	60%	3.73	932	977	45

Table 2. Partial gross margin sensitivity analysis for varying areas of soil type more susceptible to wheat powdery mildew (WPM). Analysis uses the following assumptions: farm gate wheat price $250/t, additional fungicide cost including application $37/ha, potential wheat yield 4t/ha, yield loss associated with WPM in more susceptible areas 17%.

Paddock area with high WPM	Paddock area with low WPM	Paddock average yield with no additional fungicide (t/ha)	Farm gate gross income without additional fungicide ($/ha)	Farm gate gross income with additional fungicide ($/ha)	Partial gross margin (PGM) ($/ha)
0%	100%	4.00	1000	963	*-37*
10%	90%	3.93	983	963	*-20*
20%	80%	3.86	966	963	*-3*
30%	70%	3.80	949	963	14
40%	60%	3.73	932	963	31

price is likely to increase. In this example if the fungicide cost increases to $37/ha then 22% of the area or greater would need to be at high risk of severe WPM infection to generate a positive return on fungicide investment, given the assumptions listed in Table 2.

This is a simplistic model of spatial distribution of WPM. It is likely that there will be some benefit of additional fungicides on other areas of the paddock that do not have the high WPM pressure seen on sandy rises. Therefore, these PGMs may underestimate the returns, and therefore, a smaller area of high WPM pressure will be required to cover fungicide costs.

Conclusion

Shifts in fungicide sensitivity and resistance to both DMI group 3 and QoI group 11 fungicides have been detected in WPM. Despite this, fungicides from these groups are currently still providing reasonable control. Selection of varieties with improved WPM resistance can reduce disease pressure more than any currently registered fungicide and negates the need for fungicide use for this pathogen.

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 SAGIT, the authors would like to thank them for their continued support. The input during this project from Michael Brougham, Hugh Wallwork, Tara Garrard, Kejal Dodhia and Nick Poole is gratefully acknowledged.

Contact details

Sam Trengove
Trengove Consulting, Bute SA
Phone 0428262057
samtrenny34@hotmail.com
@TrengoveSam

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

Return to contents

Notes

Novel agronomy strategies for reducing the yield decline from delayed emergence

Kenton Porker[1], Brendan Kupke[1], Melissa McCallum[1], Courtney Peirce[1], Paul Swain[1], Wayne Reid[1], Peter Hayman[1], Dane Thomas[1], Bronya Alexander[1], Andrew Ware[2] and James Hunt[3].

[1]South Australian Research and Development Institute Waite Agronomy and Climate applications; [2]Eyre Peninsula Ag Research; [3]LaTrobe University

GRDC project code: DAS1910 – 003BLX

Keywords

- sowing time, frost, phenology, crop development, yield, defoliation, establishment.

Take home messages

- Matching crop variety development to environment should remain a key focus of crop management, such as early sowing of a slower developing winter cultivar (prior to 1 May). There are some downsides to winter wheat adoption, as there is risk of later emergence (after 1 May), hence flowering later than optimal, and reduced yields.
- It is very important to make the most of early establishment opportunities because, other than genetic improvement, there were a lack of solutions for negating yield decline from later emergence or for speeding up crop development.
- Strategies to improve earlier establishment under low soil water potentials would be transformative for lower rainfall districts.
- Applications of hormones showed little ability to speed up development or increase yield of late emerged crops.
- Barley was better suited to later emergence than wheat. There are possibilities to quantify the regional differences in the role of barley and other crops compared to wheat in the rotation and sowing time schedules needs to be revaluated accordingly.

Background

Current investment to close the yield gap has focused on earlier sowing with slower developing cultivars. In order to exploit the maximum yield, the farm's sowing program has to be finished and germination needs to occur by 15 May in many districts of South Australia (SA). The management of the early sown wheat project (ULA9175069) has demonstrated that when slow developing wheats are sown before 20 April they yield similarly to a fast developing cultivar sown in its optimal window (May 1-5). Larger and more consistent losses occur in frost prone landscapes from early sown, quick developing cultivars, and delaying sowing to avoid frost losses is a trade off with yield loss due to drought and heat. At later sowing there is a significant yield penalty in both development groups due to increased heat, drought, reduced biomass and reduced tillering. The yield penalty from later emergence in winter cultivars has not been quantified and there has been less focus on reducing the yield decline from later planting through agronomic management.

Much of the Southern Region, particularly SA, is limited in the ability to fully exploit early sowing due to seasonal breaks that typically don't allow for crop establishment before 1 May in over 50% of years. The varied nature of climatic events also results in a significant percentage of seasons where the seasonal break doesn't occur until late May to early

June. In these years water use efficiency is often lower and offers potential to be improved through new approaches.

The ability to reduce the yield decline from later planting through agronomic management in wheat and barley was evaluated. Management that focused on attempts to produce more biomass and mimic the morphology of early sown crops while still flowering on time using faster developing cultivars was explored. If such an approach could be successful, this paradigm shift would reduce the trade-off from missing earlier planting opportunities.

Methods

Experiments were conducted at four locations in SA, which vary in rainfall and temperature and thus seasonal yield potential (Table 1). Three germination dates were targeted, defined here as time of sowing TOS1, TOS2 and TOS3. TOS1 was in mid-April which is optimal for winter cultivars in all environments and too early for quick developing spring cultivars. TOS2 was in early to mid-May (depending on site), which is optimal for quick developing spring cultivars. TOS3 was in early June, which is considered too late for all cultivars and the focus of this experiment. Sowing dates and site locations are outlined in Table 1.

Wheat and barley genotypes were selected based on developmental patterns. A winter cultivar suited to earlier sowing was selected with local adaptation to each site. For wheat this was either DS Bennett$^{\phi}$, Longsword$^{\phi}$ or Illabo$^{\phi}$, for barley this was Urambie$^{\phi}$ and Cassiopee. The quick developing spring wheat, Scepter$^{\phi}$ and the barley variety, Compass$^{\phi}$ were the controls across all sowing times.

Additional agronomic treatments applied at the latest sowing date (TOS3) aimed to maximise biomass and reduce the yield decline from later planting or missed opportunities in wheat and barley (Table 2). Agronomic interventions such as doubling plant density, doubling nitrogen (N) supply, applying growth promoting root auxins and hormones, and including quicker developing cultivars were tested.

Cultivar and species responses to sowing date

The trends for wheat and barley were similar for TOS1 and TOS2. Highest yields were achieved by early sown (TOS1) winter cultivars, yielding similar to their respective quick spring cultivars sown at their optimal time (TOS2). Winter barley was approximately 0.45t/ha higher yielding than winter wheat at both sowing times TOS1 and TOS2, suggesting winter barley might be better adapted than current winter wheat cultivars. Winter cultivar yields were optimised at the April germination date and both wheat and barley suffered a 12% yield penalty when emergence was delayed until mid-May (TOS2).

Spring barley yielded similarly to spring wheat at TOS1 and TOS2 (Figure 1 and Figure 2), however barley yielded 0.4t/ha higher at the later planting, suggesting barley is more suited to later emergence than wheat. Both quick spring wheat and barley suffered a yield penalty from early planting, and there is evidence of less yield decline in barley relative to wheat at later planting. In the quick spring wheat, there was a 13% yield penalty from early sowing compared to May sowing and 11% from delayed planting. In the quick spring barley there was a 12% yield penalty from early sowing compared to May sowing and there was no yield penalty from delayed planting unlike wheat. This is an important consideration for growers where breaks are likely to occur past 15 May.

When the same responses are analysed in terms of total biomass production, the trends are similar to the yield responses but there are several insightful key differences. The quick spring wheat was more effective at producing biomass from earlier planting dates than the quick spring barley, and winter wheat achieved a similar biomass to the winter barley. Therefore, the yield differences between these treatments are most likely to be due to a poorer harvest index of wheat which was driven by its poorer frost tolerance compared to barley. Barley was effective at producing more biomass than wheat at later planting dates consistent with

Table 1. Site locations, GPS coordinates and corresponding sowing dates.

Site location	Sowing date		
	TOS1	TOS2	TOS3
Minnipa	17/4/19	7/5/19	4/6/19
Loxton	15/4/19	10/5/19	4/6/19
Giles Corner	18/4/19	16/5/19	6/6/19
Cummins	15/4/19	14/5/19	14/6/19

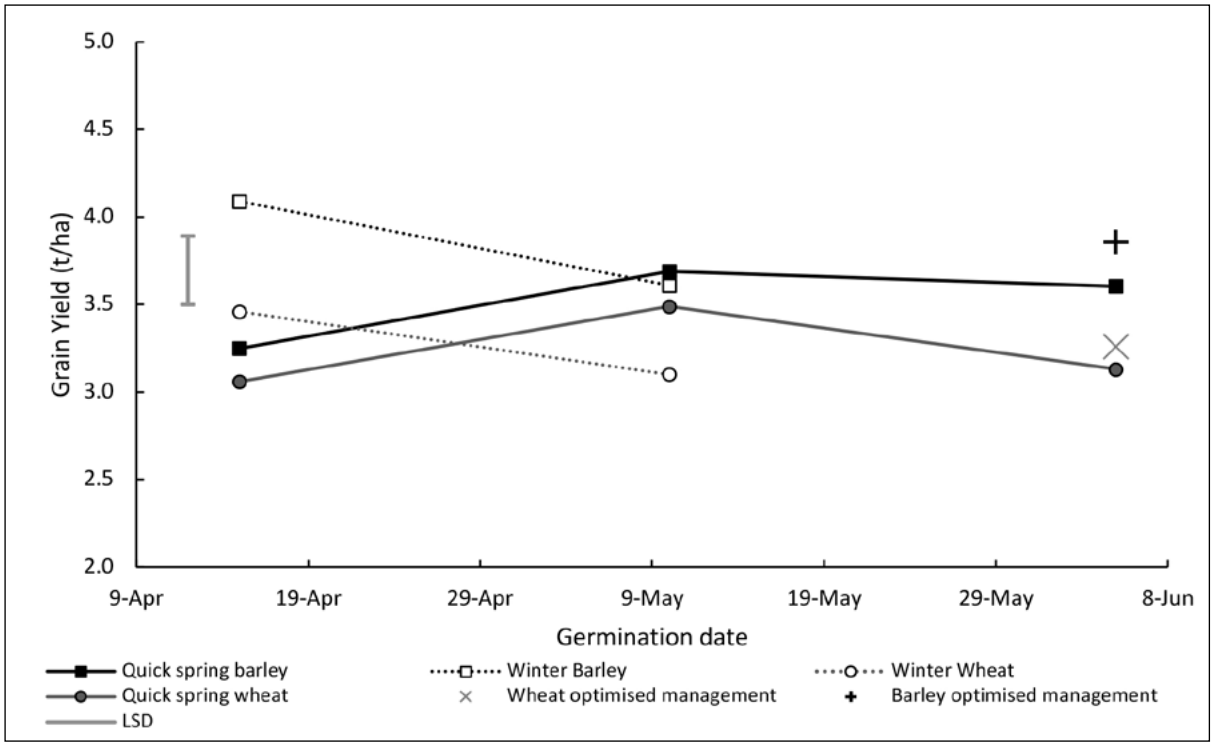


Figure 1. Grain yield responses to germination date of quick barley, quick wheat, winter wheat and barley averaged across four locations in South Australia 2019. The optimised management data points are for the late sown quick spring wheat (X) and barley (+) and represent the highest yielding treatment with different management tailored for later planting.

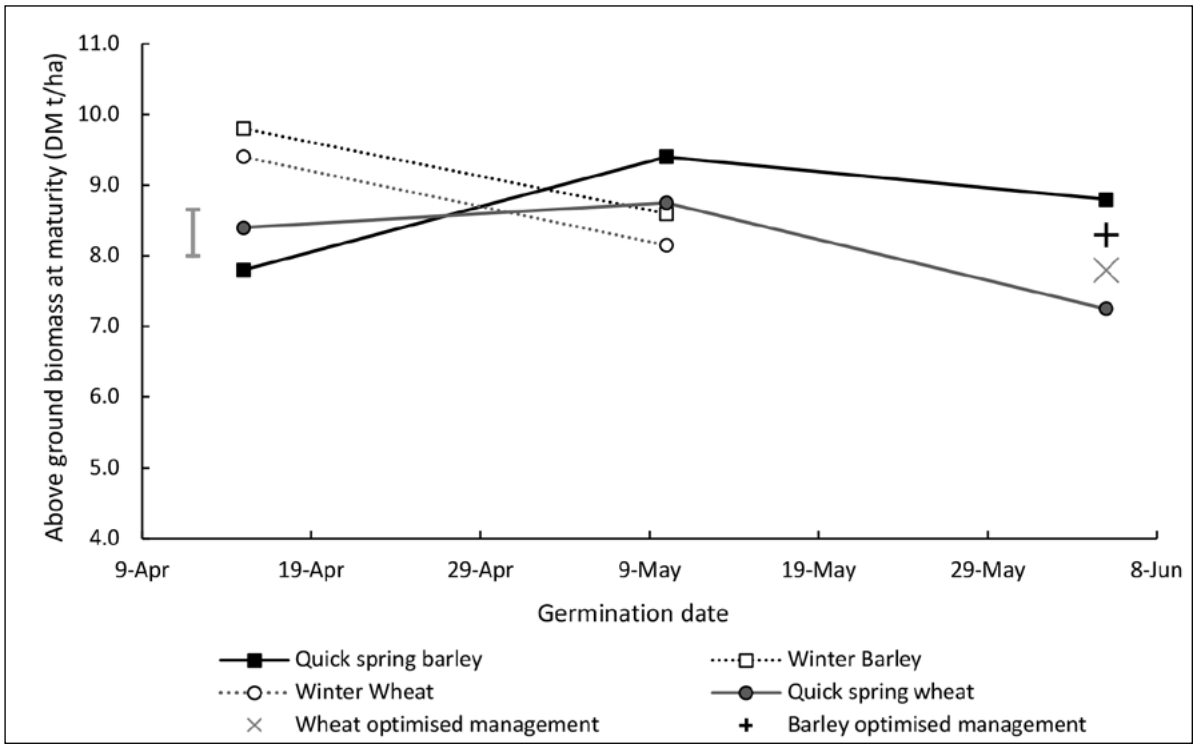


Figure 2. Total biomass responses to germination date of quick spring barley, quick spring wheat, winter wheat and barley averaged across four locations in South Australia 2019. The optimised management data points are for the late sown quick spring wheat (X) and barley (+) and represent the highest yielding treatment with different management tailored for later planting.

the yield responses. The physiological reasons for this requires further investigation. One plausible explanation is that barley has a greater ability to grow at sub-optimal temperatures associated with the vegetative phase occurring during the peak of the cold winter.

Management to limit the yield decline of late emerged crops

At later emergence, other agronomic interventions such as doubling plant density, doubling N supply, applying growth promoting root auxins and hormones did not reliably increase yield relative to control (Table 2, Figure 1 and Figure 2). There was also evidence of yield penalty with exogenous hormones; gibberellic acid and cytokinin. It was possible to increase biomass in wheat relative to the control, however this did not translate into increase in grain yield. Currently adapted cultivars performed the best under the same management regime from early planting.

Conclusions and recommendations

These data highlight that there may be limited scope to reduce yield penalties from later planting with the crop management techniques evaluated here. However, species choice is critical and barley was better suited to later planting than wheat. The mechanisms for this require further investigation and may be due to faster growth or maturity rates under suboptimal temperatures associated with delayed planting. The suitability of other species such as oats would also warrant investigation.

Matching crop variety development to environment remains the best focus of management. Our other experiments (discussed at the 2021 Grains Updates, Adelaide?) suggest there are a number of solutions to slow development and negate the yield penalties associated with sowing a quick spring variety prior to its optimal time (such as winter cultivars and resetting crops). However, the lack of solutions for negating the yield decline from later emergence means making the most of early establishment opportunities, and these techniques are even more important. These solutions require validation for adoption along with further research to improve establishment of crops prior to the 15 May.

Another interesting finding is that it has previously been assumed the yield penalty from winter cultivars emerging after 1 May is significantly greater than any spring cultivars emerging after that time. However, this research suggests that the new generation of winter cultivars may not suffer the same degree of yield decline as previously thought. This means growers potentially have more opportunities in many parts of SA to establish winter wheats than currently predicted in the next module of research. This research needs to be validated.

Table 2. Grain yield, biomass, and harvest index responses to management at later emergence (TOS3) average across all sites with standard quick – mid wheat Scepter and quick barley cultivar Compass.

Cultivar/ phenology	Management	Grain Yield (t/ha)	Biomass (t/ha)	Harvest Index
Wheat				
Scepter(Φ)	Control (180 seeds/m^2)	3.1	7.3	0.46
Scepter(Φ)	Double Seeding Density	3.1	7.4	0.42
Scepter(Φ)	Double Seeding Density + 50 Seedbed N	3.1	7.9	0.39
Scepter(Φ)	Double Seeding Density + AUXINS	3.3	7.8	0.42
Scepter(Φ)	Double Seeding Density + Gibberellic acid & Cytokine	2.9	7.3	0.38
Corack(Φ) (Quicker)	Double Seeding Density	3.2	7.8	0.40
Barley				
Compass(Φ)	Control (150 seeds/m^2)	3.6	8.8	0.44
Compass(Φ)	Double Seeding Density	3.5	8.6	0.43
Compass(Φ)	Double Seeding Density + Gibberellic acid & Cytokine	2.8	7.6	0.34
Spartacus(Φ) (Quicker)	Double Seeding Density	3.8	8.3	0.46
Spartacus(Φ) (Quicker)	Double Seeding Density + Gibberellic acid & Cytokine	3.2	8.1	0.38
CSIROB3 (Very Quick)	Double Seeding Density	3.1	7.0	0.39
	P value Treatment	<0.001	<0.001	<0.01
	LSD	0.35	0.51	0.02

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.

Contact details

Kenton Porker
Kenton.Porker@sa.gov.au

(D)Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994

Return to contents

Notes

Novel agronomy strategies for manipulating flower date and yield

Kenton Porker[1], Brendan Kupke[1], Melissa McCallum[1], Courtney Peirce[1], Paul Swain[1], Wayne Reid[1], Peter Hayman[1], Dane Thomas[1], Bronya Alexander[1], Andrew Ware[2], James Hunt[3], Michael Moodie[4], and Sarah Noack[5].

[1]South Australian Research and Development Institute Waite Agronomy and Climate applications; [2]Eyre Peninsula Ag Research; [3]LaTrobe University; [4]Frontier Farming; [5]Hart Field Site group.

GRDC project code: DAS1910 – 003BLX

Keywords

- sowing time, frost, phenology, crop development, yield, defoliation, reset.

Take home messages

- Mechanical defoliation and removal of main stem apices during early stem elongation was reliably able to 'reset' (slow down) development of early sown quick – mid spring wheat.
- Yields of reset quick – mid spring wheat were comparable to early sown winter wheat.
- The reset strategy requires fine tuning but differs from dual purpose research and current grazing recommendations.
- If slowing crop development is successful, growers may only require one cultivar and can still spread sowing dates, or plant early irrespective of seasonal break timing, and then manipulate phenology to better match the season.
- The reset strategy should complement breeding and may not be suitable for the lower rainfall zones and some seasons.
- Alternative strategies should be pursued that delay development without reducing biomass in lower rainfall environments.
- New management strategies could also apply to other crops and be used in more agro-ecological zones.
- Hormone application showed little ability to speed up development under field conditions.

Background

The timing of autumn rainfall which allows germination is variable, and spring cultivars popular in the Southern region have a narrow period during which they must germinate in order to flower during the optimal period. Growers need access to a range of genetic and management tools to more reliably ensure optimal flowering times are achieved and widen available sowing windows. The ability to manipulate wheat development in-crop using applied hormones or chemical and mechanical defoliation in southern Australia was evaluated. Interventions sought to either slow development in precocious crops that germinate before their optimal time or accelerate the development of slower developing cultivars that germinate later than is optimal.

Methods

Experiments were conducted at five locations in South Australia (SA) (Table 1). Three germination dates were targeted, defined here as time of sowing (TOS) 1, 2 and 3. TOS1 was mid-April which is optimal for winter cultivars in all environments and too early for quick developing spring cultivars. TOS2 was early to mid-May (depending on site) which is optimal for quick developing spring cultivars in most SA environments. The TOS3 was early June which is considered too late for all cultivars. The Hart site had only an early and late planting date. Sowing dates and site locations are outlined in Table 1.

Genotypes were selected based on three contrasting development patterns. A winter cultivar suited to earlier sowing was either the quick winter Longsword$^{\phi}$ at Minnipa, or the mid-quick developing Illabo$^{\phi}$. The very slow developing spring cultivar Nighthawk$^{\phi}$ was used, it has a facultative vernalisation and strong photoperiod requirement, which makes it suitable for earlier sowing. The well adapted quick - mid developing spring wheat Scepter$^{\phi}$ was sown at all sites.

Experiment 1 included defoliation treatments. A chemical anionic acid and mechanical defoliation (using a mower to remove the emerging apex) treatment were imposed to a locally adapted fast spring cultivar sown early when the crop reached Zadoks growth stage 31 – 32 (Terminal spikelet). This is known as the reset strategy.

Experiment 2 included hormone treatments; gibberellic acid and 6-Benzyladenine (Cytokine) applied to locally adapted mid - quick spring, slow spring and winter wheat cultivars that germinated either early, optimally or late. These treatments were applied at both the 5-leaf stage and the onset of stem elongation.

Experiment 1 results - flowering time and yield responses to defoliation

Flowering dates of the quick - mid spring cultivar sown in mid-April varied from 11 August at Hart to 6 September at Giles Corner and flowered before optimal flowering periods at all sites (Table 2). The winter cultivar sown mid-April flowered seven days later than optimum at Minnipa, four days later at Cummins, 16 days later at Loxton, one day later at Giles Corner, and eight days earlier at Hart.

Mechanical defoliation had a significant effect on flowering time, but the chemical defoliation did not (NS Fpr>0.05) (not presented). The effect of mechanical defoliation ranged from nine-day delay in flowering date at Giles Corner to 18 days at Hart. The mean effect of defoliation was a 13 day delay in time to flower across all sites; however this only shifted flowering to be within the optimum flowering period (OFP) defined by Flohr *et al.* (2017) at Minnipa, and still too early at the other sites.

Table 1. Site locations, GPS coordinates and corresponding sowing dates.

Site Location	Sowing Date		
	TOS1	TOS2	TOS3
Hart	16/4/19	NA	3/6/19
Minnipa	17/4/19	7/5/19	4/6/19
Loxton	15/4/19	10/5/19	4/6/19
Giles Corner	18/4/19	16/5/19	6/6/19
Cummins	15/4/19	14/5/19	14/6/19

Table 2. Anthesis dates of the quick - mid cultivar Scepter$^{\phi}$ across all sites in 2019 and in response to defoliation (Mechanical defoliation and removal of main stem apices during early stem elongation using a mower) from the mid-April germination date in experiment 1.

Site	Quick – mid Spring flowering date	Defoliated quick - mid Spring flowering date	Defoliation effect in days delayed to flowering	Winter cultivar control flower date	Optimal flowering date#
Minnipa	14 Aug	25 Aug	-11	2 Sep*	25 Aug
Cummins	22 Aug	02 Sep	-11	24 Sep	18 Sep
Loxton	18 Aug	03 Sep	-17	25 Sep	9 Sep
Giles Corner	6 Sep	15 Sep	-9	27 Sep	26 Sep
Hart	11 Aug	29 Aug	-18	16 Sep	24 Sep

*#Optimal flowering dates were derived for these locations from Flohr et al. (2017), *Longsword$^{\phi}$*

Table 3. The yield response to management combinations of an early sown quick – mid spring untreated and defoliated compared to a winter cultivar sown early, quick – mid spring sown at optimum, and quick – mid spring sown late at all locations. Letters indicate significant difference within a site.

Management Combination			Environment				
Sow Date	Cultivar	Treatment	Cummins	Giles Corner	Loxton	Hart	Minnipa
TOS1	Quick – mid spring	Untreated	3.7d	5.1b	0.6bc	2.3b	2.7b
TOS1	Quick – mid spring	Mech Defoliation	5.2a	5.9a	0.8ab	2.7a	3.1a
TOS1	Quick – mid spring	Chem Defoliation	3.6d	5.0b	0.4c	2.2b	-
TOS1	Mid – winter	Untreated	4.5c	5.5ab	1.1a	2.2b	2.7b
TOS2	Quick – mid spring	Untreated	5.6b	5.3b	0.6bc	-	2.5b
TOS3	Quick – mid spring	Untreated	4.3c	5.2b	1.0a	1.8c	2.1c
Environment			<0.001				
Management			0.003				
Environment x Management			<0.001				

Grain yield responses

The reset spring strategy (mechanical defoliation of the early sown quick – mid spring cultivar) was the highest yielding treatment at Cummins and Minnipa, and similar to either the quick – mid spring sown at optimal or the highest yielding treatments at all other sites. Importantly, compared to the untreated quick - mid spring sown early, the reset strategy yielded 1.5t/ha higher at Cummins, 0.8t/ha higher at Giles Corner, 0.4t/ha higher at Hart and Minnipa, and not significantly different at Loxton. Compared to the practice of early sown winter wheat the mechanical reset strategy yielded 0.7t/ha higher at Cummins, 0.5t/ha higher at Hart, 0.4t/ha higher at Minnipa, and was not significantly different at the other sites. The yield of the reset strategy was greater than the late-sown quick- mid developing spring at all sites except Loxton. Chemically defoliated treatments yielded similarly to the untreated early sown quick – mid spring cultivar in all environments (Table 3).

Across all sites the benefit of the reset strategy compared to the mean yield of a quick – mid spring sown early was 0.4t/ha and was not significantly different to the quick – mid developing sown on time (May) (Figure 1). The yield of the winter cultivars sown early (TOS1) were not significantly different to the quick – mid spring sown on time (TOS2), but were 0.6t/ha less than the quick – mid cultivar when both were sown at TOS2, and 0.8t/ha less when both were sown at TOS3.

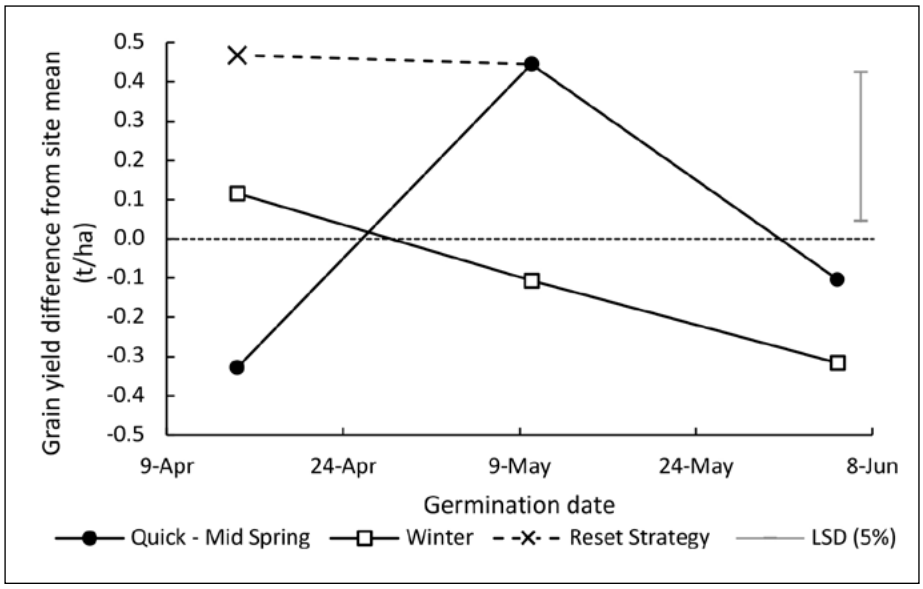


Figure 1. Mean grain yield responses of the quick - mid cultivar Scepter and slow developing winter wheat to germination date and the defoliation treatment (X) applied to Scepter(ϕ) sown early at Minnipa, Tarlee, Cummins, and Loxton in 2019.

Experiment 2 results - flowering time and yield responses to hormones

The effect of cultivar and sowing date x site interactions were greater and more significant than any hormone treatment for both grain yield and flowering date (data not shown). There was no significant effect of the hormone treatments on grain yield, despite a TOS x cultivar x treatment interaction for biomass and a site x treatment interaction for harvest index (data not shown). The largest effect on grain yield was consistent with the flowering date responses, in that there was a TOS x cultivar x site interaction. At Cummins optimum yields were achieved from flowering times around 19 September which corresponded to a quick – mid spring wheat sown on 10 May, 24 September at Loxton, and 23 September at Giles Corner (Figure 2).

Discussion and agronomic considerations

1. The reset strategy has the following advantages: seed of a smaller number of cultivars is required, and it is more robust than winter wheat if germination ends up being late. The newer generation of winter wheats evaluated in these experiments are now capable of yielding similarly to quick – mid developing wheat sown at its optimal time (10 May). This means that if germination opportunities occur in April, growers can achieve yields similar to well adapted spring cultivars sown on time (Porker *et al.* 2019). However, there are some downside risks. When the winter wheat emerged in May it suffered a significant 0.55t/ha yield penalty (compared to a quick – mid at optimal), and a 0.75t/ha yield penalty from June emergence. This highlights the downside risk of a winter wheat in southern environments if it germinates after 1 May which is likely under 'dry sowing scenarios'. The likelihood of germinating rains increases substantially in May to June in SA, increasing the risk and difficulty to match crop development speed with an optimum germination and establishment date in winter cultivars. Compared to the emergent practice of early sown winter wheat, the mechanical reset strategy yielded either higher or similar at all sites. This is an important finding as it means that growers can achieve similar to greater yields as with an early sown winter cultivar without the downside risk of a yield penalty from delayed emergence or the need to

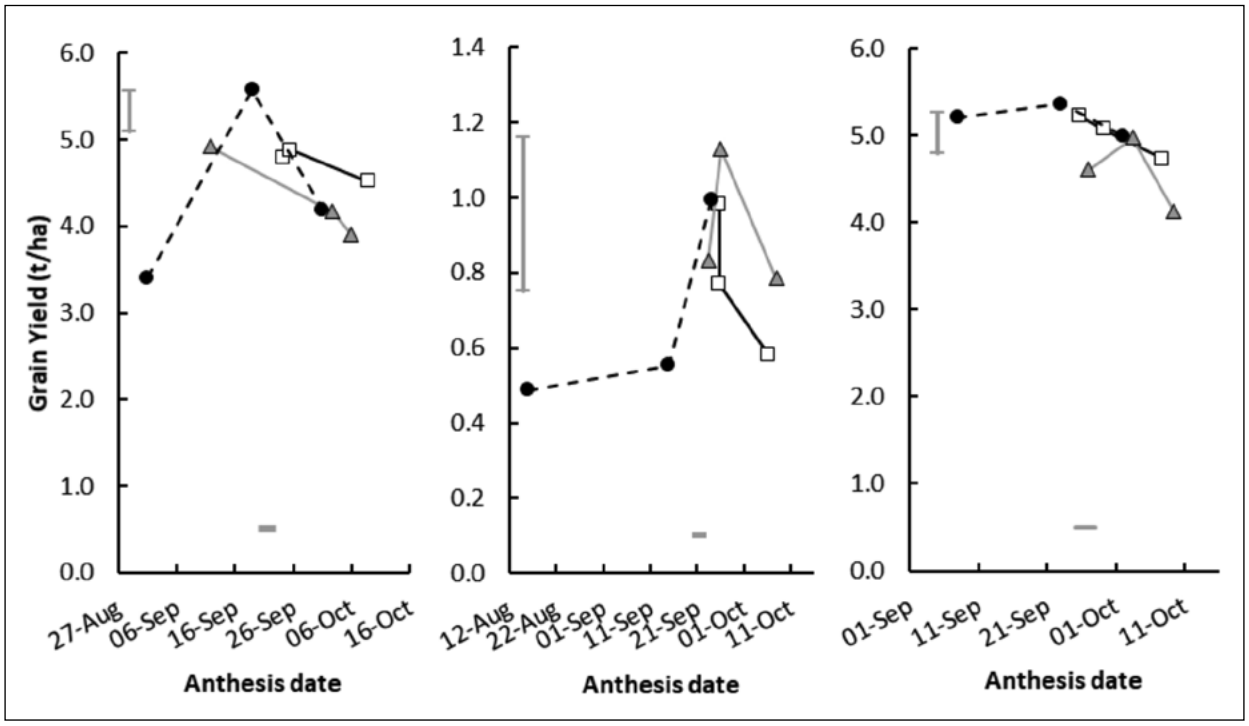


Figure 2. The relationship between flowering date and grain yield in response to sowing date (each progressive data point represents TOS1, TOS2, and TOS3) and cultivar ● fast spring, □ mid-fast winter, and the ▲slow spring across all three sites A) Cummins (left), B) Loxton (centre), and C) Giles Corner (right). The vertical grey bars indicate the LSD (5%) for grain yield, and the horizontal grey bars are the LSD for flowering time.

have multiple cultivars. If validated over sites and seasons, the reset strategy could be an alternative method for stabilising flowering time and yield that does not require growers to keep multiple cultivars.

2. The yield advantage of resetting crops was of greater magnitude in the higher yielding seasons (in field and simulation experiments) and similar to control treatments in the lowest yielding seasons. Growers to increase yields in the low rainfall regions, will likely require other solutions that can flower optimally without comprising biomass. Breeding faster developing winter cultivars that flower optimally from later establishment dates is one solution that needs to be pursued (Hunt *et al.* 2019b). LongswordA is the only fast winter cultivar currently commercially available, and feed classification of this variety will prevent widespread uptake by grain growers.
3. Our field studies only had capacity for one defoliation date, at one intensity level (cut at ground level). While we demonstrated this was effective in slowing down the development, more field experiments need to be conducted to determine the optimum timing and defoliation intensity.
4. These strategies all cost money and add another operation to farm logistics but could be offset by the value of grazing or making silage (too early to cure hay). In contrast to defoliation, hormone treatments had little effect on flowering time and yield under field conditions. Previous studies have demonstrated both gibberellic acid and 6-benzyladenine can alter plant development by directly influencing reproduction and floral initiation in winter cereals, particularly through vernalisation and photoperiod pathways (Razumov, 1960; Barabas and Csepely, 1978; Al-Jamali *et al.* 2002; Pearce *et al.* 2013). However, most of these experiments were conducted under glasshouse conditions, or were sprayed continually at more frequent intervals which are impractical interventions for field operations.
5. This resetting strategy challenges current agronomic recommendations as it differs from dual purpose research and grazing recommendations. Traditional defoliation timing in Australian spring wheats has been recommended to occur prior to the onset of stem elongation to avoid damaging the emerging apex, however these recommendations were always suggested in relation to late sown crops. Spring wheat cultivars sown on time usually incur a yield penalty when defoliated (Latta 2015, Frischke *et al.* 2015). This reset strategy is different as it deliberately tries to remove the apex in plants that are sown three weeks earlier and have emerged before their optimum date.
6. In our experiments chemical defoliation did not significantly delay flowering time and yields were similar to the untreated control. This was likely due to limited leaf burn and the desiccation effect of the acid under cold and wet winter conditions in SA. Further experiments should evaluate other chemical desiccants that are known to have a greater impact on leaf area in cereals.

Conclusion

The ability to speed up or slow down crop development within season unlocks new management possibilities not previously explored in annual grain crops. Hormone application showed little ability to speed up development under field conditions. Defoliation and removal of main stem apices during early stem elongation was reliably able to reset development of precocious spring wheat and increase yield relative to untreated controls. Yields of reset spring wheat were comparable to early sown winter wheat, meaning growers only require one cultivar and can still spread sowing dates substantially. The reset strategy needs to be fine-tuned and evaluated over sites and seasons, but if results are repeated this approach would be transformative as it offers growers the ability to plant early, irrespective of seasonal break timing and then manipulate phenology to better match the season. The approach may not be suitable for the lower rainfall zones and alternative strategies for this zone must be pursued, such as faster developing winter wheats that will maximise biomass production but flower on time from both early and late germination. New management approaches such as this complement breeding programs and are potentially a relatively low-cost adaptation tool for growers in a warming and drying climate. It could also apply to barley, used in more agro-ecological zones and doesn't have the same downside under late emergence as winter wheat.

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.

References

Al-Jamali, A., Turk, M., Tawaha, A., 2002. Effect of ethephon spraying at three developmental stages of barley planted in arid and semiarid Mediterranean locations. Journal of agronomy and crop science 188, 254-259.

Barabas, Z., Csepely, I., 1978. Shortening vernalization of winter wheat with kinetin. Euphytica 27, 831-835.

Flohr, B.M., Hunt, J.R., Kirkegaard, J.A., Evans, J.R., 2017. Water and temperature stress define the optimal flowering period for wheat in south-eastern Australia. Field Crops Research 209, 108-119.

Frischke, A., Hunt, J., McMillan, D., Browne, C., 2015. Forage and grain yield of grazed or defoliated spring and winter cereals in a winter-dominant, low-rainfall environment. Crop & Pasture Science 66, 308-317.

Hunt, J.R., Lilley, J.M., Trevaskis, B., Flohr, B.M., Peake, A., Fletcher, A., Zwart, A.B., Gobbett, D., Kirkegaard, J.A., 2019b. Early sowing systems can boost Australian wheat yields despite recent climate change. Nature Climate Change 9, 244-247.

Latta, R.A., 2015. Performance of spring cereal genotypes under defoliation on the Eyre Peninsula, South Australia. Crop and Pasture Science 66, 301-307.

Pearce, S., Vanzetti, L.S., Dubcovsky, J., 2013. Exogenous gibberellins induce wheat spike development under short days only in the presence of VERNALIZATION1. Plant physiology 163, 1433-1445.

Porker, K., Hunt, J., Harris, F., Noack, S., Moodie, M., Angel, K., al., e., 2019. Management of early sown wheat: matching genotype to environment. in: 19th Australian Agronomy Conference (Wagga Wagga Australian Society of Agronomy).

Razumov, V., 1960. The effect of gibberellic acid on development of winter cereals. Botanicheskii Zhurnal 45, 1732-1738.

Contact details

Kenton Porker
SARDI Waite Campus
0403 617 501
kenton.porker@sa.gov.au
@kentonp_ag

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

Return to contents

Notes

Notes

Integration of non-chemical tactics to improve brome grass management

Gurjeet Gill and Ben Fleet.

School of Agriculture, Food & Wine, Waite Campus, The University of Adelaide.

GRDC project code: 9175134

Keywords

- non-chemical weed management tactics, brome grass, weed management.

Take home messages

- The response of weed density to delayed sowing is influenced by not only the weather conditions, but also by the seed dormancy attributes of the weed populations. Less dormant weed populations tend to emerge quickly after the opening rains and they can be managed well by moderate delays in sowing. Conversely, high dormancy populations emerge more slowly and a delay in sowing tends to be less effective on such populations.
- At Riverton, a two-week delay in wheat sowing reduced in-crop brome grass density by 82% as compared to a 39% reduction at Mallala. As both sites received very similar rainfall in May, these large differences in brome grass establishment are likely to be associated with seed dormancy in these populations.
- Sakura® + Avadex® Xtra provided superior brome grass control than TriflurX® + Avadex® Xtra in the early sown wheat at both sites. However, follow-up post-emergent application of the imidazolinone (IMI) herbicide, Intervix® provided the best control of brome grass.
- At Riverton, there was a 9% yield penalty for the two-week delay in sowing. It is not possible to estimate the yield penalty from delayed sowing at Mallala due to severe frost damage to the crop in the first time of sowing.

Background

Weed infestations in Australia are responsible for large annual expenditures ($2.5 billion) and yield revenue losses ($745 million) for grain growers (Llewellyn *et al.* 2016). Annual ryegrass has maintained its number one ranking as the worst weed of Australian cropping systems for many years. However, brome grass has increased in importance and has climbed to be the fourth worst weed in terms of the area infested, as well as yield and revenue loss in grain crops in Australia (Llewellyn *et al.* 2016).

Brome grass tends to be difficult to control effectively with the pre-emergent herbicides that are registered for use in cereal crops. Even herbicides such as Sakura® are moderately effective and only provide weed suppression. On the positive side, evolution of herbicide resistance in brome grass has been relatively slow in comparison with ryegrass. Development of Clearfield® herbicide tolerant varieties still provides an excellent opportunity for the control of brome grass in cereal crops. Some growers are reluctant to grow Clearfield® crops due to the risk of carryover of herbicide residues into the next growing season. However, this technology appears to be the standout option at this stage for the control of brome grass in wheat and barley.

Previous research on non-chemical tactics for weed control has shown significant benefits of

higher wheat seeding rates for the suppression of ryegrass (e.g. Lemerle *et al.* 2004). Higher crop seeding rates can be easily integrated into weed control programs. Furthermore, adoption of precision agriculture technology allows growers to apply higher seeding rates only to the weediest parts of the paddock, thereby reducing the cost of weed management. Delay in crop sowing has also been suggested as a tactic for the management of dense weed infestations by allowing more time for weeds to germinate and establish prior to crop sowing. However, delayed sowing is often associated with lower crop yields, especially in the low to medium rainfall environments. Additionally, the effectiveness of delayed crop sowing is highly dependent on the rainfall received during the seeding delay and also on the seed dormancy of the target weed population. Gill and Kleemann (2013) showed that brome grass populations from cropping fields in the mid north of South Australia (SA) and Victorian Mallee regions had much longer seed dormancy than those from non-cropped habitats. This adaptation mechanism facilitates avoidance of pre-sowing weed control practices. Furthermore, research undertaken in this project has shown that the benefits of improved pre-sowing weed control by delayed sowing can be completely nullified in some weed populations by reduced competitiveness of late sown crops.

Field trials were undertaken in this GRDC investment, to investigate the effects of integrating crop sowing time, seeding rate and herbicide tactics on brome grass management. Results are presented for two field trials undertaken in 2019 to highlight the impact of these management tactics on brome grass control.

Method

Two replicated field trials were undertaken in SA in 2019 to investigate brome grass management in Razor CI Plus(b) Clearfield® wheat.

Results and discussion

Brome grass plant density and seedbank

The average seedbank of brome grass at Mallala was 1863 ± 303 seeds/m^2 and 2877 ± 406 seeds/m^2 at Riverton. Sowing time had a large influence on brome density at Riverton, with the two-week delay in sowing significantly ($P<0.05$) reducing in-crop brome grass density by 82% (Figure 1). Even though the reduction in brome density due to the two-week delay in sowing was also significant ($P<0.05$) at Mallala (38%), its effectiveness was much lower than at Riverton (82% reduction). Both sites received very similar rainfall during the month of May in 2019. Therefore, the difference in brome grass density response to delayed sowing at these two sites is likely to be related to differences in seed dormancy between the populations.

At Riverton there were significant differences between the three herbicide treatments in TOS 1 but not in TOS 2 (Figure 1a). It seems the sowing time was the dominant effect in this trial which meant that the herbicide treatments were statistically similar in TOS 2. However, there were significant differences between the herbicide treatments in TOS 1. The application of the IMI herbicide, Intervix® provided the most effective control of brome grass in both sowing times of wheat.

At Mallala, the TriflurX + Avadex Xtra mixture had a significantly higher brome plant density in TOS 1 than

Table 1. Management information for brome grass trials undertaken in 2019.

Detail	Mallala	Riverton
Crop (variety)	Wheat (Razor CL Plus)(b)	Wheat (Razor CI Plus)(b)
Sowing date	TOS 1: 16 May 2019	TOS 1: 16 May 2019
	TOS 2: 31 May 2019	TOS 2: 31 May 2019
Crop seed rate	100, 150 or 200 seeds/m^2	100, 150 or 200 seeds/m^2
Herbicides	1. TriflurX 2L/ha + Avadex Xtra 2L/ha 2. Sakura 118 g/ha + Avadex Xtra 2L/ha IBS 3. TriflurX 2L/ha + Avadex Xtra 2L/ha fb Intervix 750mL/ha post 3. TriflurX 2L/ha + Avadex Xtra 2L/ha fb Intervix 750mL/ha GS14	1. TriflurX 2L/ha + Avadex Xtra 2L/ha 2. Sakura 118 g/ha + Avadex Xtra 2L/ha IBS
Growing season rainfall (mm)	229	267

Active ingredients: Sakura = 850 g/kg pyroxasulfone; Avadex Xtra = 500 g/L triallate; TriflurX = 480 g/L trifluralin; Intervix = 33 g/L imazamox + 15 g/L imazapyr

time of sowing (TOS); incorporated by sowing (IBS); growth stage (GS); followed by (fb)

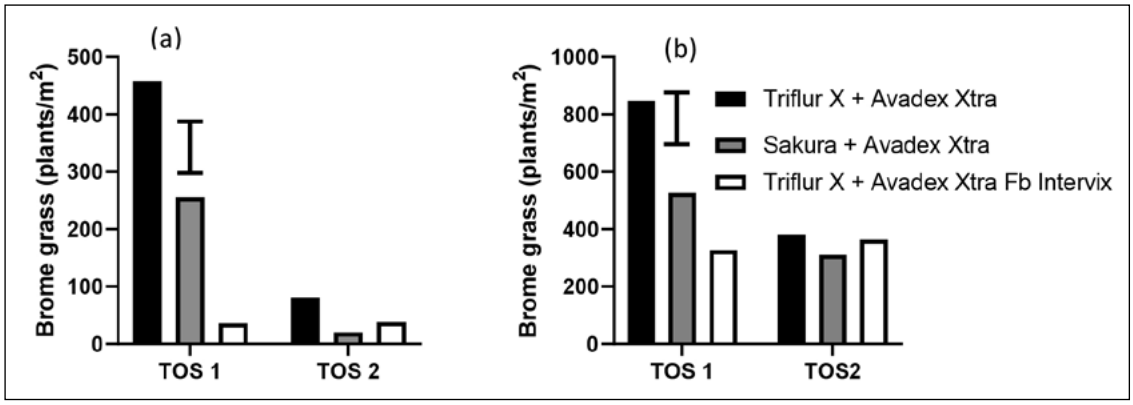


Figure 1. The effect of crop sowing time and herbicide treatments on in-crop brome grass plant density at Riverton (a) and Mallala (b). TOS 1 = 16 May and TOS 2 = 31 May. The error bars represent LSD (P=0.05).

the other herbicide treatments including the mixture of Sakura + Avadex Xtra (Figure 1b). It may seem surprising that TriflurX + Avadex Xtra fb Intervix had more than 300 brome grass plants/m2. However, these plants were very small due to late emergence from the seedbank. Most of these plants died later in the season before the panicle emergence stage (Figure 2b).

Brome grass seed production

When averaged across the wheat seeding rate and herbicide treatments, the two-week delay in seeding reduced brome seed production by 85% at Riverton and 40% at Mallala. This reduction in seed set by delayed sowing is consistent with its effect on brome grass plant density. Wheat seeding rate also had a significant effect on brome seed production. At Mallala, as wheat density increased from 100 seeds/m^2 (low) to the highest seed rate (200 seeds/m^2 – high) brome seed production was reduced by 42%. These results are consistent with previous findings that higher crop density can be an important part of an integrated weed management program.

At Riverton, the delay in crop sowing by two weeks reduced brome grass seed set by 76% for TriflurX + Avadex Xtra and 93% for Sakura + Avadex Xtra treatments. However, there was no such reduction in brome grass seed set following TriflurX + Avadex Xtra fb Intervix treatment because

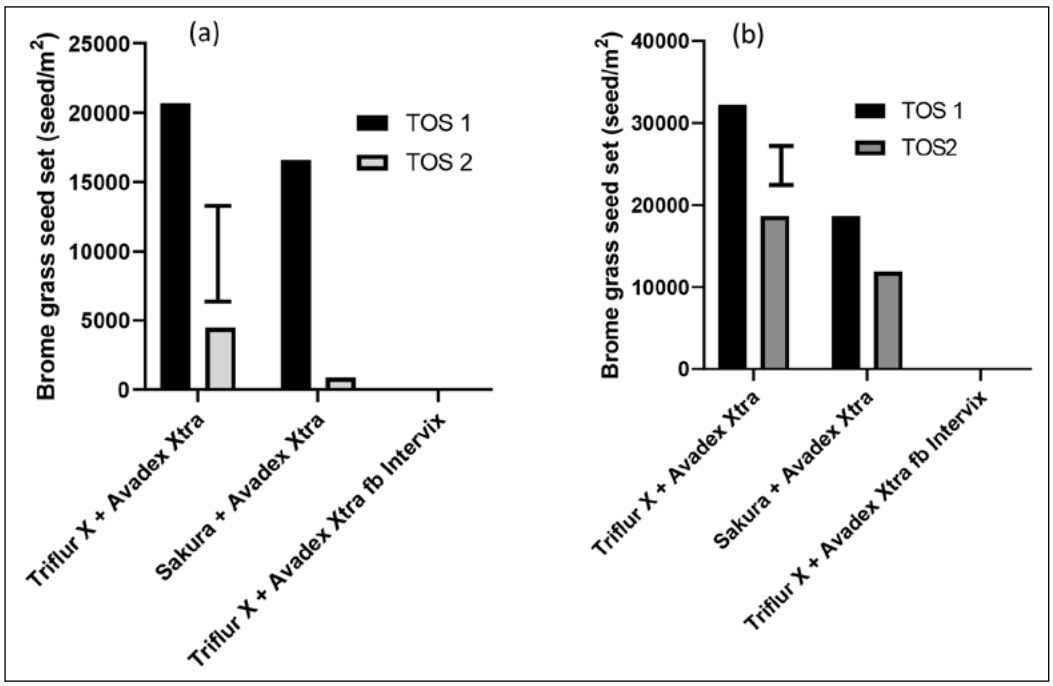


Figure 2. The effect of crop sowing time and herbicide treatments on in-crop brome grass seed production at Riverton (a) and Mallala (b). TOS 1 = 16 May and TOS 2 = 31 May. The error bars represent LSD (P=0.05).

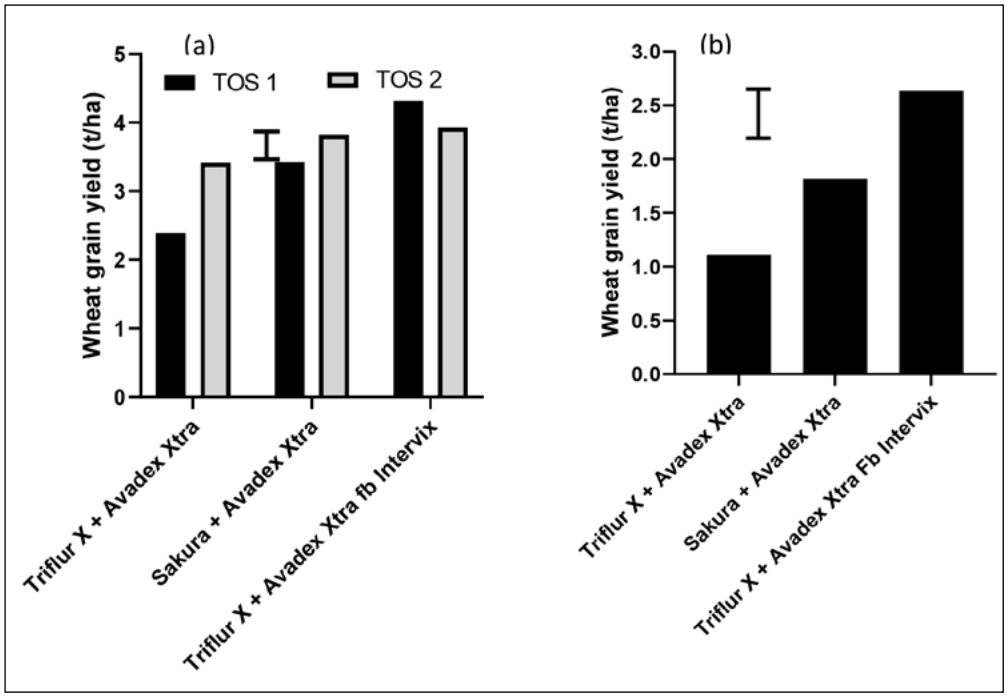


Figure 3. The effect of crop sowing time and herbicide treatments on wheat grain yield at Riverton (a) and effect of herbicide treatments on wheat yield at Mallala (b). As there was no interaction between herbicides and sowing time, average yield of the two sowing times is presented for Mallala. TOS 1 = 16 May and TOS 2 = 31 May. The error bars represent LSD (P=0.05).

the treatment prevented brome grass seed set in both times of sowing (Figure 2a). Similar effects of delayed sowing on herbicide efficacy on brome seed set were also observed at Mallala (P=0.026) (Figure 2b). Delayed sowing reduced brome seed set in TriflurX + Avadex Xtra by 42% and in Sakura + Avadex Xtra by 37%. When Intervix (Clearfield technology) was used after pre-emergent TriflurX + Avadex Xtra, it prevented seed set in brome grass (53 seeds/m^2 in TOS 1 and 0 seeds/m^2 in TOS 2). Sakura + Avadex Xtra provided significantly greater reduction in brome seed set as compared to TriflurX + Avadex Xtra at both sites.

Wheat grain yield

Wheat grain yield at Riverton ranged from 1.43t/ha to 4.47t/ha with a site mean yield of 3.55t/ha. Wheat grain yield was significantly influenced by wheat seed rate (P=0.014), with the highest seed rate yielding 14% higher than the lowest seed rate. Herbicide treatment had a significant effect on wheat grain yield (P<0.001). The interaction between TOS and herbicide treatment also had a significant effect on wheat grain yield (P<0.001). In TOS 1, when Intervix (POST) was applied after TriflurX +Avadex Xtra IBS (2.391t/ha), wheat grain yield increased by 45% to 4.32t/ha (Figure 3a). The comparison of the same treatments in TOS 2 showed only 15% increase in wheat grain yield from 3.42t/ha to 3.93t/ha. The large difference in brome grass plant density in TriflurX +Avadex Xtra IBS between TOS 1 and TOS 2 (Figure 2) is the most likely reason for these yield responses. Unlike TOS 1, TOS 2 did not have any significant difference in wheat yield between herbicide treatments as brome grass was effectively controlled by the knockdown herbicide due to the low seed dormancy in this brome grass population. As brome grass was almost completely controlled in TriflurX + Avadex Xtra fb Intervix (Figure 2), comparison of TOS 1 and TOS 2 for this treatment provides an indication of the yield penalty from delayed sowing. The wheat yield for this herbicide treatment was 4.32t/ha for TOS 1 as compared to 3.93t/ha for TOS 2, which equates to 9% yield penalty (Figure 3) or 130kg/ha/week.

Wheat grain yield at Mallala in 2019 was significantly influenced by the time of sowing (P=0.002), seed rate (P=0.043) and the herbicide treatments (P<0.001) (Figure 3b). When averaged across herbicide and seed rate treatments, wheat grain yield was only 1.17t/ha in TOS 1 as compared to 2.54t/ha in TOS 2, which was sown two weeks later. Unfortunately, there were several severe frost events at Mallala during the spring of 2019 which severely reduced wheat yield in TOS 1. There were three days of <0°C at Mallala, which indicates a severe frost risk. Wheat grain yield increased consistently with the increase in seed rate or crop

density. This trend correlates well with the improved suppression of brome grass panicle density and seed set observed in the trial. Not only did higher wheat density achieve superior weed suppression, it also provided a significant increase in grain yield.

Herbicide treatments had a significant effect on wheat grain yield at Mallala (Figure 3b). This was expected considering the high weed density present at the site and the high competitive ability of brome grass. The treatment of TriflurX + Avadex Xtra produced a wheat yield of only 1.11t/ha, which was significantly lower than the wheat yield produced following the more expensive pre-emergent herbicide mixture of Sakura + Avadex Xtra (1.81t/ha). However, when Intervix post-emergence herbicide was used, wheat yield increased further to 2.63t/ha. In this trial, integration of Clearfield® technology with pre-emergent herbicides not only prevented brome grass seed set (Figure 2b), it also produced the highest grain yields (Figure 3b).

Acknowledgements

The research undertaken in this project was 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.

References

Gill, G.S. and Kleemann, S.G.L. (2013) Seed dormancy and seedling emergence in ripgut brome (*Bromus diandrus*) populations in southern Australia. *Weed Science* 61, 222-229.

Llewellyn, R.S., Ronning, D., Ouzman, J., Walker, S., Mayfield, A. and Clarke, M. (2016) Impact of weeds on Australian grain production: the cost of weeds to Australian grain growers and the adoption of weed management and tillage practices. Report for GRDC. CSIRO, Australia.

Lemerle, D., Cousens, R.D., Gill, G.S., Peltzer, S.J., Moerkerk, M., Murphy, C.E., Collins, D., and Cullis, B.R. (2002) Reliability of higher seeding rates of wheat for increased competitiveness with weeds in low rainfall environments. *Journal of Agricultural Science* 142, 395-409.

Contact details

Dr Gurjeet Gill
Waite Campus, The University of Adelaide,
Glen Osmond, SA 5064
(08) 8313 7744
gurjeet.gill@adelaide.edu.au

[Φ]Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994

Return to contents

Notes

Movement, breeding, baiting and biocontrol of Mediterranean snails

Kym Perry[1], Helen Brodie[1], Greg Baker[1], Michael Nash[1]*, Svetlana Micic[2] and Kate Muirhead[1].

*[1]SARDI Entomology Unit; [2]DPIRD WA; *formerly.*

GRDC project codes: DAS00160, UOA1903-014BLX (9177340), CSE00061-PYC106

Keywords

- albumen gland, reproduction, movement, behaviour, biocontrol, parasitoid fly, guidelines, molluscicide.

Take home messages

- Extensive datasets highlight that baiting programs should be focused during March to June.
- Snails move in response to increases in relative humidity at ground level from late summer through autumn, providing early baiting opportunities.
- Rule-of-thumb guidelines for the movement of vineyard, Italian and small pointed snails were generated from analysis of time lapse video data.
- An introduced parasitoid fly, *Sarcophaga villeneuveana*, parasitises up to 48% of conical snails in local areas of South Australia near favourable species mixes of native vegetation.

Introduction

Grain producers have become more proficient atThis paper reports selected findings from GRDC research projects focused on improving molluscicidal control (DAS00160) and biocontrol (UOA1903-014BLX (9177340), CSE00061-PYC106)) of Mediterranean pest snails. Molluscicidal baiting is an important component of integrated snail control but provides variable levels of control despite high cost (Baker *et al.* 2017). An introduced parasitoid fly, *Sarcophaga villeneuveana*, attacks two conical snail species, *Cochlicella acuta* and *C. barbara*, with limited impact to date. Developing improved management tactics for snails remains a priority to improve growers' profitability and reduce market access risks caused by snail contamination of the grain harvest.

The GRDC project "Biology and management of snails and slugs in grain crops" (GRDC project: DAS00160, 2017–2020), led by SARDI in collaboration with DPIRD, generated new biological knowledge of pest snails and slugs, specifically their movement behaviour and reproductive activity, to assist growers to optimise the timing of baiting programs. Efficient baiting must target adult snails before most reproduction occurs. Effective baiting to ensure snails encounter pellets requires snail movement, which must be predicted before application. This project investigated the environmental triggers for mollusc movement to provide better predictive capacity. This paper presents the results for snails.

The GRDC project, "Snail biocontrol revisited – Phase II" (GRDC project: CSE00061-PYC106; 2019 – present), led by CSIRO in collaboration with SARDI, is investigating whether strains of the parasitoid fly, *S. villeneuveana*, sourced from Mediterranean regions more closely aligned with the geographic origins of the Australian C. acuta, can improve biocontrol of this species. Project results are presented elsewhere. New data generated by SARDI describing existing levels of biocontrol of *C. acuta* by *S. villeneuveana* in South Australia (SA) (SARDI-GRDC project: UOA1903-014BLX (9177340)) are presented here.

This paper summarises selected findings with relevance for management. Comprehensive datasets and analyses are presented elsewhere and in project final reports (Perry *et al.* 2020a, Perry *et al.* 2020b, Caron and Yonow 2020).

Snail breeding seasons

The reproductive cycles of three snail species were studied at four SA and four Western Australia (WA) locations between 2017 and 2020 for periods from 2–4.5 years. Target species were the vineyard snail (*C. virgata*) at three SA sites and one WA site, the white Italian snail (*T. pisana*) at one SA site, and the small-pointed snail (*C. barbara*) at three WA sites (Table 1). Nine-month datasets were collected for *C. virgat*a and *C. acuta* at three additional SA sites (for brevity, not presented). Samples of about 50 adult-sized snails were collected approximately monthly, then measurements of shell height and albumen gland length (after dissection) were recorded for each individual snail, yielding observations for 12,914 snails. Snails in a reproductive state have swollen albumen glands.

The three snail species, *C. virgata, T. pisana* and *C. barbara*, demonstrated strongly seasonal reproductive cycles with breeding seasons extending from autumn to spring (Table 1). On average, the main breeding seasons were March to late September for *C. virgata*, late February to late July for *T. pisana*, and March to October, sometimes extending into late November, for *C. barbara* in WA (Table 1). Limited data at three SA sites (four to eight months between July 2019 and March 2020) for the conical snail, *C. acuta*, suggested most breeding commenced sometime after March in 2020.

For each snail species, the timing of reproductive activity varied between seasons and/or locations, reflecting that species' activity depends, to some extent, on local environmental conditions. However, relationships between the reproductive activity and prior rainfall or other measured climate and microclimate variables (such as soil water content, soil surface wetness, and relative humidity and temperature at different heights above ground level) were not always clear, suggesting that reproductive cycles have an underlying seasonal basis. No evidence was found of significant breeding activity from late spring to summer for any snail species during this study, even when substantial movement occurred following spring or summer rainfall.

Snail movement and microclimate

Movement behaviour of snails was studied at ten locations in SA and WA (seven sites in Table 1 with exception of Manoora, plus three other SA sites) between 2015 and 2020 for periods from nine months to 4.5 years. Time lapse video footage was collected continuously at 1-minute intervals and microclimate variables (e.g., soil water content at 10 cm depth, soil surface wetness, ground level relative humidity and temperature, and others) were logged at 30-minute intervals. Video footage was analysed

Table 1. Breeding seasons by species.

Species	Study location	Study years	Breeding season average	Breeding season range
Vineyard snail, *Cernuella virgata*	SA Palmer	2015 – 2018	Mar to Sep	Feb/Mar to Jul/Oct
	SA Manoora	2015, 2017, 2018	Mar to Oct	Mar/Apr to Oct/Nov
	SA Urania	2018 – 2020	Apr to Sep	Mar/May to Aug/Oct
	WA Gairdner	2017, 2018	Mar to Oct	Feb/Mar to Oct/Nov
	4 sites	12 years	Mar to Sep	
White Italian snail, *Theba pisana*	SA Warooka	2015 – 2018	Feb to Jul	Jan/Feb to Jul/Aug
	1 site	4 years	late Feb – late Jul	
Small-pointed snail, *Cochlicella barbara*	WA Esperance Marshall	2018	Jan to Sep	
	WA Esperance Perks	2017, 2018	Mar to Sep	Feb/Apr to Sep/–
	WA Woogenellup	2017, 2018	Mar to Nov	Mar/Apr to Nov/–
	3 sites	5 years	Mar to Oct	

Table 2. Rule-of-thumb levels of relative humidity at ground level associated with the highest observed movement.

Species	Feb	Mar	Apr	May	Autumn
Vineyard snail	> 95 %	> 90 %	> 80–85 %		> 85–95 %
Italian snail	> 90 %	> 90 %	> 85–90 %		> 88 %
Small-pointed snail		> 95 %	> 95 %	> 95 %	> 95 %

using computer vision techniques developed by collaborators at University of South Australia, yielding 103,228,235 observations of individual movement distance per frame. Manual ground-truthing estimated that autodetection accuracy was approximately 85% for the round snail species but less than 40% for the small-pointed snails due to greater detection challenges. Movement data were statistically analysed to determine microclimate conditions that best explained low or high snail movement at different times of the year.

In general, snails became increasingly responsive (moved) to increases in ground level relative humidity from late summer through autumn. Other microclimate variables and interactions between variables were associated with high/low movement, however these relationships were less clear (Perry *et al.* 2020b). For simplicity, rule-of-thumb guidelines for snail movement with respect to relative humidity were generated from the data (Table 2). These guidelines are simply a set of hypotheses generated from the available data and should be tested and refined over time under field conditions. There is greater confidence in the information for the round snails, *C. virgata* and *T. pisana*, than for the small-pointed snails, based on higher detection accuracy.

Implications for bait timing

All datasets together highlighted that baiting programs targeting *C. virgata, T. pisana*, and *C. barbara* should be concentrated during the autumn and early winter period, from approximately March to June, prior to most reproduction, to maximise cost-efficiency. There are several reasons for this recommended timing:

1) Snails showed higher susceptibility to bait toxins during this period than during non-reproductive periods (Brodie *et al.* 2020, Perry *et al.* 2020b, and presentation slides).
2) Snails feed voraciously on baits immediately after exiting summer aestivation.
3) Most offspring are produced during the early phase of the breeding season; Targeting adult snails before most eggs are laid minimises offspring production.
4) Baiting prior to crop sowing minimises soil surface obstacles and alternative food sources (e.g., crop seedlings), thereby increasing the chance of bait encounter.

It is recommended that growers commence monitoring for baiting opportunities from late summer, approximately February onwards, as snails move opportunistically in response to increased moisture or relative humidity at this time. Baiting from January or earlier is likely to be less efficient because:

1) Snails may be less susceptible to bait toxins during this period compared with their reproductive periods.
2) Exposure of bait pellets to high temperatures (>35°C) can cause loss of active ingredient (Baker *et al.* 2017).
3) Baiting too early increases the chance of killing some snails that would otherwise die naturally from heat/dry stress (e.g., Perry *et al.* 2020a), thereby wasting bait.

It is suggested that baiting programs should generally cease by mid-winter or earlier as later applications are less efficient. Instead, baits should be used earlier in the season or in the following season during the optimal windows.

Time lapse video showed that initial increases in movement during late summer through autumn occurred mostly overnight (not shown). To detect this movement and confirm whether snails are feeding, growers can deploy small areas of bait in infested areas prior to widespread application.

Biocontrol of conical snails

The fly, *Sarcophaga villeneuveana*, is a specialist parasitoid of the conical snail, *C. acuta* and small-pointed snail, *C. barbara*. Strains of *S. villeneuveana* were sourced from the Montpellier region, of France, and introduced into SA by SARDI and CSIRO between 2001–2004 for biocontrol of *C. acuta* (Leyson *et al.* 2003). The fly successfully established on southern Yorke Peninsula but exhibited limited spread and impact, with pre-2018 levels of *C. acuta* parasitism estimated at less than 2% (SARDI unpublished). A current GRDC project (CSE00061-PYC106, 2019–present), conducted by CSIRO and SARDI, has focused on enhancing biocontrol success by introducing *S. villeneuveana* sourced from areas of Spain and Morocco, better matching the geographic origins of Australian *C. acuta* (Jourdan *et al.* 2019). In 2020, Moroccan fly strains were imported by CSIRO and reared in quarantine facilities at SARDI for evaluation of host specificity prior to seeking approval for a rear-release program.

To enable assessments of the impact of future fly releases, SARDI generated baseline data on the current level of conical snail parasitism by *S. villeneuveana* (project: UOA1903-014BLX (9177340)). In January and April of 2019 and 2020, *C. acuta* and

C. barbara were collected from 19 sites on Yorke Peninsula and from four different microhabitats:

1) Ground-level, in quadrats;
2) elevated (e.g., on plants, stubble and fence posts);
3) at the base of tussocks, plants and grasses; and
4) under refuges (e.g., logs and rocks).

Snails were returned to the laboratory, reared and examined for parasitism.

From 85,673 *C. acuta* and 2,412 *C. barbara* of suitable size (> 5mm) assessed for parasitism, *S. villeneuveana* was detected in snails from 13/19 sites (Figure 1). At sites where S. villeneuveana was detected, overall parasitism was 2.8% for *C. acuta* and 3.4% for *C. barbara*. Mean parasitism rates were significantly higher for *C. acuta* snails on elevated substrates (10.8%) than at the base of plants (4.1%), at ground level (4.4%) or under refuges (1.7%) (Figure 2). At individual sites and sampling dates, parasitism ranged from 0–48% for *C. acuta* and 0–27% for *C. barbara*. Higher parasitism levels were observed at sites adjacent to native vegetation flowering during periods of fly activity (spring/summer), suggesting vegetation provides food and/or shelter resources.

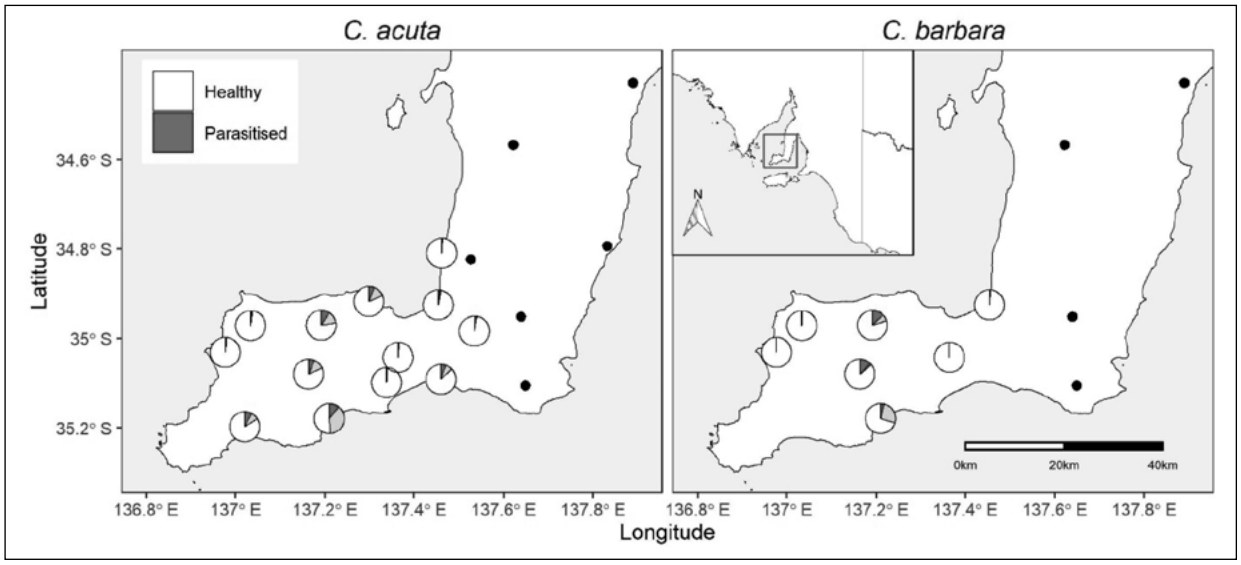


Figure 1. Parasitism levels of conical *C. acuta* and *C. barbara* by the parasitoid fly, *S. villeneuveana*. Pies show the proportion mean overall parasitism (dark shading) or maximum parasitism observed on a single sampling date (light shading) at sites where *S. villeneuveana* was present, while black dots indicate absence of *S. villeneuveana* at a sampled site.

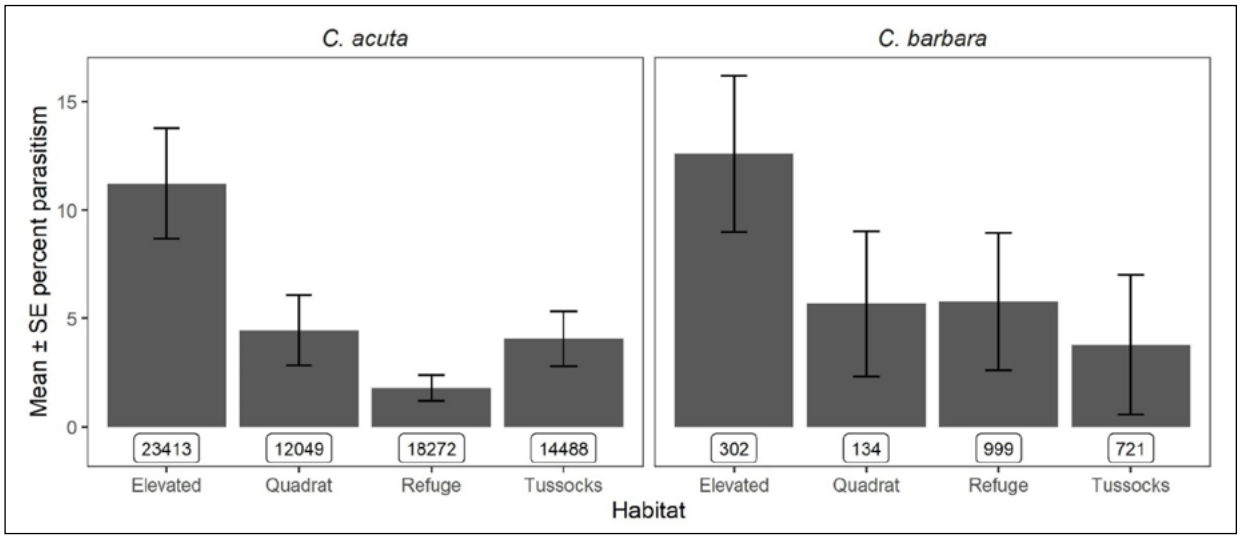


Figure 2. Parasitism of conical snails by *S. villeneuveana* in four microhabitats in 2019 and 2020. Sample sizes per category are shown in boxes.

Conclusions

Findings from DAS00160 generated a sound evidence base underpinning best practice snail management and provided growers with new information to refine their baiting strategies. Additionally, novel infrastructure (methods, analyses) for mollusc movement studies were also developed for future use. Further development is required to improve computer vision detection accuracy for conical snail species, and to generate deeper understanding of their movement and management. It was discovered that the introduced parasitoid fly, *S. villeneuveana*, performs well in the Yorke Peninsula climate in local areas with suitable habitat. Furthermore, *S. villeneuveana* attacks *C. barbara* at similar rates to *C. acuta* and is therefore suitable for release in other regions (e.g., Western Australia) for biocontrol of either species.

Acknowledgements

This research was made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC. The authors thank them for their continued support. Ivan Lee and colleagues (University of South Australia) developed and implemented the computer vision analysis of movement data. Statistical analysis was performed by SAGI South (University of Adelaide, Biometry Hub).

References

Baker GJ, Brodie H, Nash MA, Cunningham N, Perry KD (2017). Improved management of snails and slugs. *Final report for GRDC (DAS00134).* South Australian Research and Development Institute.

Brodie H, Baker GJ, Muirhead K, Perry KD (2020). "Snails: learnings from recent studies". Proceedings paper, GRDC Grains Research Updates, Adelaide 11–12 February 2020. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2019/02/snail-research-optimising-control

Caron V and Yonow T (2020). Snail biological control revisited – Phase 2. *Progress report for GRDC (CSE00061-PYC106).* CSIRO.

Jourdan M, Thomann T, Kriticos DJ, Bon MC, Sheppard A, & Baker GH (2019). Sourcing effective biological control agents of conical snails, *Cochlicella acuta*, in Europe and north Africa for release in southern Australia. *Biological Control*, 134, 1-14.

Leyson M, Hopkins DC, Charwat S, Baker GJ (2003). Release and establishment in South Australia of *Sarcophaga penicillata* (Diptera: Sarcophagidae), a biological control agent for *Cochlicella acuta* (Mollusca: Hygromiidae). In: Dussart, G.B.J. (Ed.) Slugs and Snails: Agricultural, Veterinary & Environmental Perspectives. 295–300. Proceedings 80th BCPC Symposium, British Crop Protection Council, Thornton Heath, U.K.

Perry KD, Brodie H, Muirhead K (2020a). New methods for snail control. *Final report for GRDC and SARDI (UOA1903-014BLX (9177340))*. South Australian Research and Development Institute; University of Adelaide.

Perry KD, Brodie H, Fechner N, Baker GJ, Nash MA, Micic S, Muirhead K (2020b). Biology and management of snails and slugs in grains crops. *Final report for GRDC (DAS00160).* South Australian Research and Development Institute.

Contact details

Dr Kym Perry
SARDI, Waite Campus, Urrbrae SA 5064
08 8429 0738 | 0421 788 357
kym.perry@sa.gov.au

Return to contents

Notes

Integrating glyphosate resistant canola into the farming system

Geoff Fosbery.

Farm Focus Consultants, Dongara, Western Australia (a member of the ConsultAg group of consultants).

Keywords

- Roundup Ready® canola, TruFlexTM canola, weed management, rotations.

Take home messages

- Glyphosate resistant canola is an excellent tool in the toolbox for controlling many types of herbicide resistant weeds and their seed banks but it is best to utilise another high efficacy herbicide in combination to minimise glyphosate resistance selection pressure.
- The recent introduction of the glyphosate resistant TruFlex™ canola has allowed the control of even later germinating cohorts of susceptible young weeds when canola is past the budding stage and starting to flower.
- Double stacking the rotation with a pulse/legume grown the season prior or a 10-month fallow prior to glyphosate resistant canola is reducing many weed seed banks and production risk.
- Glyphosate resistant canola has additional costs relative to open pollinated triazine tolerant (TT) canola and has normally required at least a 200 to 300kg yield increase to warrant growing UNLESS the paddock's weeds cannot be well controlled utilising present canola crop weed control strategies and tactics.

Experiences in Western Australia

Background

Canola area and production in Western Australia (WA) grew dramatically with the introduction of TT canola during the 2000s as it allowed the acceptable control of cruciferous weeds in canola crops. Adoption of Clearfield® canola was limited due to the prevalence of Group B resistant wild radish and high seed bank levels in many zones particularly where significant areas of lupins and pulses had been grown. During the 2000s the use of clethodim increased in the rotation through both rate applied and area of application. This was particularly the case in the northern medium and higher rainfall areas where lupins and canola could be grown profitably and resulted in close to 50% of cropped area receiving a dose of clethodim annually. By 2010, some 65% of randomly collected annual ryegrass populations in WA had signs of clethodim resistance to 250ml/ha of 240 g.a.i clethodim/ha while 44% of populations had signs of resistance to 500ml/ha of 240 g.a.i clethodim/ha product (*Owen et al.* 2018). In northern areas these percentages of clethodim resistant ryegrass were significantly higher than areas further south. Over this same timeframe, the lupin, canola, cereal rotations were under increased grass weed pressure, particularly from annual ryegrass, and the system needed another highly effective weed control tool added to the toolbox.

The highly effective management tool added was the introduction of the first commercially grown glyphosate resistant canola in 2009. Initially this was the introduction of Roundup Ready® canola varieties that could have two applications of Plantshield® glyphosate applied up to the six-leaf stage of the canola. Some ten years on and Western Australians have graduated to the second generation TruFlex™ glyphosate resistant canola which can have three glyphosate applications applied until the emergence of the first flower. There has also been the

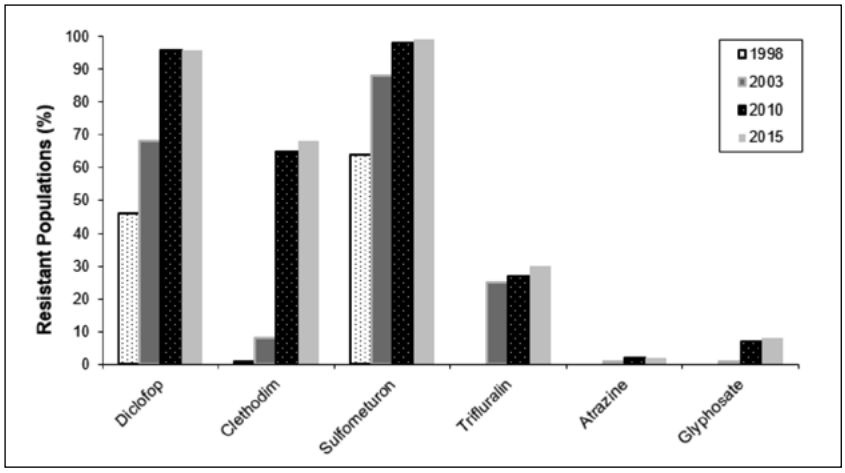


Figure 1. Annual ryegrass herbicide resistance level changes in Western Australia over four random seed collection surveys (Source: Owen, 2018).

introduction of several 'stacked' herbicide resistant canola varieties combining a range of herbicide resistance genes including triazine tolerant, Clearfield®, Roundup Ready® and TruFlex™ genetics which are allowing for even more weed control flexibility in the rotation.

Western Australian versus South Australian herbicide resistance pressures

South Australia (SA) has substantially lower levels of clethodim resistance in its annual ryegrass population than WA (Figure 1 data compared with Table 1 data).

In WA where clethodim is still generally controlling annual ryegrass well (southern agricultural areas, Figure 2) the adoption rate of glyphosate resistant canola is greatly reduced relative to non-genetically modified (non-GM) canola. This is reflected in the proportion of tonnes delivered of glyphosate resistant canola grain (GM) in the southern port zones (Esperance 9.3% and Albany 23.7%) relative to the central (Kwinana 47%) and particularly the northern port zone area (Geraldton 90.7%) (Table 2).

Table 1. Extent of resistance in annual ryegrass to various herbicides from four different regions of South Australia. Samples were considered to be resistant if > 20% of individuals within that population survived application of the herbicide.

Herbicide	Eyre Peninsula	Mid North	Mallee	South East	Average
Diclofop-methyl	47	74	22	84	56.75
Clethodim	4	7	1	19	7.75
Sulfometuron-methyl	80	71	54	66	67.75
Imazamox + Imazapyr	47	83	37	52	54.75
Glyphosate	1	1	2	27	7.75
Trifluralin	34	66	39	41	45
Prosulfocarb + S-metolachlor	1	0	0	5	1.5
Pyroxasulfone	0	0	1	5	1.5

Data courtesy of C. Preston (University of Adelaide)

Table 2. Non-genetically modified (GM) canola compared with genetically modified canola received by the CBH Group in each port zone in 2019/20 and 2020/21 harvests.

Port Zone	Harvest 2019/20				Harvest 2020/21			
	GM		Non-GM		GM		Non-GM	
	thousand tonnes	%	thousand tonnes	%	thousand tonnes	%	thousand tonnes	%
Esperance	37	13.4	240	82.6	40	9.3	389	90.7
Albany	103	28.4	260	71.6	104	23.7	334	76.3
Kwinana	160	49.4	164	50.6	254	47.0	286	53.0
Geraldton	80	87.9	11	12.1	187	90.7	19	9.3

Data courtesy of C. Preston (University of Adelaide)

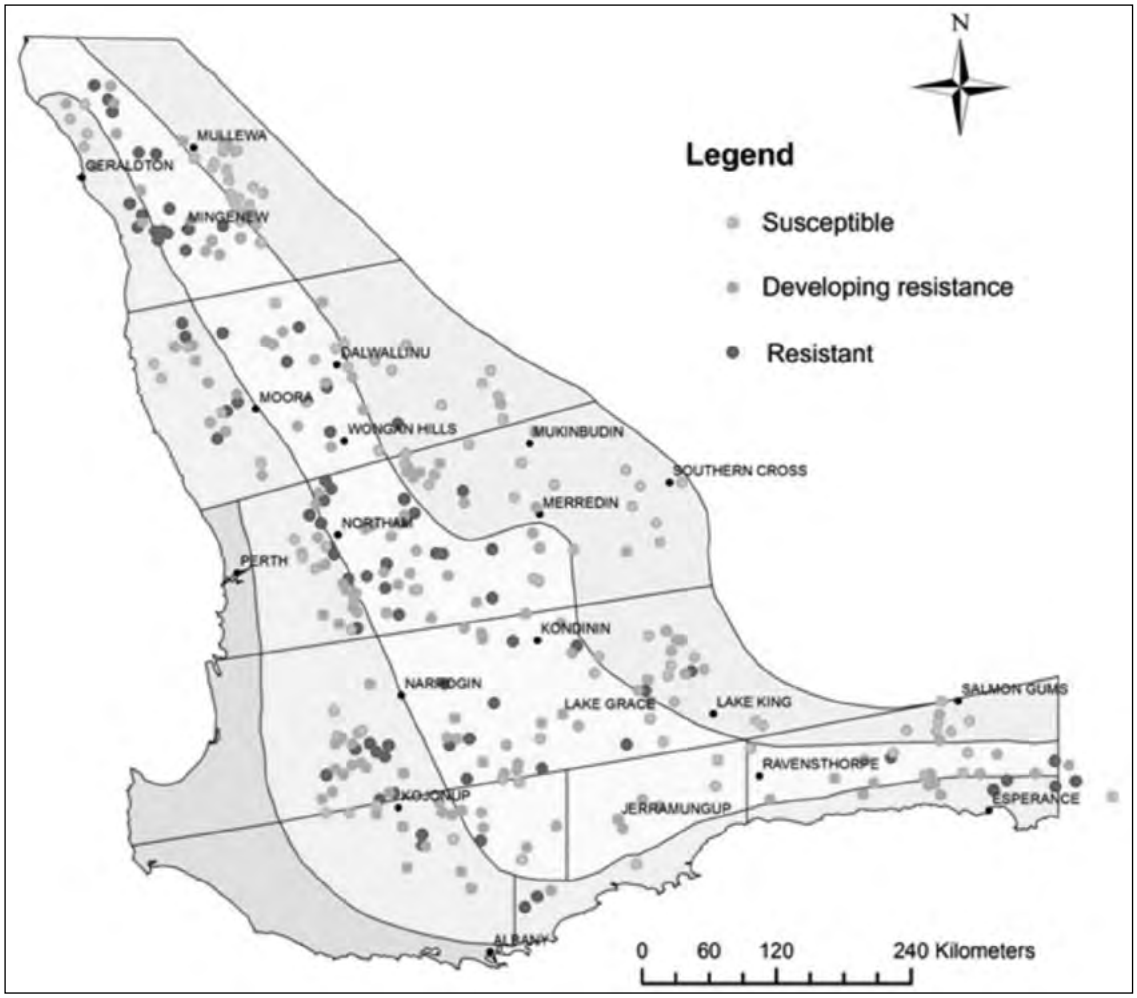


Figure 2. Map of randomly selected annual ryegrass populations, collected at harvest 2015, showing resistance levels to 60g/ha of clethodim active ingredient. (Source: Owen, 2018).

Owen (2018) found in the random survey of annual ryegrass populations in WA that clethodim resistance (60g clethodim/ha) between 2010 and 2015 seemed to plateau (Figure 1). It is thought that by adding glyphosate resistant canola to the toolbox of weed management tactics it could have contributed significantly to this plateauing of clethodim resistance development, as the adoption of glyphosate resistant canola rose dramatically from its introduction in 2009, particularly in those areas where resistance to clethodim was steadily increasing.

Given these experiences, my expectations in SA is that there would be greater adoption of glyphosate resistant canola in the zones where clethodim resistance is the greatest, presently the south eastern growing zone of SA. Other situations and areas of likely high adoption would be:

1. Where a weed species cannot be well controlled in canola and/or the farming system but can be controlled by glyphosate.
2. Where a weed species has several germinating weed cohorts and a pre-emergent herbicide does not control the later germinating cohorts. TruFlex™ canola can have Plantshield® applied safely for seven to eight weeks post germination (up to first TruFlexTM canola flower), thereby controlling many young late emerging weed cohorts.

Common practices with glyphosate resistant canola in Western Australia

1. Place in rotation

   Many farmers and consultants have learnt through the 'school of hard knocks' to utilise glyphosate resistant canola as the follow up to a lupin/pulse crop or fallow where there has been a high weed burden. In most cases canola is more responsive to the lupin/pulse or fallow benefits than cereals and particularly in lower rainfall areas the benefits of additional plant available water after a fallow have

proven a much more profitable option than growing a cereal. Note however, a single 'clean' season of glyphosate resistant canola does not solve the high weed burden problem due to weed seed bank carryover.

At low weed burden levels, a single year of glyphosate resistant canola can provide adequate control of weeds and extend the cereal component of the rotation. In well balanced farming systems this is where in the rotation most of the glyphosate resistant canola is presently grown. Our clients are gaining confidence of the higher profitability of canola after a break crop or fallow, particularly with an early germination opportunity and I believe this will become the dominant place of glyphosate resistant canola in the rotation.

2. Herbicide mixing

   Where weed pressure is high, the selection for glyphosate resistant weeds will also be high. Glyphosate resistance in weed populations is presently at relatively low levels (Figure 1 and Table 1). To keep it this way, when selection pressure is medium to high, an alternative herbicide group should be utilised in combination with glyphosate. In WA, propyzamide is the most common alternative herbicide for annual ryegrass control. In SA, with the substantially lower levels of clethodim resistance in annual ryegrass, perhaps a glyphosate and clethodim use combination is worthwhile investigating, at rates and timings listed on the label. This fits with the 'mix and rotate' axiom of herbicide resistance management.

   In low weed burden cereal stubble paddocks, particularly in lower rainfall areas, when glyphosate resistant canola is sown dry, no pre-emergent herbicide is applied. This is to allow for:

   a) A lower cost canola crop in a higher risk start of season.

   b) A fallback position of resowing to cereal if the season has a late break and a cereal is seen as a more profitable alternative.

3. Crop topping and under windrow spraying

   The great majority of glyphosate resistant (and non-GM) canola crops are treated with glyphosate via crop topping or under windrow spraying to control many of the latest emerging cohorts of weeds. These weeds are often small and 'spindly' with weak stalks or stems that are chasing light from below the canola canopy. This treatment results in little addition of seed to the weed seed bank. Not all glyphosate formulations are registered for pre-harvest use in canola.

Additional costs of glyphosate resistant canola

As an indicator of the price differential between glyphosate resistant canola (CAG1) and non-GM canola (CAN1) in the WA market, the decile 2, 5 and 8 price differentials free in store (FIS) ex Kwinana (port near Perth) since 2011 are as follows:

- Decile 2 = CAG1 -$51 relative to CAN1,
- Decile 5 = CAG1 -$38 relative to CAN1, and
- Decile 8 = CAG1 -$22 relative to CAN1.

The 2021 technology fee for TruFlexTM canola is $8.90/kg ex GST.

Seed cost is variable but is generally between $25 and $40/kg depending on seed treatment and if the variety has been superseded. Currently the better glyphosate resistant canola varieties are hybrid varieties, and therefore, seed has to be purchased annually. Recently, there has been problems securing the variety/s that a grower requires resulting in significant grower-seed supplier angst, annually. This often results in having to accept potentially lower yielding- or poorer agronomic fit-glyphosate resistant varieties!

Numerous seasons and analyses have found that similar profitability from the hybrid glyphosate resistant varieties and the open pollinated TT canola varieties is achieved when the latter yields 200 to 300kg/ha more than the former. When glyphosate resistant canola is yielding more than 1.5t/ha then this is most often achieved. However, when glyphosate resistant canola yields less than 1t/ha, it is often less profitable than open pollinated TT canola, and therefore, lower rainfall areas (with lower yields) have limited adoption of glyphosate resistant canola. In these areas, its use tends to be more opportunistic (if seed is obtainable) when late March-April germination events occur.

Conclusions

Glyphosate resistant canola will become an integral part of the rotation in some areas of SA but will not be suitable for every farm situation. This type of canola is merely another tool in the toolbox of weed control tactics and offers more diversity for some farming systems and rotations.

References

Owen M (2018), Western Australian Herbicide Resistance Survey results 2015, AHRI website, University of Western Australia.

Preston C (2020) Personal Communication, University of Adelaide, South Australia

Pontifex M (2021) Personal Communication, MarketAg, South Perth, Western Australia

Contact Details

Geoff Fosbery
P.O. Box 632, Dongara W.A., 6525
0428 225 095
gf@consultag.com.au

Return to contents

Notes

Changing market and commodity chemical regulations that you should be aware of

Gerard McMullen.

Chair National Working Party on Grain Protection (NWPGP).

GRDC project code: MCM00003

Keywords

- chemicals, maximum residue limits, MRLs, market access, domestic marketing, export marketing.

Take home messages

- It is a legal requirement to follow all label directions when applying any crop protection chemical.
- There are market access implications when using chemicals; applying a chemical according to label directions does not necessarily mean that grain will meet destination market requirements.
- Markets are continually changing their maximum residue limits (MRLs), with some key chemistry available in Australia being impacted soon.
- There is a need for advisers and growers to understand the risks of residues arising from chemical use and the impact on market acceptance. Before you intend to apply chemicals to a crop, if possible, talk to your marketer.

What is a maximum residue limit (MRL)?

All chemicals registered in Australia must be used according to label directions (for example, crop type, application rates, withholding periods, etc.). This is a legal requirement in Australia.

When using these chemicals, residues may or may not arise in the harvested grain. Residues may also arise when moving that grain using equipment such as augers and trucks that have previously held grain containing chemical residues.

An MRL is the maximum concentration of a residue resulting from the registered use of an agricultural chemical which is legally permitted or recognised as acceptable to be present in or on a food, agricultural commodity or animal feed. The Australian Pesticides and Veterinary Medicines Authority (APVMA) will set an MRL for that chemical and crop commodity combination when registering a chemical use pattern.

What are the current market requirements?

Each destination country has their own chemical legislation based on their specific chemical usage and consumption patterns. Hence different MRLs for the same chemical and commodity can apply in different markets.

Markets generally have developed their own chemical regulations and have recently moved away from relying on international standards, such as Codex Alimentarius. There is a trend towards requiring lower (or nil) residues on grain supplied. Regulations are altered based on a range of factors. Generally, markets with more sophisticated regulations alter MRLs frequently (i.e., the European Union provide notices of changes several times a year), whereas other markets may only alter their MRLs every few years. Despite this variance, many markets are increasing their level of monitoring of imported grain via sampling and testing to check compliance with their needs.

For each market, the following market access issues for Australian grain need to be managed by exporters, with growers and their advisers having a role to play:

- The market has a different MRL than the exporting country.
- For those markets that apply or default to Codex, there is no Codex MRL.
- The market has no MRL for a chemical and commodity type and does not have a default policy. Hence the MRL of zero applies.
- The market applies a low level of detection, meaning extremely low residues can be detected and may violate an MRL of nil.
- Despite government MRLs that apply, commercial contracts have different MRLs that exist. In some cases, specific chemicals are not permitted to be used.

In some instances, contracts do not state the MRLs that apply to imported grain. It is the responsibility of the supplier or marketer of the grain to ensure they know the regulations that apply and that the grain to be supplied will meet these requirements.

Specific chemical/commodity MRLs and residues of key concern to growers

Table 2 lists some chemistry currently being reviewed by key markets however, it does not necessarily mean a significant risk of residues arising or MRLs in a market may be violated (as industry implements a range of management systems to manage any potential market access issues). Nevertheless, where a chemical is being reviewed, this often leads to the MRL being lowered to either nil or an extremely low level (meaning use of that chemical is not recommended).

Where a market defaults to Codex for specific chemicals/commodities, the reviews listed in Table 2 will also impact those markets (e.g., Egypt, Ethiopia, Kenya, Saudi Arabia, United Arab Emirates).

Implications for growers and their advisers

Even though a grower may apply a chemical correctly and in accordance with label directions, the resulting grain residues may not meet market needs.

In many situations the grower and their adviser may not know the final destination market or the market MRL requirements before a chemical is used. However, if a contract exists and the market destination is listed, the market requirements must be met – ignorance is no excuse.

Residue testing is done either by the marketer or by the Australian Government National Residue Survey (NRS) on domestic grain and export grain shipments. The NRS program is funded via a grower levy.

If residues arise that exceed the market MRL, price penalties may occur, or the shipment may be rejected and returned to Australia. The reputation of Australian grain suffers. Costs may be passed from the marketer to the supplier of that grain where there is evidence of chemical misuse or false chemical use declarations. Sampling and testing of future grower loads and shipments may increase or additional segregations may need to be created, which all create extra costs. These increased costs may be passed onto the grower through the purchase price offered for the grain.

Table 1. Some key Australian markets and their chemical MRL regulations.

Market	Codex	Australia	China	European Union	Indonesia	Japan	South Korea	Taiwan	Thailand	Vietnam
Regulation applied	Not adopted by all markets	Own MRL Standard	Own MRL Standard	Own MRL Standard	Own MRL Standard	Own MRL Standard	Own MRL Standard	Own MRL Standard	Own MRL Standard	Own MRL Standard
Default MRL	No default	No default	No default	Default system	No default	Default system	Default system	No Default	Default system is complex	No default
If no MRL	ZERO	ZERO	ZERO	0.01	ZERO	0.01	0.01	ZERO	0.01	ZERO
MRL Updates	Yearly	Monthly – 6 weeks	Bi-annually	Several / year	Rarely	Often	Often	Approx. twice/year	Rarely	Rarely

Note: Details included in Table 1 are as of 6 January 2021. Variations exist for specific chemicals. MRLs are quoted in mg/kg.

Table 2. Some key chemistry being reviewed by markets.

Chemical	Market	Commodity	Timeframe for Review	Comment
Chlorpyrifos-methyl	European Union, Codex	All*	Now	Not approved for use in the EU, low MRLs apply. Expect to be reviewed at Codex shortly.
Chlorpyrifos	European Union, Australia	All	Now to soon	Not approved for use in the EU, low MRLs apply. Being reviewed in AUS, expect very low MRLs to apply.
Chlorothalonil	European Union	Pulses	Now	Not approved for use in the EU. Expect MRLs to drop significantly
Haloxyfop	European Union	Canola	Soon	Not approved in the EU, expect MRL to drop significantly
Imidacloprid	European Union	All	Now to soon	Not approved for use, expect MRLs to drop significantly
Chlorpyrifos, Chlorpyrifos-methyl, Paraquat	Thailand	All	Now	No longer permitted to be used, MRL to drop to 0.01-0.02mg/kg on 1 June 2021
Diquat, Fenitrothion, Saflufenacil	European Union	All	Now to soon	Not approved for use, MRLs are very low for many commodities and expected to drop for others
Phosphine	Codex	All	Expected 2022	Has been planned (and delayed) for several years
Dimethoate, Clethodim	Codex, European Union	All	Now to soon	Expect MRLs to lower significantly or be deleted at Codex. EU MRLs already very low
Carbendazim / Thiophanate methyl	India	Red Lentils	Now	Expect MRL to drop significantly
2,4-D, Chlorpyrifos, Deltamethrin, Thiram, Mancozeb (Dithiocarbamates)	India	Pulses, all others	Now to soon	Expect to be banned, for some chemicals MRLs will drop while for others MRLs are already very low
Diuron, Diclofop-methyl	South Korea	Barley	Now	MRLs will expire and revert to 0.01mg/kg on 31Dec21 (also for a range of other chemicals and commodities)
Carbaryl	European Union	All	Now to soon	Not approved
Carbaryl, Diquat	Japan	All	Now to soon	Chemicals being reviewed, MRLs soon to be reviewed

**MRLs may not exist for some commodities listed under "All"*

Things growers and their advisers can do to manage the impact of chemical use on market access

- Always use crop protection chemicals in accordance with the product label directions. If possible, seek advice from your marketer on market MRLs that apply, or restrictions on chemicals permitted to be used, before applying these chemicals.
- Growers are encouraged to complete Commodity Vendor Declarations correctly when details of chemicals used are sought by the trade. Failure to do so risks supplying grain that fails to meet market requirements, a loss in reputation of Australian grain and increased costs for all along the supply chain.
- On behalf of industry, the National Working Party on Grain Protection (NWPGP) is the body responsible for providing management and leadership to industry in the areas of chemical use, post-harvest storage, market requirements and monitoring changing chemical regulations and their impact on market access. Advice on market regulations, MRLs, proposed changes, etc is provided to all sectors of industry along the supply chain – seek that advice when needed.
- A range of printed material is available for grower and adviser use on the implications of chemical use on specific crops. This includes Fact Sheets on the GRDC and NWPGP websites. Presentations to a range of stakeholders throughout Australia also are provided.

Conclusion

Given the changing nature of market regulations, all stakeholders along the supply chain need to be aware of market MRLs that apply now and in the near future. Given the implications of changing market MRLs, there is a need for more awareness by growers and advisers of the impact of chemical use on market access.

Growers and their advisers need to talk to their storage agent and/or marketer and where needed other industry stakeholders, when seeking advice on market requirements.

Acknowledgement

This project is made possible by the significant contributions of growers through the support of the GRDC. The author would like to thank growers and the GRDC for their continued support.

Useful resources

On-farm Stewardship Guide 'Growing Australian Grain' http://grainsguide.grainproducers.com.au

Grains Research and Development Corporation https://grdc.com.au/

National Working Party on Grain Protection www.graintrade.org.au/nwpgp

National Residue Survey https://www.agriculture.gov.au/ag-farm-food/food/nrs

APVMA https://apvma.gov.au

Contact details

Gerard McMullen
Chair, National Working Party on Grain Protection
76 Bruce Street, Coburg, Victoria 3058
0419 156 065
gerardmcmullen@optusnet.com.au

Return to contents

GRDC™

GRAINS RESEARCH
& DEVELOPMENT
CORPORATION

Final session
Day 2

TOP 10 TIPS

FOR REDUCING SPRAY DRIFT

01 **Choose all products in the tank mix carefully**, which includes the choice of active ingredient, the formulation type and the adjuvant used.

02 **Understand** how product uptake and translocation may impact on coverage requirements for the target. Read the label and technical literature for guidance on spray quality, buffer (no-spray) zones and wind speed requirements.

03 **Select the coarsest** spray quality that will provide an acceptable level of control. Be prepared to increase application volumes when coarser spray qualities are used, or when the delta T value approaches 10 to 12. Use water-sensitive paper and the Snapcard app to assess the impact of coarser spray qualities on coverage at the target.

04 **Always expect** that surface temperature inversions will form later in the day, as sunset approaches, and that they are likely to persist overnight and beyond sunrise on many occasions. If the spray operator cannot determine that an inversion is not present, spraying should NOT occur.

05 **Use weather forecasting** information to plan the application. BoM meteograms and forecasting websites can provide information on likely wind speed and direction for 5 to 7 days in advance of the intended day of spraying. Indications of the likely presence of a hazardous surface inversion include: variation between maximum and minimum daily temperatures are greater than 5°C, delta T values are below 2 and low overnight wind speeds (less than 11km/h).

06 **Only start spraying** after the sun has risen more than 20 degrees above the horizon and the wind speed has been above 4 to 5km/h for more than 20 to 30 minutes, with a clear direction that is away from adjacent sensitive areas.

07 **Higher booms increase drift**. Set the boom height to achieve double overlap of the spray pattern, with a 110-degree nozzle using a 50cm nozzle spacing (this is 50cm above the top of the stubble or crop canopy). Boom height and stability are critical. Use height control systems for wider booms or reduce the spraying speed to maintain boom height. An increase in boom height from 50 to 70cm above the target can increase drift fourfold.

08 **Avoid high spraying speeds**, particularly when ground cover is minimal. Spraying speeds more than 16 to 18km/h with trailing rigs and more than 20 to 22km/h with self-propelled sprayers greatly increase losses due to effects at the nozzle and the aerodynamics of the machine.

09 **Be prepared** to leave unsprayed buffers when the label requires, or when the wind direction is towards sensitive areas. Always refer to the spray drift restraints on the product label.

10 **Continually monitor** the conditions at the site of application. Where wind direction is a concern move operations to another paddock. Always stop spraying if the weather conditions become unfavourable.
Always record the date, start and finish times, wind direction and speed, temperature and relative humidity, product(s) and rate(s), nozzle details and spray system pressure for every tank load. Plus any additional record keeping requirements according to the label.

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

Keeping the glyphosate option – the state of play

Katie Asplin.

CropLife Australia.

Keywords

- glyphosate, regulation.

Take home messages

- Everyone has a role to play in agricultural debates in Australia.
- The gap between science and the public discourse must be filled with credible evidence to ensure access to key agricultural production tools.
- Every independent, science and risk-based regulatory agency has comprehensively evaluated glyphosate and found it safe, when used according to label directions.
- It is paramount that all effective and safe pest management options are available for growers and environmental land managers to avoid environmental damage, loss of biodiversity and agricultural productivity.

Background

It is becoming increasingly apparent that too often there is a gap between science/evidence and the public discourse. We see this in the glyphosate debate, which threatens farmer access to key agricultural production tools. In such cases, we need to fill this gap with credible information so that Australian farmers maintain their ability to grow and produce food in an environmentally sustainable, efficient and profitable manner.

With the global population set to top nine billion people by 2050, the world will need to produce more food than ever before. That is a staggering challenge which will require a huge effort from everyone in the agricultural supply chain and every tool in the tool-box that enables growers and producers to do what they do best.

Discussion

Since 2018, there has been an increase in glyphosate media reporting. This is largely the result of court proceedings.

Agricultural chemicals, including glyphosate, continue to be some of the most regulated products in the world. The world's most advanced, independent and scientifically competent regulators have comprehensively evaluated glyphosate and declared it to be safe when used according to label directions. This includes Germany, European Union, New Zealand, Canada, the United States and Japan.

Agricultural chemicals are only registered for use in Australia when they present no unacceptable risks to users, the public and the environment. The Australian Pesticides and Veterinary Medicines Authority (APVMA) is responsible for regulating these chemicals in Australia and is globally renowned for its comprehensive, rigorous, science and evidence-based assessments.

In 2015 the International Agency for Research on Cancer (IARC) released a monograph naming glyphosate a probable carcinogen. Following that, the APVMA undertook a comprehensive reconsideration nomination assessment. They found no grounds for glyphosate to be reconsidered.

The misleading and exaggerated commentary surrounding the IARC monograph on glyphosate is unfounded and must stop. IARC only plays the limited role of advising regulatory bodies on potential hazards, allowing the relevant regulatory agencies to assess if there are any associated risks and manage them appropriately.

A risk assessment, as conducted by the APVMA, involves considering both the hazard associated with a chemical as well as the likelihood and extent of exposure to that chemical. By determining the hazard, the regulator identifies the potential for that chemical or product to cause harm. If the combination of hazard and exposure are not likely to cause harm, or any potential impacts can be mitigated through personal protective equipment or other risk management processes, the product is considered safe to use and will be registered. This is why label directions for use must be followed.

Conclusion

It is paramount that all effective and safe pest management options are available for growers and environmental land managers to avoid environmental damage, loss of biodiversity and agricultural productivity. Any restriction to the use of glyphosate, one of the most commonly used and safest herbicides, would limit the Australian farmers' and land managers' available options to the detriment of sustainable food production, as well as the natural and managed environment.

CropLife will continue to contribute to the discussion on glyphosate to ensure the voice of science and evidence is part of the narrative. It is equally important that everyone within the agricultural community continue to share fact based information with their networks. Adequately equipping the broader agriculture sector with information is critical to ensuring farmers maintain access to these crucial products.

CropLife has produced a range of materials which include answers to commonly asked questions about glyphosate. Contact publicaffairs@croplife.org.au for access.

Useful resources

Glyphosate – the facts (https://croplife.org.au/glyphosate)

Glyphosate fact sheet (https://www.croplife.org.au/wp-content/uploads/2020/07/GlyphosateFacts_2020.pdf)

APVMA glyphosate information (https://apvma.gov.au/node/13891)

Contact details

Dr Katie Asplin
Director – Science and Stewardship Policy (Chemistry)
CropLife Australia
02 6273 2733; 0420 874 865
katie.asplin@croplife.org.au
@dr_kards

Return to contents

Notes

Notes

Herbicide mode of action global alignment

Katie Asplin.

CropLife Australia.

Keywords

- herbicide, mode of action, resistance, herbicide resistance.

Take home messages

- Herbicide Mode of Action (MoA) classifications will be updated to align with the new globally aligned system.
- The science hasn't changed – just the classification codes on product labels and literature will change from a letter to a number.
- Continue to follow current integrated weed management strategies and rotation plans.
- More information will be provided to growers and advisers throughout 2021.
- Growers can expect to start seeing herbicide labels with the new mode of action classification system from early 2022.

Background

Farming is becoming increasingly global. Farmers, agronomists and academics around the world are now, more than ever, sharing and accessing information to assist them to grow crops, while managing sustainability issues such as herbicide resistant weeds.

It's important then that the herbicide MoA classification system used in Australia be aligned with the global classification system to ensure Australian farmers and advisers can access the most up-to-date information relating to managing herbicide resistance.

Discussion

Herbicide Mode of Action (MoA) classifications have been updated internationally to capture new active constituents and ensure the MoA classification system is globally relevant.

The global MoA classification system is based on numerical codes which provides infinite capacity to accommodate new herbicide MoA coming to market, unlike the alphabetical codes currently used in Australia.

CropLife is working with key herbicide resistance management experts, advisers, GRDC and the Australian Pesticides and Veterinary Medicines Authority (APVMA) to ensure farmers and agronomists are aware of the planned changes.

Farmers can expect to start seeing herbicide labels with the new mode of action classification system from early 2022. There will be a transition period during which herbicide labels will exist in the supply chain, some bearing the legacy alphabetical MoA classifications, and others transitioned to the global numerical system.

The numerical classification system should be fully implemented by the end of 2024.

A mobile app compatible with Android and Apple systems is available via the HRAC website (https://hracglobal.com/index.php?q=app) at no cost to users. It will cross reference the herbicide active ingredient with its former MoA letter and new MoA number. Printed materials will also be made available to enable cross referencing of the changes.

Conclusion

CropLife is working with industry experts to identify the consequences of these changes regarding how products fit into an integrated weed management (IWM) program and will provide more specific guidance on the changes in mid-2021.

The way growers use herbicides in the field will not change. The science hasn't changed and the mix and rotate messages remain correct. It is just the classification codes used on product labels and literature that will change from a letter to a number. Growers are advised to continue to follow their current IWM strategy and rotation plans.

Acknowledgements

This project is made possible by the significant contributions of CropLife members and the herbicide mode of action alignment advisory group.

Useful resources

CropLife Australia resistance management https://www.croplife.org.au/resources/programs/resistance-management/

Global classification lookup app available for download https://hracglobal.com/tools/classification-lookup

Glyphosate fact sheet (https://www.croplife.org.au/wp-content/uploads/2020/07/GlyphosateFacts_2020.pdf)

Contact details

Dr Katie Asplin
Director – Science and Stewardship Policy (Chemistry)
CropLife Australia
02 6273 2733; 0420 874 865
katie.asplin@croplife.org.au
@dr_kards

Return to contents

Notes

Notes

Group G herbicides – how to fit them into the farming system

Christopher Preston.

School of Agriculture, Food & Wine, University of Adelaide.

Keywords

- contact herbicide, herbicide soil activity, herbicide water solubility.

Take home messages

- New registrations for Group G herbicides are expanding the ways these herbicides can be used.
- The choice of a spike with knockdowns should be based on activity against the most problematic weeds.
- Care needs to be taken with pre-emergent applications in light soils and where crop tolerance is not high to keep the herbicide out of the crop row.

Group G herbicides – how they work

Group G herbicides inhibit the enzyme protoporphyrinogen IX oxidase (PPO or Protox) in the chlorophyll biosynthesis pathway. The mode of action of these herbicides is quite complex. Inhibition of Protox results in an accumulation of the substrate for the enzyme, protoporphyrinogen IX, which leaks out of the chloroplast into the cytoplasm. Within the cytoplasm, protoporphyrinogen IX undergoes non-enzymatic oxidation to protoporphyrin IX. In the light, protoporphryin IX is converted to a radical, which then reacts with lipids in the cell membrane, destroying the integrity of the cell. This leads to the bleaching symptoms seen with Group G herbicides.

These herbicides are mostly absorbed by the shoots, even when applied to soil. They are typically contact herbicides with typically no translocation out of the treated leaf. This means that good coverage is important for activity. Group G herbicides control broadleaf weeds and usually have little or limited activity against grasses.

Group G herbicide use patterns

The most common use pattern for Group G herbicides in grain production in Australia has been as a spike application with knockdown herbicides to control weeds prior to sowing the crop. The registration of additional Group G herbicides and expansion of registrations in recent years has increased the potential use patterns for these herbicides. Most products are registered for spike applications with glyphosate or paraquat; however, many now have other applications as well. One of the newer use patterns is as a pre-emergent herbicide. Table 1 lists the Group G herbicides registered for use in grain production in Australia and their registered uses.

Chemical characteristics and behaviour of Group G herbicides

Much of our thinking about the behaviour of Group G herbicides has been influenced by the products that have been in use for a long time. There is a tendency to think of Group G herbicides having low solubility, resulting in contact herbicide behaviour and limited movement in the soil. Table 2 describes the solubility and binding to organic matter characteristics for various Group G herbicides. There is a wide range in solubility of Group G herbicides, with some more recently registered herbicides having much higher water solubility than has been traditionally associated with Group G herbicides.

Table 1. Registered use patterns of Group G herbicides in grain production in Australia.

Herbicide (Trade name)	Spike	Pre-sowing residual	In crop	Late/Crop top	Fenceline
Oxyfluorfen (Goal®, Striker®)	✓				
Butafenacil (B Power®)	✓				
Tiafenacil (Terrad'or®)	✓				
Carfentrazone (Hammer®, Affinity® Force)	✓		✓		
Pyraflufen-ethyl (Ecopar®)	✓		✓		
Flumioxazin (Terrain®)	✓	✓			v
Saflufenacil (Sharpen®)	✓			✓	
Fomesafen[a] (Reflex®)		✓			
Saflufenacil + Trifludimoxazin (Voraxor®)	✓	✓			✓

[a]*Registration of Reflex is expected in 2021*

Table 2. Water solubility and binding to organic matter characteristics of Group G herbicides.

Herbicide	Solubility (mg/L)	Binding to organic matter (K_{OC}) (mL/g)
Pyraflufen-ethyl	0.082	1949
Oxyfluorfen	0.116	7566
Flumioxazin	0.786	889
Trifludimoxazin	1.78	~570
Butafenacil	10	365
Carfentrazone-ethyl	29.3	486
Fomesafen	50	228
Tiafenacil	110	~18
Saflufenacil	2100	~30

As can be seen from Table 2, the compounds with low water solubility have high binding to soil organic carbon and those with high water solubility have low binding to soil organic carbon. This means the products with low water solubility will be particularly immobile in soil. For instance, saflufenacil, with high water solubility and low binding to soil organic matter, is highly mobile in soil. Saflufenacil will be particularly mobile in sandy soils with low organic matter.

These properties influence the behaviour of Group G herbicides, both in plants and in soil. For an herbicide to enter a leaf, it needs to cross the waxy cuticle. This is not a problem for a lipophilic herbicide like oxyflurofen. It readily moves into the cuticle following the concentration gradient (Figure 1). However, once it reaches the inside of the cuticle, its low water solubility means it will only slowly permeate the cell wall space. Due to the low water solubility, there is little movement from the site of application. This results in the classic spotting of leaves that is seen from application of these herbicides.

As the water solubility of the Group G herbicides increases, there will be more movement within the leaf, resulting in larger areas of damage from each surface droplet. For instance, saflufenacil, being highly water soluble, passes through the cuticle in a different manner and is much more mobile in the leaf. Saflufenacil also has some movement out of the treated leaves, but it is very limited.

The solubility of the herbicides also influences how they will behave on the soil surface. Oxyfluorfen with its low water solubility is used in horticulture to create a surface seal of herbicide to control emerging broadleaf weeds (Figure 2). Due to the low solubility of oxyfluorfen, any breaks in the surface seal, such as what happens with traffic, can allow weeds to emerge without contacting the herbicide. Flumioxazin, with low water solubility, has similar behaviour. However, saflufenacil is much more mobile and creates a wider band of herbicide, making it harder for the weeds to avoid contact.

The other factor in the activity of Group G herbicides is the ability of plants to detoxify them. There are variations between the herbicides and between species in the rate at which the herbicides can be detoxified. The combination of exposure, movement and detoxification capability of the herbicides influences the weed spectrum. Because

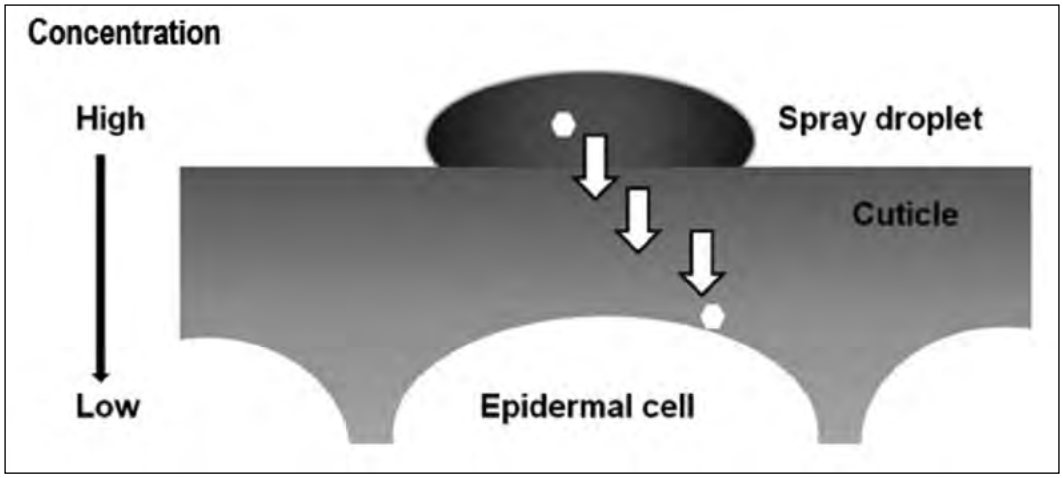


Figure 1. Movement of a lipophilic herbicide across the cuticle driven by the concentration gradient from high in the spray droplet to low in the cell wall space.

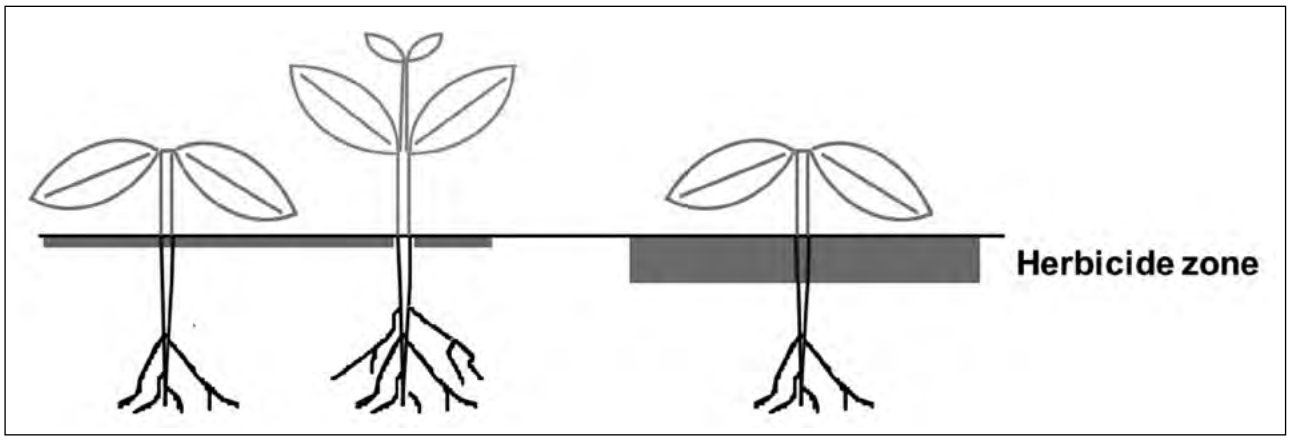


Figure 2. Some Group G herbicides with low water solubility create a surface seal on the soil surface. The herbicide is absorbed by the weed shoot as it emerges through the herbicide zone. Any break in the herbicide zone could allow the weed to avoid picking up the herbicide (left) and survive. More soluble herbicides have a wider herbicide band (right) making any breaks in the surface seal less important.

of their limited water solubility and the growth pattern of grasses, Group G herbicide are more effective against broadleaf weeds than grasses. The more water-soluble compounds will tend to have higher grass activity; however, this can be reduced by high rates of detoxification.

Fitting Group G herbicides into Australian grain production systems

With the introduction of new herbicides and new uses of existing Group G herbicides, there will be increased choice in their use. There are now many herbicides that can be used as spikes with knockdown herbicides. The choice of product for this use should be dictated by the main weeds of concern. Where mallows are the main concern, carfentrazone-ethyl remains a good choice. For fleabane, saflufenacil would be a better choice. In situations where glyphosate-resistant ryegrass is an issue, tiafenacil will provide the highest level of efficacy.

Plant back restrictions need to be considered with some of the newer Group G herbicides. Most have no plant back restrictions when spike rates are used. However, plant backs to canola for tiafenacil and saflufenacil range from 1 to 6 weeks, depending on the rate used.

Starting with flumioxazin, registrations for Group G herbicides for pre-emergent weed control have been developed. Terrain (flumioxazin) is registered for use prior to wheat and some pulses, Reflex (fomesafen) is registered for use prior to pulse crops and Voraxor (saflufenacil + trifludimoxazin) is registered for use prior to wheat, barley and durum, primarily for the control of broadleaf weeds. It is important to keep the herbicide away from the

crop row where there is insufficient crop safety. This means knife-points and press-wheel seeding equipment should be used with pre-emergent uses of these herbicides. Pulse crops have some tolerance to fomesafen, and this herbicide can also be used post-sow, pre-emergent (PSPE) on all winter pulse crops, except lentils.

The more water-soluble products (Reflex and Voraxor) will tend to provide better weed control due to their greater movement within the soil. However, that also increases their risk of producing crop damage, particularly in lighter soils. Factors that allow movement of the herbicide into the crop row will exacerbate crop damage.

Carfentrazone and pyraflufen-ethyl can be used mixed with MCPA (2-methyl-4-chlorophenoxyacetic acid) to control broadleaf weeds post-emergent in cereal crops. Saflufenacil is registered for control of green material late in pulse crops and flumioxazin and Voraxor are registered for fence line weed control.

Should we worry about resistance to Group G herbicides?

Currently there is no known resistance to Group G herbicides in Australia. However, there are 13 weed species across the world with resistance to Group G herbicides. Most of these are broadleaf weeds; however, resistance has occurred in three grass weeds: annual ryegrass, wild oats and crowsfoot grass.

Where resistance to Group G herbicides has occurred, it has been typically in situations where Group G herbicides have been used intensively, including horticulture, turf and soybeans. As yet in Australia, Group G herbicides have not been used intensively in grain production. Mostly their use has been as spikes with knockdown herbicides, which targets a smaller percentage of the weed population. The expanded use patterns for Group G herbicides in grain production is likely to increase the selection pressure for resistance. Choices will need to be made about where Group G herbicides fit best in rotations.

Resistance to Group G herbicides is often the result of target site mutations, but non-target site resistance mechanisms are also known. There are a number of known mutations in PPX2, the gene for the target enzyme, which result in variations in the amount of resistance to different Group G herbicides. Resistance when it does occur in Australia is likely to be unpredictable and herbicide testing will be a useful tool in managing resistance.

Useful resources

GRDC Fact Sheet – Mixing knockdown partners with Group G herbicides

https://grdc.com.au/__data/assets/pdf_file/0028/381736/10408-GRDC-Fact-sheet-Group-G-herbicides.pdf

Specific guidelines for Group G herbicides

https://www.croplife.org.au/resources/programs/resistance-management/specific-guidelines-for-group-g-herbicides/

Contact details

Dr Chris Preston
School of Agriculture, Food & Wine,
University of Adelaide
0488 404 120
christopher.preston@adelaide.edu.au

Return to contents

Notes

THE 2020-2022 GRDC SOUTHERN REGIONAL PANEL

January 2021

GRDC™ GRAINS RESEARCH & DEVELOPMENT CORPORATION

CHAIR - JOHN BENNETT

Lawloit, VIC

Based at Lawloit, between Nhill and Kaniva in Victoria's West Wimmera, John and his family run a mixed farming operation across diverse soil types. The farming system is 70 to 80 per cent cropping, with cereals, oilseeds, legumes and hay grown. 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.

M +61 429 919 223 E john.bennett5@bigpond.com

DEPUTY CHAIR - KATE WILSON

Hopetoun, VIC

Kate is a partner in a large grain producing operation in Victoria's Southern Mallee region and produces wheat, canola, lentils, lupins and field peas. Kate has been an agronomic consultant for more than 20 years servicing the Mallee and northern Wimmera. Kate is passionate about producing high quality grain, whilst enhancing the natural ability of the soil. Kate is passionate about research and the extension of that research to bring about positive practice change to growers.

M +61 427 571 360 E kate.wilson@agrivision.net.au

MICHAEL CHILVERS

Nile, TAS

Michael runs a family farming enterprise at Nile in the Northern Midlands of Tasmania, having successfully transitioned from a dryland grazing enterprise to intensive mixed farming. He has broad experience in resource management, strategic planning and risk profiling, human resource management and operational logistics. He was a member of the GRDC high rainfall zone RCSN (now Grower Network) for six years. Michael was a GRDC-supported Nuffield Scholar in 2012 studying systemisation and expansion models. He served on the Board of Nuffield Australia for two years, acted as state chair for three years, and regularly leads the China leg of the Nuffield Global Focus tour.

M +61 409 974 556 E fchilvers@bigpond.com

ANDREW RUSSELL

Rutherglen, VIC

Andrew is Managing Director and a shareholder of Lilliput AG, and a Director and shareholder of the affiliated Baker Seed Co, a family-owned farming and seed cleaning business. He manages a 2500ha mixed cropping enterprise south of Rutherglen. Lilliput AG produces wheat, canola, lupin, faba bean, triticale, oats and sub clover for seed and hay. Andrew served on the GRDC's medium rainfall zone RCSN (now Grower Network) and has held many leadership roles. He holds a Diploma of Rural Business Management and an Advanced Diploma of Agriculture.

M +61 417 401 004 E arussell@lilliput-ag.com.au

JON MIDWOOD

Inverleigh, VIC

Jon has worked in agriculture for the past three decades, both in the UK and in Australia. He has managed Grainsearch, a grower-funded company evaluating European wheat and barley varieties for the high rainfall zone, and his consultancy managed the commercial contract trials for Southern Farming Systems (SFS). Jon was a member of the GRDC's HRZ (RCSN (now Grower Network) and became a GRDC Southern Panel member in 2015. In 2020 Jon set up an independent consultancy, TechnCrop Services.

M +61 400 666 434 E jon@techcrop.com.au

LOU FLOHR

Lameroo, SA

Lou is a farmer based at Lameroo in the Southern Mallee of South Australia. With her parents and partner, she runs a mixed farming enterprise which includes export oaten hay, wheat, barley, a variety of legumes and a self-replacing Merino flock. Prior to returning to the family farm, Lou had a 10-year agronomy career, servicing the Upper South East and Mallee. She is passionate about her industry, particularly in recognising the role that women play in the industry and on the land.

M +61 429 083 927 E flohrlouise@gmail.com

ANDREW WARE

Port Lincoln, SA

Andrew is a research agronomist, based at Port Lincoln on SA's Eyre Peninsula. He started his career with the South Australian Research and Development Institute (SARDI) at the Minnipa Agriculture Centre, and then spent time at CSIRO in Adelaide. Andrew managed the family farm on Lower Eyre Peninsula for 10 years before returning to SARDI in late 2009. In 2019, Andrew started his own research company EPAG Research, delivering applied research across Eyre Peninsula. Andrew received the GRDC Southern Panel's Emerging Leader award in 2018, and prior to joining the Panel he served on the GRDC's low rainfall zone RCSN (now Grower Network).

M +61 427 884 272 E andrew@epagresearch.com.au

PRU COOK

Dimboola, VIC

Pru was raised on a mixed farm at Diapur in Victoria's Wimmera region. She has worked at the Victorian Department of Primary Industries and GRDC, where she implemented GRDC's first social media strategy. She then worked at Birchip Cropping Group, managing and supporting extension projects. She has recently started her own business focusing on extension, project development and management.

M +61 438 923 258 E pru.cook@gmail.com

MICHAEL TRELOAR

Cummins, SA

Michael is a third-generation grain grower based at Cummins on South Australia's Eyre Peninsula, where he grows wheat, barley, canola, beans, lupins and lentils on a range of soil types. He has been involved in the South Australian Grains Industry Trust, the Lower Eyre Agricultural Development Association and the South Australian No Till Farmers Association. He believes research and development underpins profitability in Australian farming systems and the GRDC is pivotal in delivering research outcomes that support growers.

M +61 427 765 034 E mbattreloar@bigpond.com

MICHELLE WATT

Melbourne, VIC

In February 2020 Professor Michelle Watt was appointed the Adrienne Clarke Chair of Botany at the University of Melbourne. From 2015 to 2019, she was Director of the Plant Sciences Institute at the Helmholtz Centre and Professor of Crop Root Physiology at the University of Bonn in Germany. Prior to 2015 Michelle was at CSIRO. She has been in multi-partner projects with Australia, the USA, India, the Philippines, UK and Germany in the under-studied but critical area of plant roots. She is President of the International Society of Root Research and Co-Chair of the Root Phenotyping

E watt.m@unimelb.edu.au

DR NICOLE JENSEN

Canberra, ACT

Nicole is general manager of GRDC's Genetic and Enabling Technologies business group. She brings a wealth of experience in digital agriculture, plant breeding and genetics from roles she has held in Australia and internationally in the seed industry.

M +61 26166 4500 E Nicole.Jensen@grdc.com.au

P Level 4 | 4 National Circuit, Barton ACT 2600 | PO Box 5367, Kingston ACT 2604
T +61 2 6166 4500 **F** +61 2 6166 4599 **E** grdc@grdc.com.au

KEY CONTACTS

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

SOUTHERN REGION

ADELAIDE
Level 1
187 Fullarton Road
DULWICH SA 5065

P: +61 8 8198 8400
southern@grdc.com.au

OPERATIONS GROUP

SENIOR REGIONAL MANAGER
Craig Ruchs
Craig.Ruchs@grdc.com.au
M: +61 4 7771 0813

BUSINESS SUPPORT TEAM LEADER
Amanda Jane
Amanda.Jane@grdc.com.au
P: +61 8 8198 8402

CONTRACT ADMINISTRATOR AND PANEL SUPPORT
Claire West
Claire.West@grdc.com.au
P: +61 8 8198 8401

CONTRACT ADMINISTRATOR
Mark Waterhouse
Mark.Waterhouse@grdc.com.au
P: +61 8 8198 8406

APPLIED RESEARCH AND DEVELOPMENT GROUP

MANAGER AGRONOMY, SOILS, NUTRITION AND FARMING SYSTEMS
Stephen Loss
Stephen.Loss@grdc.com.au
M: +61 4 0841 2453

MANAGER AGRONOMY, SOILS, NUTRITION AND FARMING SYSTEMS
Allison Pearson
Allison.Pearson@grdc.com.au
M: +61 4 1887 4748

MANAGER WEEDS (NATIONAL)
Jason Emms
Jason.Emms@grdc.com.au
M: +61 4 3954 9950

CROP PROTECTION MANAGER SOUTH
Ruth Peek
Ruth.Peek@grdc.com.au
M: +61 4 5553 4040

GENETICS AND ENABLING TECHNOLOGIES GROUP

SENIOR MANAGER ENABLING TECHNOLOGIES
Tom Giles
Tom.Giles@grdc.com.au
M: +61 4 1788 9860

SENIOR MANAGER NATIONAL VARIETY TRIALS
Sean Coffey
Sean.Coffey@grdc.com.au
M: +61 4 2865 2226

MANAGER NATIONAL VARIETY TRIALS SOUTH
Rob Wheeler
Rob.Wheeler@grdc.com.au
M: +61 4 0114 8935

MANAGER NATIONAL VARIETY TRIALS SYSTEMS
Neale Sutton
Neale.Sutton@grdc.com.au
M: +61 4 3857 9992

MANAGER RESEARCH PLATFORMS
Trevor Garnett
Trevor.Garnett@grdc.com.au
M: +61 4 5790 6770

NATIONAL VARIETY TRIALS OFFICER
Ben O'Connor
Ben.O'Connor@grdc.com.au
M: +61 4 9988 7749

CONTRACT ADMINISTRATOR
Dianne Wright
Dianne.Wright@grdc.com.au
P: +61 8 8198 8407

GROWER EXTENSION AND COMMUNICATIONS GROUP

GROWER RELATIONS MANAGER
Courtney Ramsey
Courtney.Ramsey@grdc.com.au
M: +61 4 2827 4018

GROWER RELATIONS MANAGER
Randall Wilksch
Randall.Wilksch@grdc.com.au
M: +61 4 3776 9098

GROWER RELATIONS MANAGER
Tom Blake
Tom.Blake@grdc.com.au
M: +61 4 1889 3186

COMMUNICATIONS MANAGER
Sharon Watt
Sharon.Watt@grdc.com.au
M: +61 4 0967 5100

STRATEGY AND BUSINESS DEVELOPMENT

GENERAL MANAGER - STRATEGY AND BUSINESS DEVELOPMENT
Ron Osmond
Ron.Osmond@grdc.com.au
M: +61 4 0000 2640

ACTING HEAD BUSINESS DEVELOPMENT
Fernando Felquer
Fernando.Felquer@grdc.com.au
M: +61 4 1351 1412

Acknowledgements

We would like to thank those who have contributed to the successful staging of the Adelaide GRDC Grains Research Update:

- The local GRDC Grains Research Update planning committee (see page 2 for list of contributors)
- Industry supporters that include:

Adama Australia Pty Ltd

AGT

BASF Australia

Bayer

FMC

GenTech Seeds (Pioneer)

Intergrain

Nufarm/Nuseed

Pacific Seeds (Advanta)

UPL Australia

GRDC
GRAINS RESEARCH
& DEVELOPMENT
CORPORATION

Networking event supported by

AGT

Barista coffee supported by

ADAMA

Trade display supported by

BASF
We create chemistry

INTERGRAIN
Growing Together

FMC
An Agricultural Sciences Company

nuSEED

Nufarm
Grow a better tomorrow

BAYER

UPL

Pacific Seeds
Growing possibilities

PIONEER

Networking event supported by

Australian Grain Technologies

Australia's largest plant breeding company, providing improved varieties of wheat, durum, barley, lupin and canola to Australian farmers.

Barista coffee supported by

ADAMA Australia

ADAMA Australia is a leading global manufacturer and distributor of crop protection solutions, with a heritage of nearly 70 years.

We understand that farming is complex and full of ever increasing challenges. We recognise that in order to make a genuine difference, we can't do this alone. Neither can farmers. So we work together with our partners in Australia and around the world to find ways to simplify it.

Together, we develop simple, practical and innovative solutions in crop protection and beyond to make the complex job of farming a little easier. www.adama.com/australia

Trade display supported by

BASF Agricultural Solutions

Farming today is more complex than ever before with the unpredictability of the weather, control of pest and weeds, market price development, scarcity of natural resources. These challenges demand BASF to continue its commitment to creating innovative solutions for growers, supporting them with the task of nurturing a hungry planet.

BASF has been creating chemistry for over 150 years and with a broad portfolio of fungicides, insecticides, herbicides and seed treatments, we help farmers to sustainably increase the yields and the quality of their crops. By nurturing a culture of global innovation in alignment with our local customers' needs, our technologies aim to ensure that crops grow healthier, stronger and more resistant to stress factors, such as heat, drought or frost.

We also offer a range of smart solutions for pest problems in urban and rural areas. From products to protect buildings from termites to rodent control products with a softer environmental profile, we help our customers to keep their homes, food establishments, and businesses clean and pest-free.

Bayer

At Bayer, we work to shape agriculture through breakthrough innovation for the benefit of farmers, consumers and our planet.

Bayer has been investing in Australian agriculture for almost 100 years, supplying leading brands backed by expert advice in the areas of seeds and plant biotechnology, crop protection and non-agricultural pest control. Our spirit of innovation and curiosity means we are always looking to develop more advanced solutions to environmental and commercial challenges to shape Australian agriculture.

On and off the farm, we work closely with our customers, our business and research partners and the wider community to improve the security of our food and fibre supplies and our overall quality of life. This great tradition is also our commitment to the future – entirely in line with our mission: science for a better life.

FMC Australia Boilerplate

FMC is an agricultural sciences company – but it is not just an agricultural sciences company. It is part of the community, and part of the solution to the challenges of global food security.

FMC advances farming directly, through innovative and sustainable crop protection technologies. And it advances farming indirectly, by supporting the communities that farmers rely on.

From our industry leading discovery pipeline, to unique application systems, we are passionate about bringing new solutions to growers around the world, while looking after our own people by creating opportunity and supporting diversity.

Our six Core Values define who we are and how we do business: Integrity, Safety, Sustainability, Respect for People, Agility, and Customer Centricity. As individuals and as a team of over 100 people across Australia and New Zealand we are guided by these values. It's what sets FMC apart and it's the key to our long-term growth and sustainability as a company.

FMC has manufacturing operations throughout the world, working to strict safety, environmental and quality control standards. For the Australian and New Zealand markets, the company has a local manufacturing plant located one hour north of Sydney. The Wyong facility has more than thirty years history of quality crop protection manufacture, including herbicides, fungicides, insecticides and adjuvants. To learn more, please visit www.fmccrop.com.au

InterGrain - Cereal Breeding Leaders

As one of the leaders in cereal breeding in Australia, InterGrain exists to deliver grower value through the delivery of market leading wheat, barley and oat varieties. Our highly successful wheat, barley and oat breeding programs are designed to target the major cereal growing regions of Australia. We believe that the continuous development of improved crop genetics is fundamental to ensuring a highly competitive grains industry in Australia.

InterGrain's shareholders are the WA State Government (62%) and GRDC (38%). InterGrain employs 45+ staff and has offices in Perth and Horsham. We also have marketing staff based in Northam, Adelaide and Wagga Wagga.

Nuseed

WE'RE AUSTRALIAN, JUST LIKE OUR SEED.

The Nuseed story began in the heart of Australia's grain growing country, so we're deeply connected with the needs of Australian farmers.

Since that first seed was sown in 2006, we have grown into a global seeds business with Nuseed germplasm now planted by farmers across the globe. In Australia, our dedicated crop breeding teams work with the best available genetics to produce a pipeline of varieties that perform in Australia's tough conditions.

At our state-of-the-art Innovation Centre in Horsham, Victoria, our R&D team works hard on developing new canola varieties to give you more choice in your cropping program, like our new triazine tolerant hybrids now available under the HyTTec® brand. We're also one of the only seed companies in Australia still developing new open pollinated TT varieties, because we know they're an important part of many growers' crop plans. And we're working on some exciting new projects that are going to offer plant-based solutions to some pressing consumer needs as part of our BEYOND YIELD™ strategy.

Pacific Seeds

Pacific Seeds was established in Central Queensland in 1962. Through technological innovations and collaboration with Australian growers, Pacific Seeds has grown to become the country's leading seed provider.

Today, Pacific Seeds provides customers with the highest quality Canola, Field Corn, Grain Sorghum, Grazing Oats, Summer Forage and Wheat seed varieties. From technical guides to agronomic insights, Pacific Seeds also has the latest information and advice to give customers the best results.

Committed to innovation

For almost 60 years, Pacific Seeds has invested heavily in research and development and partnered with world-class researchers to ensure it continues to deliver industry breakthroughs, so their customers are always equipped with the latest in seed technology.

In 1974 Pacific Seeds released Australia's first hybrid sunflower, in 1988 introduced the world's first hybrid canola, and in the early 90s, MR-Buster saw Pacific Seeds lead the way in hybrid grain sorghum. By 1996, it had merged with Advanta Seeds, and brought herbicide tolerance technology to canola through the Hyola® hybrids. Most recently, Pacific Seeds has developed and released igrowth® sorghum, world first, innovative technology improving grower flexibility and weed control options.

Seed tested to local conditions

The Pacific Seeds technology development (TD) program works with some of the best growers, businesses and institutions in Australia to continually trial and evaluate advances in crop management, ag-tech and agronomy. Each year, dozens of TD trials are conducted across the cropping regions of Australia with existing varieties and advanced experimental varieties to provide insights into product performance under different conditions.

The results of these trials don't exist in isolation. They are gathered; and using biometric analysis are compared and standardised the region and environment. This means confidence in how Pacific Seeds varieties, both existing and new, perform across environments and seasons.

Producing the best seed

Careful treatment is required through the growing, harvesting and processing cycles to ensure seed germination and quality is at the highest level. Where possible, sites are spread across geographies, ensuring constant monitoring for unwanted weeds, pests and pathogens. Depending on the crop and relevant quarantine restrictions, Pacific Seeds produce seed in both domestic and international locations.

Prior to reaching a farmer for planting, each seed lot will have undergone multiple tests for key factors such as seed vigour, germination and physical purity. Before being released for sale, Pacific Seeds products meet stringent quality benchmarks.

Real paddock experiences and evaluation, in addition to partnerships with industry experts, allows Pacific Seeds to provide real-world solutions to both growers and industry. These solutions are provided freely to growers and industry through Pacific Seeds agronomy publications, field days, industry events and farm visits.

Pacific Seeds is committed to innovation and seeing growers' full farming potential realised.

Pioneer® seeds Australia

At Pioneer we understand the best leaders serve. We believe we have a unique responsibility to help improve grower's operations, promote good stewardship through the value chain and advance the science of agriculture in Australia. We do this by delivering improved seed genetics and inoculant products to farmers, producing and distributing high-quality seed and supporting our customers by sharing knowledge of our products and agronomic practices. Pioneer has been operating in Australia for more than 40-years, serving customers with integrity, unmatched agronomic knowledge and solutions to help them succeed. Because when you partner with Pioneer, we are with you from the word GO. www.pioneerseeds.com.au

UPL

The fifth agrochemical company in the world, after the acquisition of Arysta LifeScience, UPL is a global leader in global food systems.

The new UPL offers an integrated portfolio of both patented and post-patent agricultural solutions for various arable and specialty crops, including biological, crop protection, seed treatment and post-harvest solutions covering the entire crop value chain.

With a revenue of US$3.14 billion, UPL is now present in 130+ countries.

We have market access to 90% of the world's food basket and are focused on ushering growth and progress for the complete agricultural value chain including growers, distributors, suppliers and innovation partners.

The new UPL is a solutions company. It's about what we can do with our customers, with farmers, with the whole network to drive world agriculture to the next level.

Prefer to provide your feedback electronically or 'as you go'? The electronic evaluation form can be accessed by typing the URL address below into your internet browsers:

www.surveymonkey.com/r/AdelaideGRU

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

- Complete the survey on one device
- One person per device
- 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.

2021 Adelaide GRDC Grains Research Update Evaluation

1. Name

ORM and/or GRDC has permission 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. Current market drivers and opportunities for Australian grain: *Richard Simonaitis*

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

4. 11.05 am	**The rise of glyphosate resistance** *Peter Boutsalis*	**Insecticide resistance – lessons to be learnt** *Paul Umina*	**Targeted amelioration in sandy soils to maximise crop water use** *Lynne Macdonald*	**Know the new 'lingo' from the National Phenology Initiative** *Corinne Celestina*	**None**

Content relevance /10 Presentation quality /10

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

5. 11.45 am	**Blackleg infection of canola – latest developments and yield impacts from foliar fungicide use** *Steve Marcroft*	**Measuring impact of inoculation with a new rhizobia testing tool** *Ross Ballard*	**The agronomic value of precision planting technologies** *Glenn McDonald*	**Maximising benefits from vetch in our farming systems** *Stuart Nagel*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

6. 12.25 pm	**Wins and tribulations of chaff lining as a weed reduction tool** *Chris Davey*	**Revised critical soil test values for key nutrients across different soil & break crop types** *Nigel Wilhelm*	**Insecticide resistance – lessons to be learnt** *Paul Umina*	**Improving lentil performance on sandy soils** *Sam Trengove*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

LUNCH

7. 2.00 pm	**Targeted amelioration in sandy soils to maximise crop water use** *Lynne Macdonald*	**Nitrogen fertiliser use efficiency rules of thumb put to the test** *Roger Armstrong*	**Drivers of insect pressure and new management tools for troublesome insects** *Rebecca Hamdorf,*	**Wins and tribulations of chaff lining as a weed reduction tool** *Chris Davey*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

8. 2.40 pm	**Latest knowledge on treatment of soil acidification** *Brian Hughes*	**Improving lentil performance on sandy soils** *Sam Trengove*	**Maximising benefits from vetch in our farming systems** *Stuart Nagel*	**Blackleg infection of canola – latest developments and yield impacts from foliar fungicide use** *Steve Marcroft*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

9. 3.20 pm	**Nitrogen fertiliser use efficiency rules of thumb put to the test** *Roger Armstrong*	**Drivers of insect pressure and new management tools for troublesome insects** *Rebecca Hamdorf*	**Latest strategies in canola disease control** *Steve Marcroft*	**The rise of glyphosate resistance** *Peter Boutsalis*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

10. GrainInnovate – innovation through disruption (TeleSense Aust example): *Marcus Kennedy*

Content relevance ☐ /10 Presentation quality ☐ /10

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

11. GrainInnovate – innovation through disruption (FluroSat example): *Marie Marion*

Content relevance ☐ /10 Presentation quality ☐ /10

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

12. GrainInnovate – innovation through disruption (SwarmFarm example): *Andrew Bate*

Content relevance ☐ /10 Presentation quality ☐ /10

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

DAY 2

13. Early risers session: Enabling technologies: *Tom Bishop*

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

14. 9.00 am	**Achieving the big yields** *Eric Watson & Nick Poole*	**The health report - pulse disease update** *Sara Blake & Blake Gontar*	**Phosphorus application recommendations based on soil characterised zones and testing - does it pay?** *Sean Mason*	**Reducing input costs without compromising pulse production potential** *Sarah Day*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

15. 9.40 am	**Achieving the big yields** *Eric Watson & Nick Poole*	**To spray or not to spray – what does the Russian Wheat Aphid threshold calculator advise?** *Maarten Van Helden*	**Frost mapping – a future management tool** *Uday Nidumolu*	**Cereal disease wrap up** *Tara Garrad, & Sam Trengove*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

16. 10.50 am	**Novel agronomy strategies for improving yield** *Kenton Porker*	**Integration of non-chemical tactics to improve brome grass management** *Gurjeet Gill*	**Latest management tactics for snail control** *Kym Perry*	**Reducing input costs without compromising pulse production potential** *Sarah Day*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

17. 11.30 am	**GM technology - farming system learnings from WA** *Geoff Fosbery*	**Phosphorus application recommendations based on soil characterised zones and testing - does it pay?** *Sean Mason*	**The health report - pulse disease update** *Sara Blake & Blake Gontar*	**Cereal disease wrap up** *Tara Garrad, & Sam Trengove*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

18. 12.10 pm	To spray or not to spray – what does the Russian Wheat Aphid threshold calculator advise? *Maarten Van Helden*	Integration of non-chemical tactics to improve brome grass management *Gurjeet Gill*	Use of chemicals and residues arising - impact, understanding and potential trade issues *Gerard McMullen*	Novel agronomy strategies for improving yield *Kenton Porker*	None

Content relevance ☐ /10 Presentation quality ☐ /10

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

19. Keeping the glyphosate option – the state of play: *Katie Asplin*

Content relevance ☐ /10 Presentation quality ☐ /10

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

20. Group G herbicides – how to fit them into the farming system: *Chris Preston*

Content relevance ☐ /10 Presentation quality ☐ /10

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

Your next steps

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

22. 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

23. This Update has increased my awareness and knowledge of the latest in grains research

Strongly agree	Agree	Neither agree nor Disagree	Disagree	Strongly disagree
❑	❑	❑	❑	❑

24. Do you have any comments or suggestions to improve the GRDC Update events?

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

26. ☐ **Yes I'm interested in contributing to the next Adelaide Grains Research Update planning committee (provide your name in Q1).**

Thank you for your feedback.