ADELAIDE
SOUTH AUSTRALIA
TUESDAY 6TH
WEDNESDAY 7TH

FEBRUARY 2024

GRAINS RESEARCH UPDATE

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GRAINS RESEARCH UPDATE

GRDC
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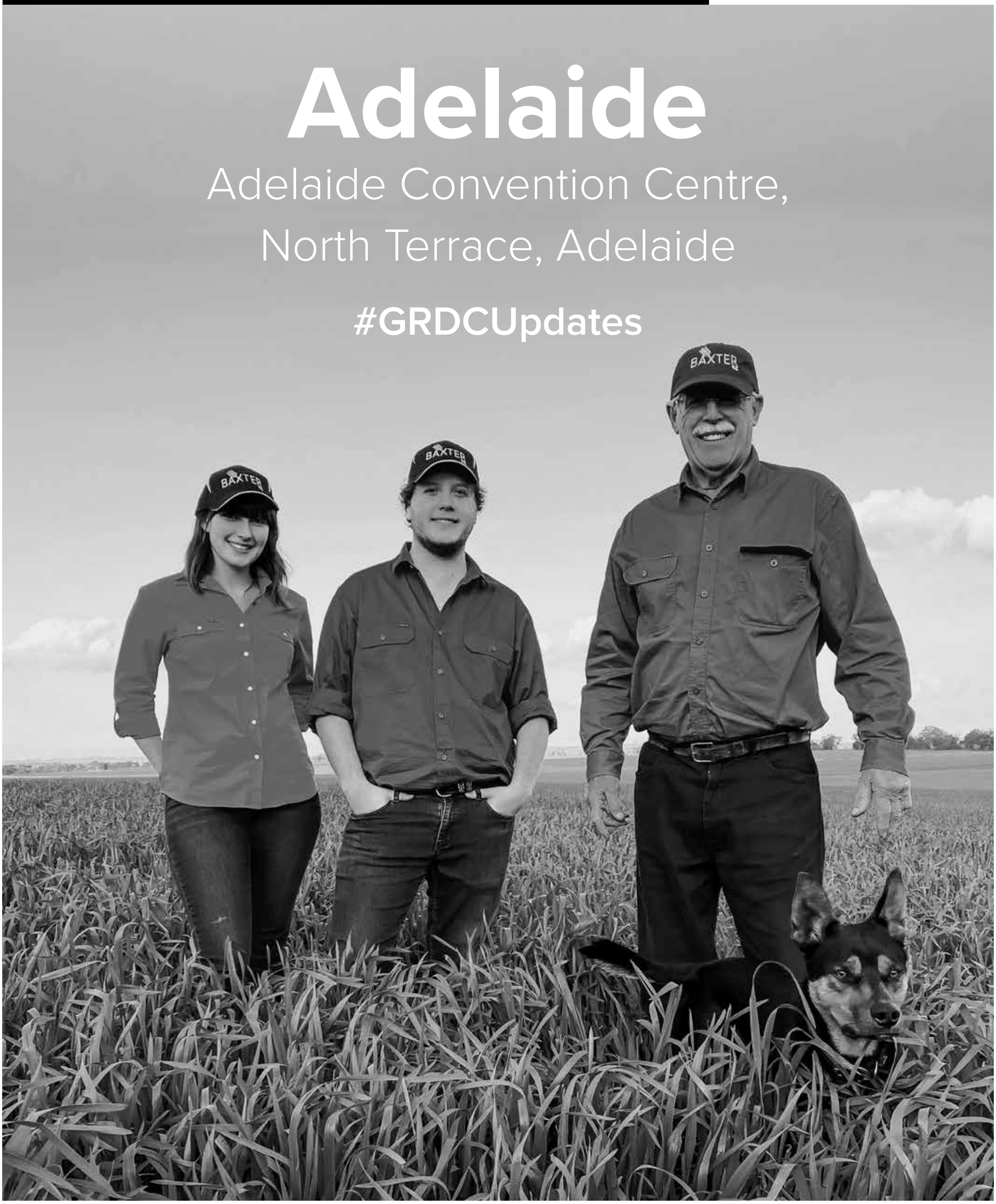
Adelaide

Adelaide Convention Centre,
North Terrace, Adelaide

#GRDCUpdates



2024 Adelaide GRDC Grains Research Update planning committee

Rebekah Allen	*Hart Field Site Group*	**Darryn Schilling**	*YPAG*
Scott Hutchings	*Cox Rural*	**Dan Vater**	*Australian Grain Technologies*
Darren Pech	*Elders*	**Nigel Wilhelm**	*SARDI*
Michael Brougham	*Elders*	**Tim Bateman**	*GRDC*
Georgia Cole	*Platinum Ag*	**Matt McCarthy**	*ORM*
Jake Rademacher	*Growers Supplies*	**Jamie Thornberry**	*ORM*
Ashley Pilkington	*ADAMA*		

Adelaide GRDC Grains Research Update
convened by ORM Pty Ltd.

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GRDC Welcome

Proceedings for the GRDC Grains Research Update – Adelaide, 6-7 February 2024

Welcome

Thanks for coming to the 2024 GRDC Grains Research Update – Adelaide.

The Grains Research Updates is one of GRDC's most popular and important investments, connecting hundreds of researchers, advisers, consultants and growers across the country to review key findings from the latest grains research, development and extension. This interaction benefits the development of new knowledge and innovation enormously, helping ensure that emerging technologies and practices are readily adopted by grain growers to enhance their enduring profitability.

GRDC is currently negotiating with service providers for another five years of Research Updates nationally, so these will continue until 2029. The Research Updates complement the GRDC Farm Business Updates, which focus on developing the farm business skills and knowledge that growers need to run a profitable business – these were also recently contracted for another five years.

As in previous years, the 2024 Grains Research Update – Adelaide showcases the most relevant and useful topics and experts from across GRDC's investment portfolio as recommended by our planning committee of growers, advisers and researchers. We hope it will provide much valuable information for growers and advisers to successfully manage cropping enterprises in 2024 and beyond.

The 2023 season was generally favourable for grain growers, with record harvests in Victoria, but below average yields in parts of South Australia. Profits were helped out by some useful prices. In many areas, soil moisture conserved over summer underpinned winter rainfall and contributed to crop performances. Certainly, crop water use efficiencies were high as a result of improved varieties and management stemming from GRDC investments. Given the wet summer and good soil moisture levels in many districts, crops in 2024 could have significant potential as we head into autumn.

It was a busy year for GRDC staff. In June 2023, we launched our RD&E Plan (2023-2028) which explains our strategy in investing about $1.0 billion over the next five years to benefit the grains industry. Reflecting industry input into the plan, there will be a greater focus on transformational innovations and sustainability, including ways to reinforce human capital and community trust. As a result of GRDC's healthy financial position, you may have noticed a significant increase in projects over the past six months or so.

Throughout last year, GRDC's National Grower Network (NGN) team were busy on the road engaging directly with growers and industry stakeholders to identify local priorities for investment. These engagements resulted in about 20 new investments and initiatives in response to short-term and local opportunities across the southern region. More NGN events are planned in 2024 and we welcome your ongoing participation.

During 2023 the RiskWi$e investment got up and running, led by CSIRO working with grower groups across the country. These groups are investigating the rewards and risks associated with key cropping decisions. Late last year two procurements were produced as a flow on from the Hyperyielding Crops project which is coming to a conclusion shortly – these will see ongoing paddock benchmarking and discussion groups in the high rainfall zone, as well as trial work in the medium and high rainfall zones. Grain Automate is another initiative that kicked off in 2023 – it will include a portfolio of new research investments aimed at delivering outcomes for grain growers in machine autonomy and intelligent systems. Reinvestment is National Variety Trials is also currently being finalised for another five years.

For growers and advisers, we have retained our popular sponsorship to participate in study tours. So, if you feel inspired to travel to other regions after the Update, then please submit an application by February 28 - for more information, search for 'study tour' at grdc.com.au. These and many other investments will keep improving the impact of GRDC's portfolio to support the enduring profitability of grain growers.

We look forward to your engagement during the Update – whether it is asking questions, sharing knowledge, networking or engaging on social media (#GRDCUpdates). Your participation is key, and we hope these proceedings provide rich and detailed information to complement what you will hear and experience during the Update that you can refer to again. Of course, you're encouraged to follow up with presenters for more detailed data and discussion.

For now, please enjoy the Update and these proceedings, and we look forward to seeing how you implement and adapt what you learn.

Stephen Loss
Senior Regional Manager South

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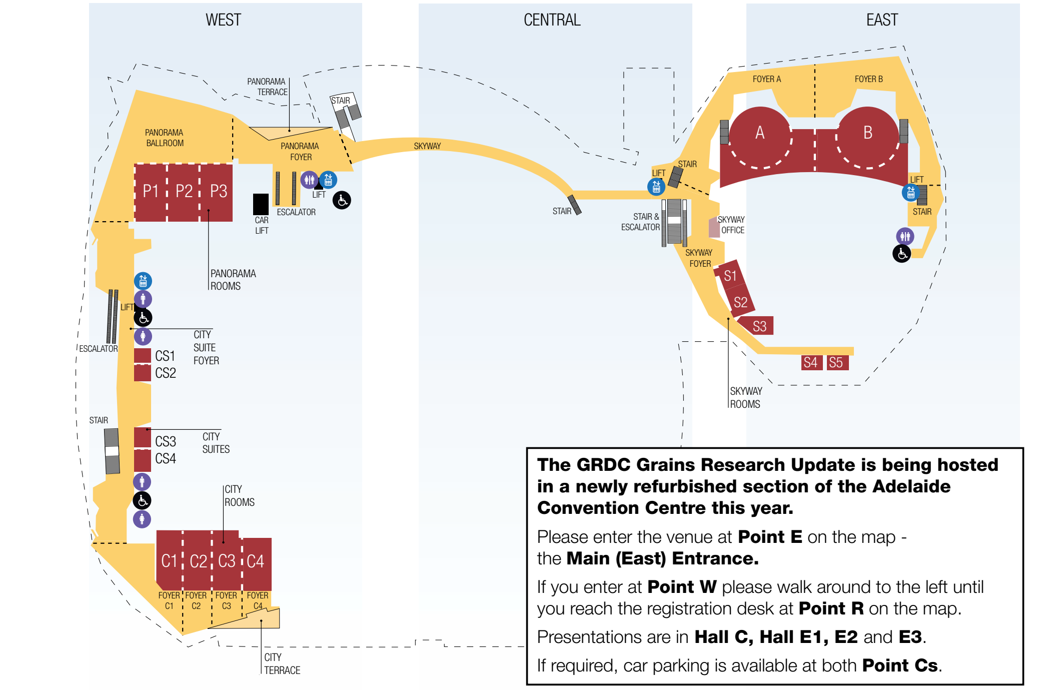
UPPER LEVEL



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

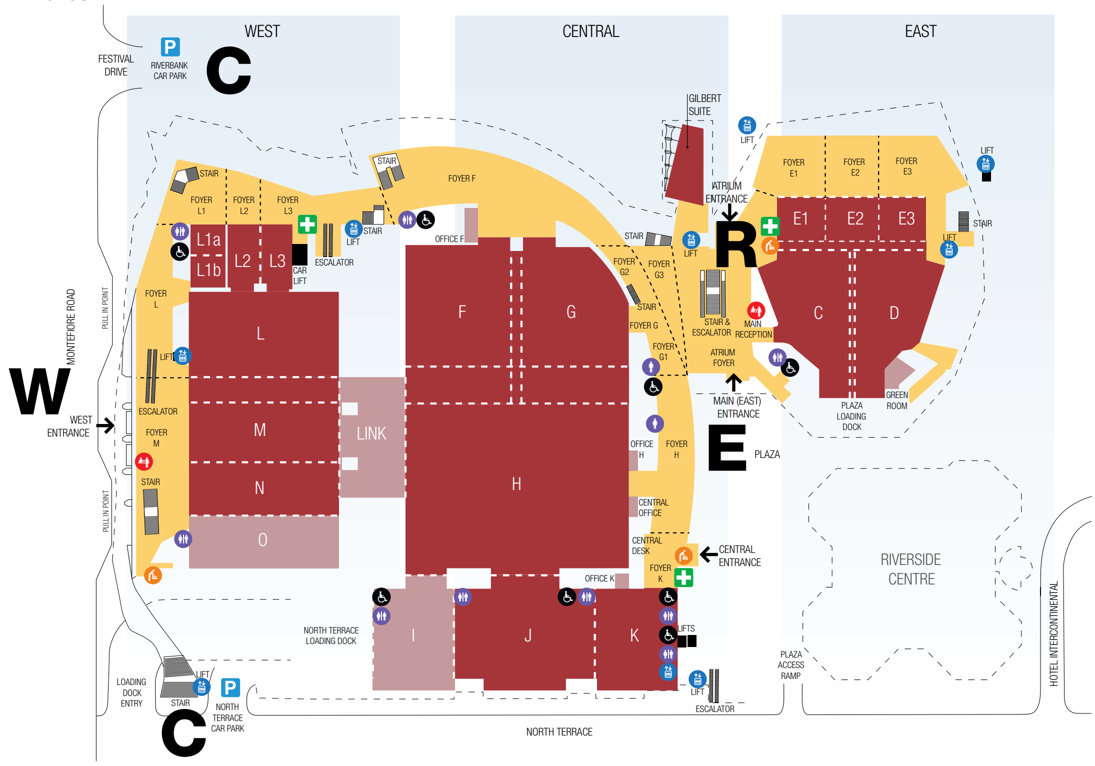
Please enter the venue at **Point E** on the map - the **Main (East) Entrance.**

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

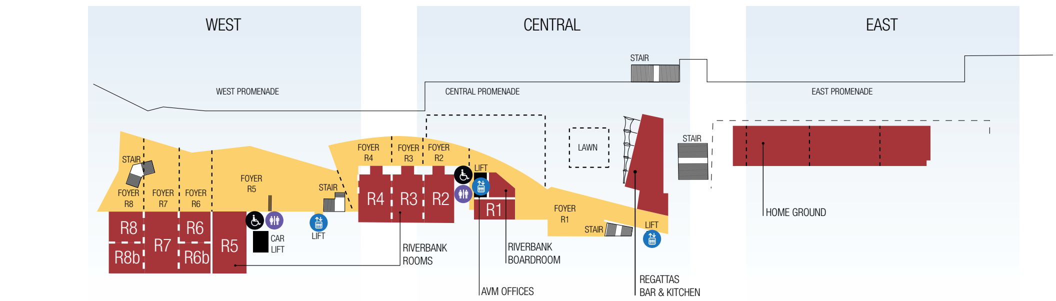
Presentations are in **Hall C, Hall E1, E2** and **E3**.

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

GROUND LEVEL



LOWER LEVEL



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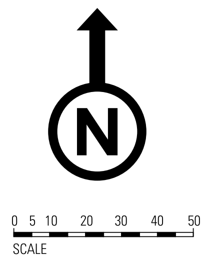


Aug 2018

Contents – DAY 1

GRDC Grains Research Update ADELAIDE

Contents – DAY 2

WEED smart
every weed every seed
every farm every year

The WeedSmart Big 6

Weeding out herbicide resistance in winter & summer cropping systems.

The WeedSmart Big 6 provides practical ways for farmers to fight herbicide resistance.

How many of the Big 6 are you doing on your farm?

We've weeded out the science into 6 simple messages which will help arm you in the war against weeds. By farming with diverse tactics, you can keep your herbicides working.

Rotate Crops & Pastures

Crop and pasture rotation is the recipe for diversity

- Use break crops and double break crops, fallow & pasture phases to drive the weed seed bank down,
- In summer cropping systems use diverse rotations of crops including cereals, pulses, cotton, oilseed crops, millets & fallows.

Mix & Rotate Herbicides

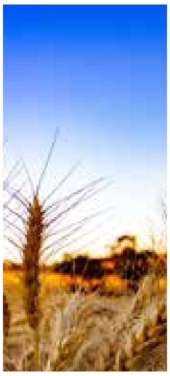
Rotating buys you time, mixing buys you shots.

- Rotate between herbicide groups,
- Mix different modes of action within the same herbicide mix or in consecutive applications,
- Always use full rates,
- In cotton systems, aim to target both grasses & broadleaf weeds using 2 non-glyphosate tactics in crop & 2 non-glyphosate tactics during the summer fallow & always remove any survivors (2 + 2 & 0).

Increase Crop Competition

Stay ahead of the pack

Adopt at least one competitive strategy (but two is better), including reduced row spacing, higher seeding rates, east-west sowing, early sowing, improving soil fertility & structure, precision seed placement, and competitive varieties.



Double Knock

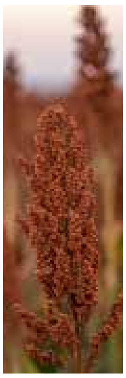
Preserve glyphosate and paraquat

- Incorporate multiple modes of action in the double knock, e.g. paraquat or glyphosate followed by paraquat + Group 14 (G) + pre-emergent herbicide
- Use two different weed control tactics (herbicide or non-herbicide) to control survivors.

Stop Weed Seed Set

Take no prisoners

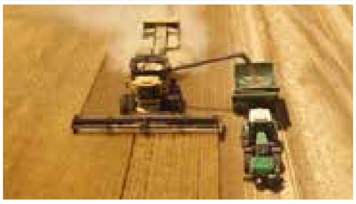
- Aim for 100% control of weeds and diligently monitor for survivors in all post weed control inspections,
- Crop top or pre-harvest spray in crops to manage weedy paddocks,
- Consider hay or silage production, brown manure or long fallow in high-pressure situations,
- Spray top/spray fallow pasture prior to cropping phases to ensure a clean start to any seeding operation,
- Consider shielded spraying, optical spot spraying technology (OSST), targeted tillage, inter-row cultivation, chipping or spot spraying,
- Windrow (swath) to collect early shedding weed seed.



Implement Harvest Weed Seed Control

Capture weed seed survivors

Capture weed seed survivors at harvest using chaff lining, chaff tramlining/decking, chaff carts, narrow windrow burning, bale direct or weed seed impact mills.



WeedSmart Wisdom

Never cut the herbicide rate – always follow label directions
Spray well – choose correct nozzles, adjuvants, water rates and use reputable products,
Clean seed – don't seed resistant weeds,
Clean borders – avoid evolving resistance on fence lines,
Test – know your resistance levels,
'Come clean. Go clean' – don't let weeds hitch a ride with visitors & ensure good biosecurity.

www.weedsmart.org.au

GRDC Grains Research Update ADELAIDE

PROGRAM DAY 1 – FEBRUARY 6th

8:00 am	**Registrations**	
8:55 am	**Welcome to country**	
9:05 am	**GRDC Opening**	***Nigel Hart ,*** *Managing Director,* ***GRDC***
9:15 am	**Current and likely impacts on international grain markets**	***Nick Carracher,*** *Lachstock Consulting*
9:45 am	**Adopting innovative agronomic practices and research - A Canadian experience**	***Dr Sheri Strydhorst,*** *Alberta, Canada*
10:20 am	**GRDC Awards Presentation**	
10:30 am	**Morning tea**	

CONCURRENT SESSIONS (40 minutes including time for room change)

	Hall C	Room E1	Room E2	Room E3
11:00 am	**The market and agronomic challenges of carbendazim usage.** *Panel:* ***Leigh Nelson,*** *GRDC* ***Gerrard McMullen,*** *National Working Party for Grain Protection,* ***Jake Rademacher,*** *Grower Supplies*	**An update on powdery mildew.** ***Sam Trengove,*** *Trengove Consulting*	**Cereal disease management 2024 and key strategies for detection.** ***Grant Hollaway,*** *Astute Ag*	**Key learnings from long term lime response trials.** ***Brian Hughes,*** *SARDI*
11:40 am	**Leveraging seed treatments and management strategies to effectively control crown rot.** ***Steven Simpfendorfer,*** *NSW DPI*	**New development scales for wheat and barley.** ***Corinne Celestina,*** *University of Melbourne*	**Back Chat' discussion with Dr Sheri Strydhorst. Facilitated Q & A in follow up to Plenary with Sheri.** ***Sheri Strydhorst,*** *Alberta, Canada*	**Digging Deeper:** **Back to nitrogen basics - Soil testing and nitrogen budgeting fundamentals.** ***James Hunt,*** *University of Melbourne.* ***Jeff Braun,*** *The Agronomist*
12:20 pm	**BOM developments in long term forcasting accuracy - The implications for Autumn sowing.** ***Jonathan How,*** *BOM*	**The impacts of canopy closure and N on frost mitigation.** ***Ben Smith,*** *Agrilink Consultants*	**Integrated pest management strategies and the impact of beneficials.** ***Luis Mata,*** *CESAR Australia*	**Digging Deeper:** **Broad leaf weed management - Identifying critical growth stages, timings and treatments.** ***Chris Davey,*** *Next Level Agronomy.* ***Darren Pech,*** *Elders*

12:55 pm **LUNCH**

CONCURRENT SESSIONS (40 minutes including time for room change)

	Hall C	Room E1	Room E2	Room E3
1:55 pm	**The N Bank - Why and How?** *James Hunt,* *University of Melbourne*	**An update on powdery mildew.** *Sam Trengove,* *Trengove Consulting*	**Cereal disease management 2024 and key strategies for detection.** *Grant Hollaway, Astute Ag*	**BOM developments in long term forcasting accuracy - The implications for Autumn sowing.** *Jonathan How, BOM*
2:35 pm	**Key learnings from long term lime response trials.** *Brian Hughes, SARDI*	**The impacts of canopy closure and N on frost mitigation.** *Ben Smith,* *Agrilink Consultants*	**Strategies for optimising glufosinate and tackling efficacy challenges.** *Chris Preston,* *University of Adelaide*	**Leveraging seed treaments and management strategies to effectively control crown rot.** *Steven Simpfendorfer,* *NSW DPI*
3:15 pm	**Agronomic strategies when growing lentils in marginal areas.** *Agronomist Panel*	**Integrated pest management strategies and the impact of beneficials.** *Luis Mata, Cesar Australia*	**The N Bank - Why and How?** *James Hunt,* *University of Melbourne*	**Strategies for optimising glufosinate and tackling efficacy challenges.** *Chris Preston,* *University of Adelaide*

3:55 pm **AFTERNOON TEA**

4:20 pm	**Molecular and phenotypic characterisation of synthetic auxin herbicide tolerant pulse germplasm**	*Simon Michelmore, (PhD)*
4:30 pm	**Physiology of yield determination in faba bean genotypes with differing phenological and morphological traits**	*James Manson, (PhD)*
4:40 pm	**Profitable nitrogen decision making & risk management**	***Peter Hayman*** *SARDI* **&** ***Barry Mudge*** *Barry Mudge Consulting*
5:20 pm	**DRINKS & FINGER FOOD IN TRADE DISPLAY AREA**	

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

PROGRAM DAY 2 – FEBRUARY 7th

8:15 am **REGISTRATIONS**

	Hall C	Room E1	Room E2	Room E3
9:00 am	**Strategies for post amelioration sowing and crop establishment on sandy soils.** *Mel Fraser,* *Soil Function Consulting*	**Novel weed control technologies from the USA - New possibilities for Australian growers.** *Michael Walsh,* *Charles Sturt University Wagga Wagga*	**The efficacy of mice baits and impact of background food availability.** *Steve Henry, CSIRO*	**Establishing A decision matrix for disease management strategies.** *Thomas Jones, BCG*
9:40 am	**Does timing trump precision? - Optimising canola establishment.** *Kenton Porker, CSIRO*	**Showcasing new rhizobium strains for group E and F inoculent groups.** *Liz Farquharson, SARDI*	**Building soil biological capacity on low performing soils.** *Gupta Vadakattu, CSIRO*	**Evaluating varietal response in oaten hay.** *Alison Frischke, BCG*
10:20 am	**MORNING TEA**			
10:50 am	**Emerging strategies for managing pulse foliar diseases.** *Sara Blake, SARDI*	**GRDC Ag Tech Startups Forum** *Michelle Demers, BioScout, Peter Johnston, Honeag, Les Finemore, Yarta*	**Does timing trump precision? - Optimising canola establishment.** *Kenton Porker, CSIRO*	**Establishing A decision matrix for disease management strategies.** *Thomas Jones, BCG*
11:30 pm	**Building soil biological capacity on low performing soils.** *Gupta Vadakattu, CSIRO*	**GRDC Ag Tech Startups Forum** *Michelle Demers, BioScout, Peter Johnston, Honeag, Les Finemore, Yarta*	**Novel weed control technologies - New possibilities for Australian growers.** *Michael Walsh, Charles Sturt University Wagga Wagga*	**Evaluating varietal response in oaten hay.** *Alison Frischke, BCG*
12:10 pm	**The efficacy of mice baits and impact of background food availability.** *Steve Henry, CSIRO*	**Showcasing new rhizobium strains for group E and F innoculent groups.** *Liz Farquharson, SARDI*	**Strategies for post amelioration sowing and crop establishment on sandy soils.** *Mel Fraser,* *Soil Function Consulting*	**Emerging strategies for managing pulse foliar diseases.** *Sara Blake, SARDI*

12:50 pm **LUNCH**

PLENARY SESSION :

1:30 pm	**Building rapport and effective communication with clients**	*Clint Vawser, Oasis*
2:10 pm	**Optimising efficacy of pre-emergent chemistry**	*Chris Preston, University of Adelaide*

2:50 pm **CLOSE**

KNOW BEFORE YOU SOW

PREDICTA® B and PREDICTA® rNod

PREDICTA B DNA Soilborne disease tests

PREDICTA rNod Rhizobia test

Cereal root diseases and poor rhizobia inoculation decisions in grain legumes cost grain growers in excess of $300 million annually in lost production.

PREDICTA® B and PREDICTA® rNod soil testing services and your accredited agronomist can help you to identify before seeding, the soil borne disease risk in cereals, and whether an appropriate rhizobium inoculant should be applied to grain legume crops.

Enquire with your local agronomist or visit http://pir.sa.gov.au/research/services/molecular_diagnostics/predicta_b

PREDICTA® B has tests for most soil-borne diseases of cereals and some pulse crops:

- Crown rot (cereals)
- Rhizoctonia root rot
- Take-all (including oat strain)
- Root lesion nematodes
- Cereal cyst nematode
- Stem nematode
- Blackspot (field peas)
- Yellow leaf spot
- Common root rot
- Pythium clade f
- Charcoal rot
- Ascochyta blight of chickpea
- White grain disorder
- Sclerotinia stem rot

New PREDICTA® rNod has tests for rhizobia:

- Group E and F (lentil, faba bean, pea and vetch)
- Group N (chickpea)
- Groups G and S (lupin and serradella)

Government of South Australia
Primary Industries and Regions SA

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Adopting innovative agronomic practices and research – a Canadian experience

Sheri Strydhorst.

Sheri's Ag Consulting Inc.

Keywords

- crop rotation, nitrogen use efficiency, on-farm research, western Canada.

Take home messages

- Western Canadian grain growers are trying to balance enhanced nitrogen use efficiency (NUE), reduced greenhouse gas (GHG) emissions and on-farm profitability. However, agronomic solutions do not achieve all three simultaneously and the most profitable solution is the most widely implemented.
- Grain growers are faced with an overwhelming number of 'quick fixes' that distract them from putting enough time and attention towards foundational agronomic practices. On-farm trials take considerable time and effort, but they are an excellent tool to understand the frequency and magnitude of benefits associated with 'quick-fixes'.
- Simple crop rotations dominate western Canada as they are easy to implement on large acres and are generally profitable. However, countless research studies document the benefits of diversified rotations. Scientific findings alone do not provide enough incentive for many growers to diversify their crop rotations. Grain growers should consider starting with small changes to their crop rotations to experience the benefits first-hand.
- Decisions based on peer-reviewed research and/or on-farm testing help grain growers to invest in profitable agronomic practices and not throw good money after 'quick fixes'. To achieve long-term sustainability, grain growers should start small and slowly increase the diversity of their rotations.

Background

Canada, Australia and all grain-producing regions are facing a myriad of abiotic and biotic stresses that limit crop yields, marketability and profitability. Producers may compromise foundational agronomic practices, such as nutrient management and crop rotation, while spending too much time, effort and money on 'quick-fixes'. Navigating this complicated space can be aided by on-farm trials and unbiased, peer-reviewed research.

Balancing NUE, GHG emissions and farm economics

Improving NUE is critically important to achieve improved profitability and reduce the environmental footprint of food production. In Canada, there is growing public and political pressure to improve NUE and reduce GHG emissions. However, adoption of enhanced efficiency fertilisers (EEF) and biologicals is limited due to their lack of profitability at the farmgate. Peer-reviewed research highlights that, on some soil types, the use of foundational nitrogen (N) management practices negates the on-farm benefits of EEF and highlights the need for other economic incentives to increase EEF adoption if the sole benefits are reduced GHG emissions.

Sorting out the truth of 'quick-fixes'

There are an overwhelming number of 'quick fix' solutions being marketed to grain growers. It becomes more and more complicated to sort through worthwhile products and products that are a waste of time and resources. To benefit a farm, a product must work consistently year after year and produce enough yield benefit to cover the cost of the product and its application.

Academic and government researchers do not run product comparison research trials. In the absence of third party, independent research, on-farm trials provide an ideal platform to test the frequency of a product's benefit (is the benefit seen once every three years or every year?) and the magnitude of the product's benefit (is the yield increase 2% or 10%?).

Balancing logistic ease with complex crop rotations

In western Canada, crop rotations are primarily two-year, spring wheat-canola rotations, which are profitable and easy to implement on large acreages. However, there are increasing examples of soil-borne disease and low NUE that could be managed with more diverse rotations. Furthermore, numerous research studies repeatedly find that inclusion of N fixing pulse crops and/or winter cereal crops provide numerous system health improvements.

A recent survey of western Canadian grain growers indicated 62.5% agree or strongly agree they need to diversify their current crop rotation. The same survey found that having a crop rotation with better net economic returns would be the number one reason convincing them to change their current crop rotation. Given the profitability of current crop choices, diversification is challenging for western Canadian grain growers.

Method

Balancing NUE and farm economics through the lens of small plot research

A recently published study from Fast et al. 2023 tested the benefits of EEFs on spring wheat grain yield and quality at eight locations, representing three different soil types, over four growing seasons. The five N sources tested were:

- urea
- urea + urease inhibitor, N-(n-butyl) thiophosphoric triamide (NBPT)
- urea + nitrification inhibitor, Nitrapyrin
- urea + dual-inhibitors, (NBPT + Dicyandiamide)
- polymer-coated urea, Environmentally Smart Nitrogen®.

Each N source was tested at four N rates (60, 120, 180 and 240kg N/ha) with all N fertiliser applied at planting in either a mid- or side-row band.

Balancing the benefits of N fixing foliar bacteria with yield through the lens of on-farm research

Alberta Grains, a commodity organisation funded through a refundable producer levy, has built a robust program for on-farm research to evaluate agronomic questions related to the performance of genetics and/or management practices on individual producer farms. In 2022, four on-farm trials tested the performance of two biological products (Utrisha-N™ and Envita®) with an untreated control on spring wheat for their ability to increase yield and quality.

Balancing logistic ease with complex crop rotations by implementing small plot research

A diverse team of experts collaborated on a four-year research project to evaluate yield and yield stability, NUE and net economic returns of six crop rotations in the Southern Prairies, Northern Prairies and Red River Valley ecozones of western Canada. Six crop rotations tested in the study were:

- the traditionally recommended rotation in each ecozone
- pulse or oilseed intensified rotation
- a diversified rotation with multiple pulse species and/or winter cereals
- a market driven rotation based on crop types selected for their high commodity prices
- a high-risk rotation
- a soil health rotation.

Results and discussion

Balancing NUE, GHG emissions and farm economics

The Fast et al. 2023 study found that N source affected grain yield in the Dark Brown soils only. Here, the dual-inhibitor treatment increased grain yield relative to urea and polymer-coated urea. However, on the Black Chernozem and Dark Grey Luvisol soils, there was no improvement in yield or grain quality with the EEFs compared to untreated urea.

The use of a dual-inhibitor resulted in higher net returns ($62 CAD/ha) than urea in the Dark Brown soils (Figure 1). However, on the other soil types, there was no economic incentive for grain growers to use an EEF product.

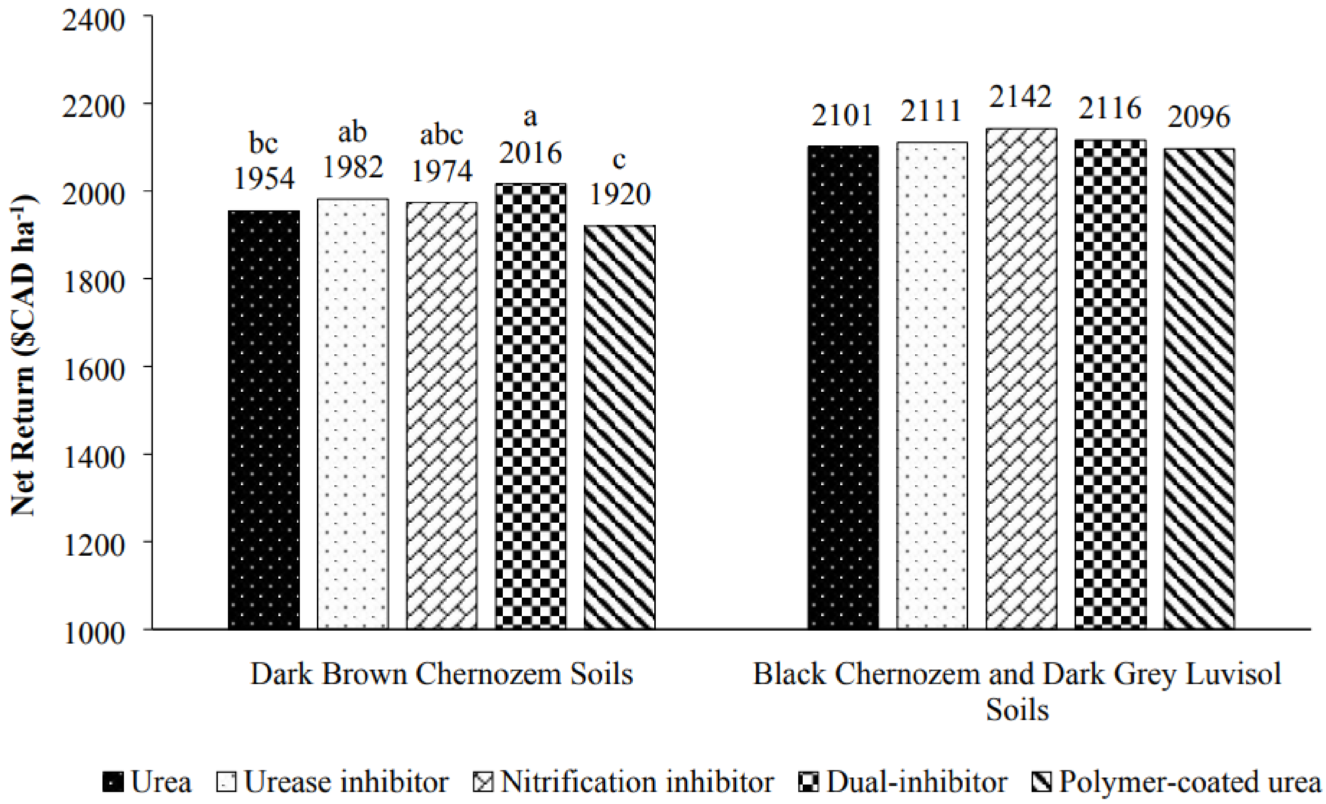

Figure 1. Net return response to N source in both Dark Brown Chernozem and Black Chernozem (combined) with Dark Grey Luvisol Soils. Values are least square means. Different letters above means indicate significant differences between N sources at $p \leq 0.05$. Source: Fast et al. 2023.

The lack of yield response to the EEFs in the Black Chernozems and Dark Grey Luvisols may be attributed to the use of N fertiliser best management practices. For example, the foundational agronomic practices of N application at the 'Right TIME' and the 'Right PLACE' are thought to be mitigating the benefits of the 'Right SOURCE' on these two soil types.

Sorting out the truth of 'quick-fixes'

At all four on-farm testing locations, there was no statistical difference in yield or quality parameters when Utrisha-N™ and Envita® *foliar* N fixing bacteria treatments were applied under these trial conditions, compared with the check (Table 1). In comparison, advertisements to growers cite a 2.2bu/ac (0.12mt/ha) yield increase, which occurs 67% of the time (based on data from 12 responsive field trials in 2021). When assessing the likelihood of an economic response, growers need to proceed cautiously, as the company advertised revenue from the 0.12mt/ha of increased grain sales (based on spring wheat at $364 CAD/mt) is $43.68 CAD but the product sells for approximately $16 CAD/ac ($39.54 CAD/ha). Given that there is also an application cost, it is very challenging for this practice to be profitable, especially when this yield increase cannot be counted on annually.

Table 1: Spring wheat yields in response to N fixing biologicals, from Alberta Grain's four on-farm testing locations in 2022.

	Spring Wheat Yield (t/ha)			
Treatment	Irrigated Dark Brown Chernozem	Dark Brown Chernozem	Black Chernozem	Dark Gray Chernozem
Control	5.65 a	2.48 a	4.64 a	6.61 a
Biological Product 1	5.58 a	2.52 a	4.80 a	6.62 a
Biological Product 2	5.53 a	2.51 a	n/a	6.58 a
p-value	0.6023	0.7954	0.3709	0.5481
CV%	3.88%	4.99%	4.54%	1.13%

Within each site, yields followed by the same letter are not significantly different based on a Tukey mean separation at p=0.05.

On-farm implementation of more diverse rotations

In the Northern Prairies, the higher net returns often associated with the market driven rotation are attributed to the high frequency of canola in the rotation and the high canola crop prices. This market driven rotation often has canola being grown in three of four years, which is an agronomically risky practice due to the long-term impacts of canola disease build up in short rotations. The soil health rotation consistently has some of the lowest net returns, due to the lack of yield in the green manure year of the rotation resulting in no saleable grain in one of four years.

Table 2: Net economic returns of the crop rotation treatments at the four locations in the Northern Prairies ecozones of the Canadian Prairies.

	Net Economic Returns (CAD/ha)			
Rotation Treatment	Beaverlodge	Lacombe	Scott	Melfort
Control	$40.11 ab	$264.65 bc	$60.34 b	$175.32 a
Intensified	-$72.65 bc	$297.02 b	-$52.44 c	$163.51 a
Diversified	$141.79 a	$283.78 b	-$76.31 c	$155.90 a
Market Driven	$46.04 ab	$577.56 a	$270.73 a	-$7.76 b
High Risk	$55.60 ab	$264.70 bc	-$47.44 c	$18.83 b
Soil Health	-$125.01 c	$132.65 c	-$81.62 c	$32.91 b

Within each site, net economic returns followed by different letters are significantly different based on a Tukey mean separation at p=0.05.
Adapted from: Strydhorst and Liu, 2023.

When assessing trends from all site-years, the intensified rotation (POS) had relatively high yields combined with a low CV, giving it some of the most consistent yields over time and growing environments (Figure 2).

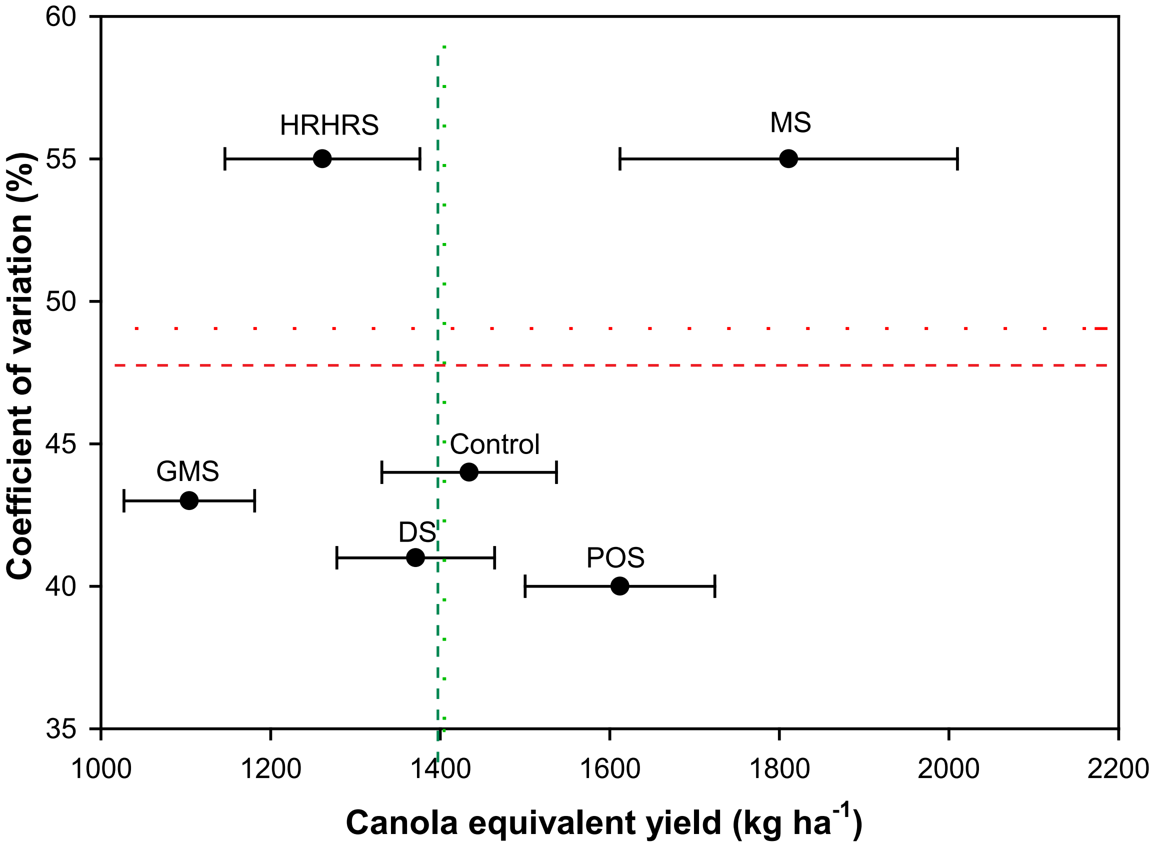

Figure 2. Yield stability of the crop rotation treatments over 27 site years. The horizontal black bars represent the standard error of the mean. The vertical dashed line indicates the Canola Equivalent Yield averaged across all six crop rotation treatments: Control; POS, Pulse- or Oilseed- Intensified System; DS, Diversified System; MS, Market Driven System; HRHRS, High Risk System; and GMS, Green-Manure, Soil Health System. The horizonal dashed line is the average CV across all six crop rotations. Adapted from: Strydhorst and Liu, 2023.

If a grower has been adhering to a wheat-canola rotation across all their fields (i.e. 2023ha farm with 31 fields), grain growers need to give serious thought to taking a small step beyond their comfort level and diversify their rotations. This could take the form of a wheat-barley-canola rotation on one of the 31 fields. Then, the following year, a feasible goal would be to introduce a pea-wheat-canola rotation on a second field. The idea is not to become overwhelmed by the changes but to gradually incorporate them into the routine. Diversity can be achieved by gradually adding winter cereals, pulse crops and other cereal species. Over time, the small steps accumulate and lead to a more diversified rotation across the entire farm.

Conclusion

- When foundational best management practices are used, such as 'Right TIME' and 'Right PLACE', the benefits from Right 'SOURCE', such as EEFs, might be limited on some soil types. Grower adoption of EEFs will depend on profitability.
- Caution must be used when deciding to apply products which are not 'tried and true', and profitability may not be guaranteed. On-farm testing is a platform to assess product profitability when third-party independent research is lacking.
- While the benefits of more diverse crop rotations have been documented in research studies, the operational logistics and the lack of rotations with better net returns make it challenging for growers to diversify their rotations. However, grain growers should consider slowly implementing more diverse rotations on a small portion of their farms. This will allow them to capture some of the yield stability and long-term system health benefits.
- While foundational agronomic practices take more time, planning, and knowledge, they present growers with the opportunity to harvest some low hanging fruit while maintaining yields and profitability.

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Notes

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Concurrent session Day 1

Cereal disease update 2024

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GRDC project codes: DJP2104-004RTX; DAQ2304-008RTX; DAW2112-002RTX; UOS2207-002RTX; CUR2302-002RTX

Keywords

- fungicide resistance, net blotch, septoria tritici blotch, stripe rust.

Take home messages

- Proactive disease management, which combines variety selection, paddock selection and appropriate fungicide use, provides proven sustainable and economic disease control.
- Septoria tritici blotch reduced grain yield in highly susceptible wheat varieties by 28% in the Victorian MRZ (Wimmera) and 13% in the LRZ (Mallee).
- Net form of net blotch (NFNB) is common in barley and caused grain yield loss of up to 18% in susceptible varieties in 2023.
- Fungicide resistance is now common in cereal pathogens in Southern Australia and so, strategies to manage diseases under fungicide resistance environments are required.

Background

Implementation of proactive strategies for the control of cereal diseases can prevent avoidable losses when seasonal conditions are suitable for disease. This paper provides an update on the latest research regarding cereal diseases for South Australian growers.

Avoiding suckers for sustainable disease control

The most important component of an integrated disease management strategy by far is the avoidance of highly susceptible (or sucker) varieties. We often assume that, for genetic control, we need to grow resistant varieties (that is, those rated R, RMR or MR), when actually varieties with a rating of MS (and in some cases, MSS) or better will provide ongoing protection from loss, especially when these varieties are grown on a large scale.

As shown in Figure 1, the risk of yield loss increases exponentially with increasing susceptibility. This shows that avoiding highly susceptible varieties can result in large reductions in disease risk. Also, highly susceptible varieties produce large amounts of inoculum, which has implications not just for that season, but also for the next.

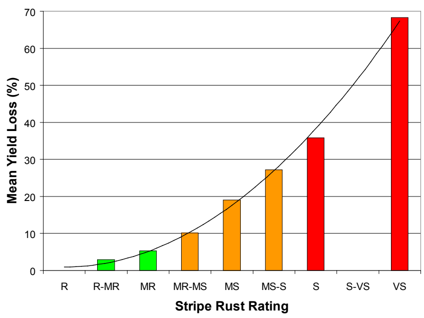

Figure 1. Varietal resistance rating and grain yield loss due to wheat stripe rust (mean of six sites across Vic, SA and NSW) in 2005.

Yellow leaf spot (YLS) in wheat is an example of how replacing highly susceptible varieties (for example, Yitpi, LRPB ScoutΦ, LRPB PhantomΦ) with partially susceptible varieties (for example, ScepterΦ, RockStarΦ, LRPB TrojanΦ, VixenΦ) provided widespread disease control. Completely resistant varieties weren't required.

Conversely, wheat powdery mildew is an example of where partially resistant varieties (for example, Yitpi, LRPB ScoutΦ, AxeΦ) were replaced with highly susceptible varieties (for example, ScepterΦ, RockStarΦ, LRPB TrojanΦ, VixenΦ, CorackΦ, WallupΦ) on a large scale, resulting in powdery mildew becoming an important disease.

Rust update

Rust, in particular wheat stripe rust, was common in south-eastern Australia in 2023 due to the high levels of rust present in 2022 and its carry over on volunteer wheat growing over summer (the green-bridge). The common use of up-front treatment (for example, fungicide on fertiliser) provided good early suppression of disease, however high disease occurred when integrated control was not used.

With early summer rain events in many parts of the south-east, rust carry over on volunteer cereals is expected going into the 2024 season. Therefore, good rust management will be required with practices including:

- removing the green bridge (volunteer cereals) by mid-March
- using a current cereal disease guide to check resistance ratings of varieties and, where possible, avoiding susceptible varieties
- having a fungicide management plan, with an emphasis on up-front control options
- using the free StripeRustWM App for iPads and tablets.

Internationally, Australia is in the enviable position of having excellent information on the national distribution of cereal rusts and their pathotypes (strains). This enables accurate disease resistance ratings for current and new varieties, and support for breeders in the development of resistant varieties. This surveillance by the University of Sydney, with GRDC's support, during 2023 (until the end of November) received 289 samples of rust nationally, with results from 228 samples returned to date.

Wheat stripe rust

Pathotype analysis during 2023 identified four pathotypes of wheat stripe rust in eastern Australia: 239 E237 A- 17+ 33+ (90 isolates), 238 E191 A+ 17+33+ (47 isolates), 198 E16 A+ J+ T+ 17+ (19 isolates), and 238 E191 A- J+ T+ 17+ (12 isolates). Interestingly, the "238 pathotype" (Pt. 238 E191 A+ 17+ 33+, first detected in 2021) was most common in northern Australia, while the "239 pathotype" (2017) was most common in southern Australia. This difference in distribution may be due to the relative resistance/susceptibility of the varieties grown in the north and south to these two pathotypes. Due to the diversity in pathotypes present in eastern Australia, the resistance ratings in current disease guides reflect a 'worse case' against any of these four pathotypes.

Barley grass stripe rust

In 1998, a new specialised form (f. sp.) of stripe rust was detected on barley grass and a few barley varieties. This became known as 'BGYR' ('Barley Grass Stripe (Yellow) Rust') and does not infect wheat. In 2021, a new variant was detected (BGYR+) which has a large change in virulence that increased vulnerability in many varieties (for example, Capstan, Empress, Finniss, Keel, Ketch, Prior and Ulandra are all susceptible as seedlings). This new pathotype is now common in eastern Australia, with more reports of low levels of stripe rust in barley crops since 2021. Note that true barley stripe rust is still exotic to Australia.

The increasing occurrence of the BGYR+ pathotype on barley grass provides opportunity for it to undergo further changes in virulence. Ongoing monitoring and research to understand the vulnerability of barley varieties to potential future changes is vital in assessing and managing the risk it poses to the industry.

Barley leaf rust

During 2023, 33 samples of barley leaf rust were received from which three pathotypes were identified: 5457 P- (23 isolates), 5457 P+ (9 isolates), and 5656 P+ (4 isolates). All carry virulence for the resistance gene ***Rph3***, which is in 20 barley varieties. Pathotypes 5457 P- and 5457 P+ belong to a single clonal lineage of the barley leaf rust population that was first detected in WA in 2001 and considered to be exotic. Since then, members of this lineage have dominated in Australia and now account for 89% of isolates. Work on fungicide insensitivity by the University of Sydney revealed that this lineage is insensitive to several DMI fungicides.

Septoria in wheat

Septoria tritici blotch (STB) has become a widespread disease in wheat across south-eastern Australia, with yield and quality losses common in many parts due to increased area of susceptible varieties and conditions conducive to disease. AgVic trials during 2023 demonstrated losses of up to 28% and 13% in susceptible varieties in the medium (Wimmera) and low rainfall (Mallee) regions of Victoria, respectively (Table 1). Yield losses due to STB in the Mallee were reported for the first time. These trials clearly demonstrated the benefit of avoiding highly susceptible varieties in both the Wimmera and Mallee to reduce losses due to STB (Table 1).

Table 1: Septoria tritici blotch severity and grain yield of wheat varieties with (Max) and without (Min) disease at Longerenong (MRZ) and Kinnabulla (LRZ), Victoria, 2023.

Variety	Rating	Disease severity^{A} (% leaf area affected) in Max. treatment		Grain yield (t/ha)					
		Longerenong	Kinnabulla	Longerenong			Kinnabulla		
		11 Sep Z59^{B}	8 Sep Z59	Max.^{C}	Min.	Loss (%)^{D}	Max.	Min.	Loss (%)
LRPB Lancer$^{(D}$	MS	10a	5a	5.87	6.16ns	5	5.14	5.15ns	0
Hammer CL Plus$^{(D}$	MSS	27b	9b	5.21	6.19**	16	5.00	5.26**	5
Scepter$^{(D}$	S	55d	27de	5.37	6.45**	17	5.21	5.77**	10
Calibre$^{(D}$	S	58d	25cd	5.74	6.60**	13	4.76	5.44**	13
Razor CL Plus$^{(D}$	SVS	70e	29e	3.87	5.35**	28	4.01	4.38*	8
LRPB Impala$^{(D}$	SVS	42c	24c	4.88	5.76**	15	4.42	4.79*	8
P		<0.001	<0.001						
Lsd (0.05)		7.3	2.76						

*AWithin column means with one letter in common are not significantly different (0.05). ** = statistically significant at 5% and * = 10%. BDate of assessment made and Zadoks growth stage. C Max. = Maximum disease treatment (No disease control with 1kg STB infected wheat stubble); Min. = Minimum disease treatment (No stubble, Seed (Fluquinconazole 167g/L @ 300mL/100kg seed) + Foliar applied fungicide at Z31 (Epoxiconazole 500g/L @ 125mL/ha) + Z39 (Benzovindiflupyr 40g/L + Propiconazole 250g/L @ 500mL/ha)). D Yield loss % for each variety was presented as % yield decrease vs the minimum disease treatment.*

Where susceptible (S) or worse rated varieties are grown, fungicides may be required to protect yield. Consistent with previous research, two fungicide applications (at Z31 and Z39) increased grain yield by 16% in Wimmera and 10% in Mallee (Table 2). Always rotate fungicides with different modes of action to ensure effective suppression and slow fungicide resistance development.

Table 2: Septoria tritici blotch severity (% leaf area affected) and yield loss in wheat (ScepterA (S)) in response to fungicide treatments at Longerenong (MRZ) and at Kinnabulla (LRZ), Victoria, 2023.

Treatments	Longerenong			Kinnabulla		
	Disease severity^{A} 11 Sep Z59	Grain yield (t/ha)	Yield gain %^{B}	Disease severity 8 Sep Z59	Grain yield (t/ha)	Yield gain %
Untreated control	58^{d}	4.78^{a}	-	31^{c}	4.98^{a}	-
Seed	55^{d}	5.08^{ab}	-	31^{c}	5.02^{ab}	-
Foliar at Z31	33^{b}	5.16^{ab}	-	19^{b}	5.36^{cd}	7
Foliar at Z39	46^{c}	4.93^{a}	-	18^{b}	5.22^{bc}	5
Foliar at Z31 + Z39	30^{ab}	5.45^{b}	14	9^{a}	5.49^{d}	10
Seed + Foliar: Z31+Z39	26^{a}	5.55^{b}	16	9^{a}	5.49^{d}	10
P	<0.001	0.016		<0.001	<0.001	
Lsd (0.05)	7.2	0.47		2.15	0.22	

^{A}Within a column, means with one letter in common are not significantly different at 0.05. ^{B}Yield gain % is the percentage yield increase vs the untreated control. Fungicide treatments on seed (Fluquinconazole 167g/L @ 300mL/100kg seed) or foliar (Epoxiconazole 500g/L @ 125mL/ha at Z31 and Benzovindiflupyr 40g/L + Propiconazole 250g/L @ 500mL/ha at Z39).

Net form of net blotch (NFNB) in barley

Net form of net blotch (NFNB) is a common foliar disease of barley in south-eastern Australia due to the adoption of susceptible varieties (for example, RGT PlanetΦ (SVS) and Spartacus CLΦ (S)). During 2023, AgVic trials in the Wimmera (Wallup) demonstrated losses of up to 18% in the susceptible variety RGT PlanetΦ (SVS) (Table 3). The partial resistant variety Titan AxΦ (MS) had less infection and no yield loss, again showing the benefit of avoiding highly susceptible varieties.

Table 3: Net form of net blotch severity (%) and yield in two barley varieties in response to different fungicide treatments at Wallup, Victoria, 2023.

TreatmentB	Disease severityΦ (% leaf area affected) RGT PlanetΦ (SVS)		Titan AxΦ (MS)		RGT PlanetΦ (SVS)		Titan AxΦ (MS)
	Z39 29/8	Z82 10/10	Z37 29/8	Z82 10/10	Grain Yield (t/ha)	Yield gain %B	Grain Yield (t/ha)
Untreated control	10	41e	3	1	4.41ab	-	5.79
Seed	9	34d	-	-	4.52ab	-	-
Foliar at Z31	2	23b	0	0	5.10de	18	5.99
Foliar at Z39	11	29cd	3	1	4.70bc	-	5.91
Foliar at Z55	11	29cd	-	-	4.32a	-	-
Foliar at Z31 + Z39	2	14a	0	0	5.22e	21	5.86
Seed + Foliar Z39	11	26bc	0	0	4.87cd	13	5.97
Seed + Foliar: Z31+Z39	2	12a	0	0	5.29e	22	6.24
P	<0.001	<0.001	<0.001	0.176	<0.001		0.464
Lsd (0.05)	3.23	5.90	0.53	ns	0.34		ns

[A]Within a column, means with one letter in common are not significantly different at 0.05. [B]Yield gain % based on percentage yield increase vs the minimum disease. Fungicide treatments on seed (Fluxapyroxad 333g/L @ 150mL/100kg seed) or foliar (Prothioconazole 210g/L +Tebuconazole 210g/L @300mL/ha)

Fungicides are an important part of NFNB control in susceptible varieties. Best economic control for NFNB management was provided by dual foliar application at Z31 and Z39 (Table 3). Earlier applications tend to provide most of the suppression in shorter season environments and later applications in longer high-rainfall environments. But unlike previous seasons, seed applied fluxapyroxad (an SDHI), the active ingredient in the seed treatment Systiva®, did not provide expected NFNB control due to resistance to this active. Likewise, field resistance and reduced sensitivity toward triazoles, such as tebuconazole and propiconazole, have also been increasing in frequency. See the section on fungicide resistance below for more details.

Fungicide resistance

Resistance to fungicides is becoming an increasing threat to cereal crops across Australia. The status of resistance to fungicides in important cereal diseases is summarised in Table 4 and is based on work by the Fungicide Resistance Group (FRG) at the Centre for Crop and Disease Management (CCDM) and the University of Sydney's rust program.

Fungicide resistance management

There are five strategies that growers can adopt to slow the development of fungicide resistance and therefore, extend the longevity of the limited range of fungicides available.

- Avoid susceptible crop varieties. Where possible, select the most resistant crops suitable and/or avoid putting susceptible crops in high-risk paddocks.
- Rotate crops. Avoid planting crops back into or adjacent to their own stubble.
- Use non-chemical control methods to reduce disease pressure. Delaying sowing, early grazing are examples of strategies that can reduce disease pressure.
- Spray only if necessary and apply strategically. Avoid prophylactic spraying and spray before disease gets out of control.
- Rotate and mix fungicides/modes of action (MoA). Use fungicide mixtures formulated with more than one MoA, do not use the same active ingredient more than once within a season, and always adhere to label recommendations.

For more information on the management of fungicide resistance, consult the 'Fungicide Resistance Management Guide', available from www.afren.com.au

Table 4: Status of fungicide resistance cases in Vic and SA cereal crops (Nov 2023).

	StatusA		
Disease	**Group 3 (DMI)**	**Group 7 (SDHI)**	**Group 11 (QoI)**
Barley			
Powdery mildew	Lab detection	Not detected	Not detected
Net form net blotch	Reduced sensitivity	Field resistance	Reduced sensitivity (SA)
Spot form net blotch	Reduced sensitivity	Not detected	Not detected
Leaf rust	Reduced sensitivity	Not detected	Not detected
Wheat			
Septoria tritici blotch	Reduced sensitivity	Not detected	Reduced sensitivity (SA)
Powdery mildew	Field resistance		Field resistance

[A]**Lab detection** - *Measurable differences in sensitivity of the pathogen to the fungicide when tested in the laboratory. Detection of resistance in the lab can often be made before the fungicide's performance is impacted in the field;* **Reduced sensitivity** – *Some reduction in fungicide performance which may not be noticed in the field. Serves as a warning that resistance is developing in the pathogen. Increased fungicide rates as per registered labels may be necessary.* **Field Resistance** - *Fungicide fails to provide an acceptable level of control of the target pathogen at full label rates.*

Conclusion

In the absence of proactive disease control in cereals, yield losses can be greater than 20%. It is, therefore, important that plans are developed to effectively manage cereal diseases this season. Disease management plans should consider paddock and variety selection and, where the risk warrants, the proactive and prudent use of fungicides that avoid overuse to protect their longevity.

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Useful resources

Cereal disease guide (http://agriculture.vic.gov.au/cereal-disease-guide)

Australian cereal rust survey (https://www.sydney.edu.au/science/our-research/research-areas/life-and-environmental-sciences/cereal-rust-research/rust-reports.html)

Septoria tritici blotch in wheat (https://grdc.com.au/resources-and-publications/all-publications/factsheets/2022/septoria-tritici-blotch-in-wheat)

Fungicide Resistance (https://afren.com.au)

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Notes

Messages emerging from long term lime trials to combat soil acidity

Brian Hughes, Andrew Harding, Nigel Fleming and David Woodard.

SARDI and University of Adelaide

GRDC project codes: UOA2206-009RTX

Keywords

- acidity, incorporation, lime, soil pH.

Take home messages

- Long-term trials sites tracking the effectiveness of liming across a range of cropping and soil types are providing detailed information on the effects on crop yields, lime movement, lime rates and pH changes.
- The effectiveness of incorporation of lime depends on the soil depth to the acidic layer and the type and effectiveness of incorporation and resulting mixing impact.
- Soil monitoring has provided a higher level of information on pH change and the impact of liming treatments than measuring grain yield alone.
- Differences in lime quality, outside of large differences in neutralising value and lime fineness have resulted in small or no differences in yield over time.
- Consistent impacts occur on plant trace element levels when liming including increased molybdenum and decreased manganese. Decreased copper for livestock is potentially an issue at some sites.

Background

Soil acidity is increasing across the dryland cropping area of South Australia (SA) due to more intensive and productive farming practices. It is estimated around 3 million hectares are now at pH levels where acidity may be an issue and this is expected to increase to 4 million hectares in SA over the next few decades.

Dual soil acidity projects were undertaken in Victoria (Vic, via Southern Farming Systems) and across South Australia in seasons 2019 to 2021. These included the establishment of new long term field trials, training of PhD students and a strong extension focus with the establishment of the SA Acid Soils website. A combined project across the Southern Region commenced in 2022 and will continue until 2025. This project is evaluating 20 sites including several new demonstration sites, supporting a post-doctoral study on the impact of liming on greenhouse gas emissions and delivering a strong extension program on findings.

This paper will focus on crop yield responses to lime, incorporation impacts, differences observed between liming products, trace element impacts and economics of liming at some sites.

Method

During 2023, nineteen existing and one new lime trial were monitored for dry matter and grain yield, with most sites having plant nutrient analysis completed as well. Several sites had detailed pH analyses during Autumn 2023. Seven sites were located in Vic and the rest across SA. Most sites have been established since 2019, although there are three sites older than this, with Westmere established in 2014. This paper is focussed on results from SA sites, with replicated design. Seven of these sites were sown and managed by the South Australian Research and Development Institute (SARDI) Agronomy team or Trengove Consulting and associates. In contrast, other sites were sown and monitored in paddock by growers. Sites were mostly chosen from acid areas identified through Veris pH mapping. Treatments varied within the local district and included liming products as well as manures at three sites, biochar, clay, gypsum and granulated lime treatments. At most sites, a sulphur treatment (known to reduce soil pH) was included to demonstrate where the yield would drop to if liming was not undertaken in the next few years.

Results and discussion

Lime responses

The largest positive yield responses to lime application have been observed with lentils, vetch and beans, however, smaller responses occurred in barley and acid-sensitive wheat varieties. No lime responses were observed in acid-tolerant wheat varieties, lupins or oats, although deep ripping, spading and clay have had impacts on these crop types. No response has been observed in canola from the two trials monitored, however, in both cases, the sites were not in very acid-responsive situations. In the year of application of lime, little or no response to lime was observed and, as a generalisation, lime responses increase in significance the longer they persist.

A range of lime response curves have been developed and crops can be assessed against treatments, pH of different layers or, in some cases, aluminium (Al) levels. Response curves varied significantly between crop type and site. Examples are shown with lime responses against treatments at Mallala in 2022 in Figure 1, responses against pH (0–5cm) in Figure 2a, and Al versus pH relationships highlighting differences between sites in Figure 2b.

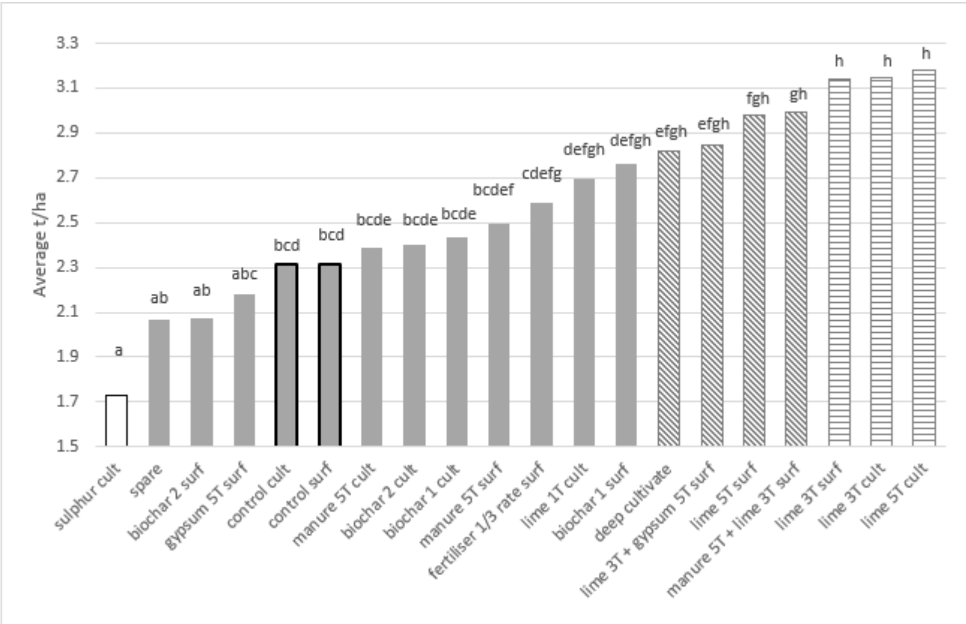
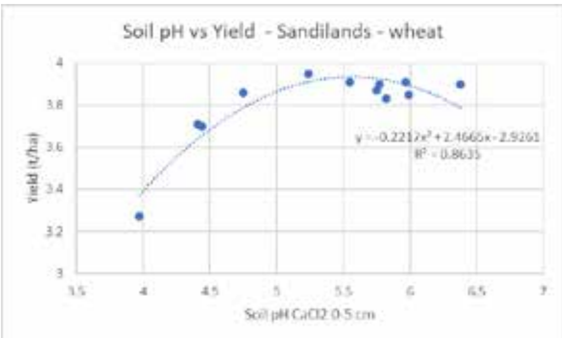


Figure 1. Lime response in lentils at Mallala in 2022. P value <0.001 and Lsd at 5% of 0.49t/ha. Shaded groups are based on multiple comparison.



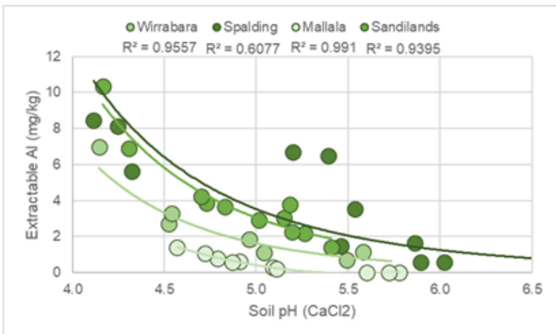


Figure 2.a – Lime response by pH level, Sandilands, 2023. **Figure 2.b** – Al vs pH(CaCl2) relationship at four sites.

Impacts of incorporation

A key requirement when assessing the possible impact of lime incorporation is understanding the soil pH profile. Four categories of acidification have been described and trial sites are attributed to categories as follows:

- Surface acidification – 0–10cm acid, often clay layer at 10cm (Mallala, Brooker)
- Deeper acidification – 0-15 to 20 cm acid (Sandilands, Spalding, Tungkillo)
- Stratified acidification/subsurface acid – 0–5cm slightly acid/ neutral, 5–15cm acid, (Kapunda, Koonunga- post liming), sandy 5–25cm acid (Lameroo, Yumali- not limed)
- Subsoil acidification – A horizon slightly acid/ neutral, B horizon acid – not normally an issue in cropping soils.

Understanding the type and depth of incorporation and the effectiveness of mixing helps to determine whether lime incorporation is justified. Several methods have been used in selected trials described below:

- Tyned cultivator – at Sandilands, Koonunga and Kapunda
    - At Sandilands, yield of incorporated lime treatments was significantly better than surface applied treatments in year 2 in 2020 in lentils but not since. Soil pH data in 2023 suggested plots with the incorporated treatments have a slightly improved subsurface pH compared with surface applied treatments.
    - At Koonunga, yield of incorporated lime treatments was better than surface applied treatments in year 3 in 2021 under beans but not in other years. Other deeper treatments, such as mouldboard and granulated lime to depth, were much better than tyned incorporated in 2021, 2022 and 2023.
- Offset disc to 7.5cm – at Mallala
    - No significant difference was observed (slight trend only) in 2020 while in 2022 when in lentils and had significant responses to lime but no significance due to cultivation.
- Rotary hoe – at Spalding, Yumali, Lameroo and Wirrabara
    - Provided a good mix to 10cm, cultivation impacts at Yumali still significantly better than surface applied lime after four seasons.
- Mouldboard plough – at Koonunga
    - Koonunga had lime application prior to the trial but acidity down to 25cm. Mouldboard ploughing has been significantly better than surface applied lime or tyned incorporation over last three years when the trial has responded. The impact of the different incorporation treatments at this site is shown in Figure 3 and highlights the positive impact of the mouldboard plough and subsoil Calciprill a granulated lime in increasing the pH around 5–15cm.

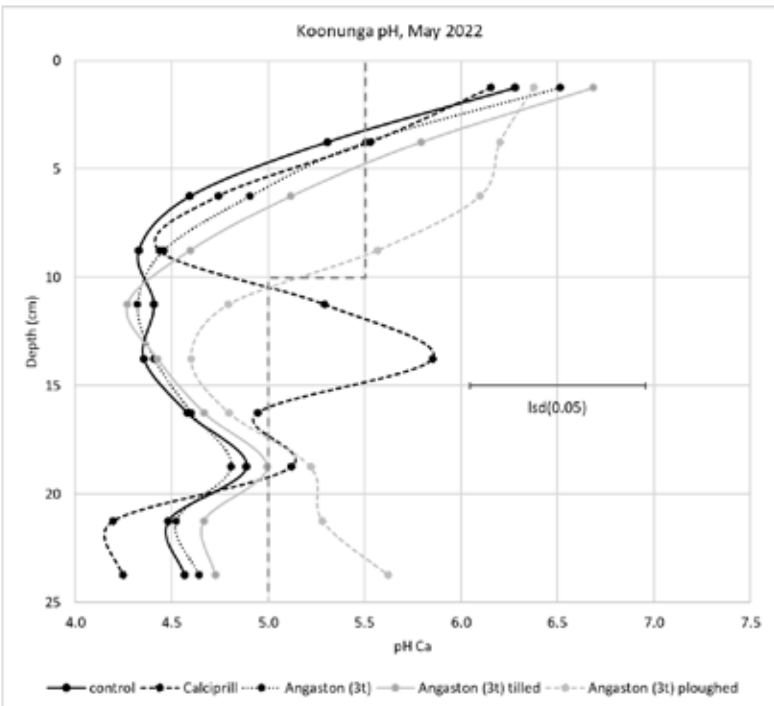


Figure 3. Impact of treatments on pH of profile at Koonunga.

- Deep ripping
  - Deep ripping has been undertaken at several sites. At the silicious sand sites at Yumali, Bute and Lameroo, deep ripping alone gave a response, while at the sandy loam sites at Sandilands and Mallala, deep ripping gave nil to small responses. Where lime was added prior to deep ripping, responses were much more significant than deep ripping alone compared to controls.
- Sandy soil modification
  - The use of spading and inclusion plates with and without lime was tested at two sites and provided significant response from the treatment without liming. At Lameroo in year 3, the lime with spading seemed to be having an additional impact on dry matter.
  - The use of clay at Yumali had been the highest yielding treatment overall (significant responses in years 3 and 4). This treatment increased soil pH, as well as overcame other sand issues such as high-water repellency and low CEC.
  - The impact of different treatments on pH by layer is shown in Tables 1 and 2, which highlight that little pH change occurs without adding lime when ripping, spading or using inclusion plates where no clay was added.

Table 1: Impact on the pH profile from a range of treatments at Yumali (sand over clay), 2023.

Treatment	Depth (cm)				
	0-5	5-10	10-15	15-20	20-25
sulphur cult	4.61	4.39	4.27	4.46	4.68
control	4.97	4.61	4.61	4.57	4.87
spare 1	5.00	4.66	4.51	4.57	4.51
spare 2- rescape	4.96	4.60	4.63	4.76	4.61
1T low lime surf	5.69	4.80	4.69	4.70	4.72
3T medium lime surf	6.42	5.32	4.91	4.92	4.70
5T high lime surf	6.77	5.79	5.40	4.68	4.91
deep rip	4.87	4.56	4.51	4.47	4.49
cultivate	5.02	4.73	5.15	4.69	4.78
100T clay cultivate	5.80	5.48	5.15	4.83	4.82
deep rip + cultivate + 3T lime	6.06	5.39	5.16	4.68	4.80
biochar 3T + lime 3T + cultivat	6.10	5.61	5.15	5.04	5.06
3T medium lime cult	6.06	5.55	4.92	4.91	4.94
5T high lime cult	6.48	5.77	5.16	4.92	4.88
lime 2- Cawtes 3T	5.80	4.75	4.78	5.46	5.18
lime 3 - Hensckhe 3T	6.30	5.30	4.79	5.00	4.86
cultivate with rotary hoe					$HSD_{0.05}$=0.99
Agricola main lime used					
pH range	>6.5	5.5-6.5	5.0-5.5	4.5-5.0	<4.5
Approx Shading					

Table 2: Impact on the pH profile from a range of soil modification treatments at Lameroo, 2023.

Treatment	Depth (cm)					
	0-5	5-10	10-15	15-20	20-25	25-30
control	5.53	4.71	4.71	4.94	5.41	5.82
inclusion ctrl	5.09	4.74	4.58	4.56	4.68	4.85
inclusion + lime 3T	6.32	5.68	5.05	5.08	5.00	5.65
spading control	5.49	4.84	4.59	4.62	4.85	5.22
spading + lime 3T	6.24	5.79	5.43	5.13	5.66	6.06
sp +lime 3T+manure 5T	6.15	5.59	5.55	5.36	5.43	6.14
spading +manure 5T	5.44	4.97	4.75	4.55	4.68	5.08
spading done to 30cms					$HSD_{0.05}$=1.14	

Comparing limes

At several sites, locally available lime products were compared for various parameters. Two approaches were taken: some trials compared products as is and other trials compared products after their neutralising values were adjusted to 100%. Comparisons were made of yield, NDVI, plant and soil tests on several trials.

Impacts on yield

Historically, the largest differences in grain yield were observed in the Tungkillo trial, where higher rates of Agricola and Southern limes gave around 60% more grain yield over 4 years after lime application compared with 25–40% for the much coarser products. Application of Agricola lime led to a significantly better yield increase in year 2 (see Figure 4).

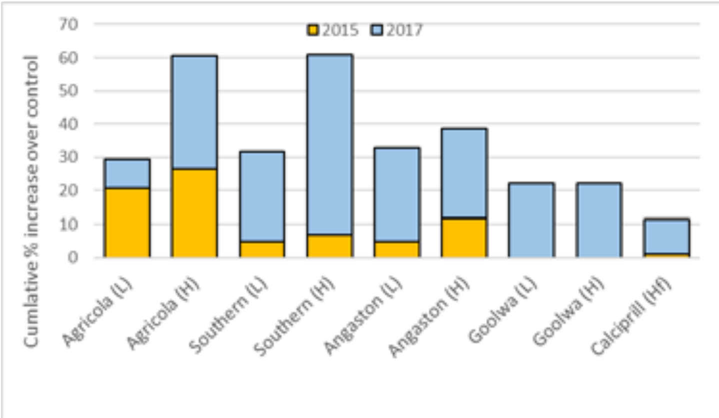


Figure 4. Cumulative grain yield (%) increase by lime treatment compared to the control at Tungkillo Trial Site between 2015 and 2017. (H – high rate 6T/ha, L- low rate 3 T/ha)

At Wirrabara, where products were adjusted for NV, the Clare quarry lime gave a slightly better cumulative yield over time, with an extra 1–2t/ha grown over a 9-year period, in comparison with coarser products including Kulpara, old Angaston and Nutrilime. This was evident in year 2 in barley, when the finer product gave the best yield.

At Sandilands, no yield differences have been observed from dolomites versus limes. At Yumali, some differences were observed, which can, in part, be attributed to the lower NV of the Cawtes product, where all products were applied at 3t/ha.

Impacts on soil and plant indicators

At Sandilands, the differences in the observed soil cations showed the impact of dolomites versus lime. In Figure 5a and 5b, levels of 0–10cm soil exchangeable calcium and magnesium are presented for Sandilands, 5 years after surface application at 4t/ha, with dolomites highlighted.

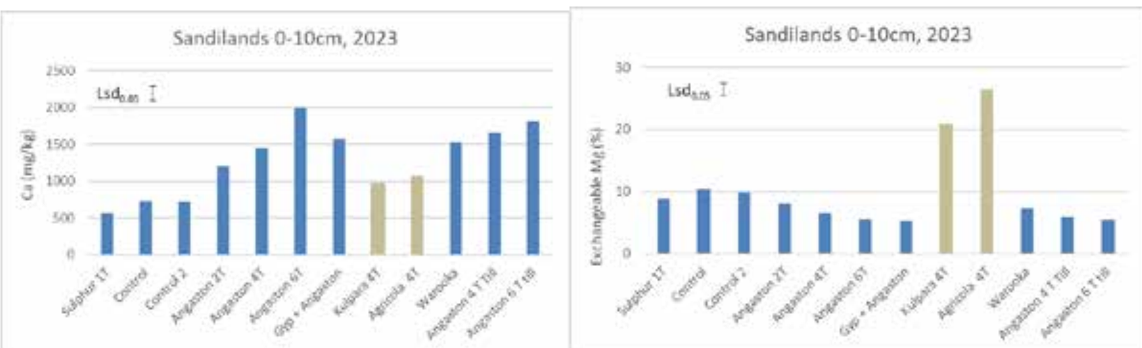


Figure 5. a – Soil calcium (mg/kg) Sandilands 2023. b – Soil magnesium (per cent) Sandilands 2023.

Plant indicators for the same group of tests indicated that there were only slight effects on plant magnesium (Mg) and calcium (Ca) by the dolomites versus lime, with both levels for all treatments within the adequate range for Ca and Mg (see Table 3).

Table 3: Plant tests for Sandilands, wheat Youngest Emerged Blades (YEBs) with P values

Treatment	Nitrogen %	Phosphorus %	Potassium %	Calcium %	Magnesium %	Sodium %	Sulphur %	Boron mg/kg	Copper mg/kg	Zinc mg/kg	Manganese mg/kg	Iron mg/kg	Aluminium mg/kg	Molybdenum mg/kg	Chloride %
Dolomites															
Agricola 4T	5.39	0.37	4.09	0.36	0.17	0.02	0.40	3.73	2.90	22	68	110	5.67	0.32	1.33
Kulpara 4T	5.08	0.36	4.20	0.32	0.16	0.02	0.37	5.13	3.15	21.5	64	103	4.93	0.27	1.4
Limes															
Angaston 4T	5.30	0.37	4.06	0.41	0.15	0.02	0.40	3.83	3.38	22	73	113	8	0.37	1.3
Warooka	4.98	0.37	4.08	0.38	0.14	0.02	0.37	4.40	3.47	21	66	103	6.60	0.35	1.27
Control	5.27	0.36	4.05	0.37	0.15	0.02	0.39	3.67	2.80	24	113	110	7.40	0.21	1.33
Sulphur	5.00	0.32	3.84	0.33	0.13	0.02	0.39	3.53	2.87	23	117	106	13.33	0.18	1.20
P value	ns	0.003	ns	ns	0.008	ns	ns	ns	ns	ns	<0.001	ns	<0.001	<0.001	ns
Adequate/ normal level	3.5-5.4	0.3-0.5	2.4-4	0.21-0.4	0.13-0.3	<0.5	0.15-0.4	5-10	5-50	15-70	25-300			0.1-0.5	<2.0
Low	3.4	0.24-0.29	1.5-2.3	<0.18	0.11-0.12		<.15	2-4	2-4	14	12-24			0.05-0.09	
Deficient	<3.4	0.24	<.15		<0.11			<2		<14				<0.05	

Impact on trace elements – Mo, Mn, Cu

Impacts on trace elements are far more significant by the lime vs control treatments vs sulphur plots. Lime treatments significantly increased molybdenum (Mo) at all sites and across all crops and, in many of the legumes, Mo levels were at critically low levels (see Table 3).

At all sites, manganese (Mn) was reduced by liming rates and other treatments which impact on pH, for example, claying. In most cases, the reduced level of manganese was still well above the critical level. However, low Mn has been reported as an issue in isolated crops and pastures, particularly lupins and sub-clover after liming, suggesting a need to apply Mn as a foliar treatment to these at-risk plants often linked to sandier soils, and/or to avoid excessively high rates of lime at such sites.

A third trace element under consideration is copper, particularly linked to livestock health which have higher requirements above what is required in plants. Where Mo is increased, there is the potential for copper deficiency through a Cu:Mo interaction. In most cases, the liming treatments were not decreasing copper in the plant (see Table 3), however they are increasing molybdenum. Avoid applying extra Mo as a fertiliser when liming, as availability of existing Mo will increase substantially with the pH change from liming.

Economics of liming

The economics of liming and other treatments has been assessed for two sites at Yumali and Sandilands. For Yumali, when taking into account costs and returns of treatments, the best three treatments are medium lime 3t/ha cultivated, clay cultivated @100t/ha and deep rip/cultivate and lime 3t/ha, returning an extra $700–900/ha (up to 3t grain). At Sandilands, the best five treatments are Angaston 4t/ha + rip, Kulpara 4t/ha surface, Agricola 4t/ha surface, Angaston 4t/ha + gypsum @5t/ha and Angaston 6t/ha surface, each returning around $300/ha; tilled treatments are behind these. No account has been made of residual amounts of lime applied, as 4t/ha at Sandilands will possibly account for acidification produced over a 15-year period.

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Useful resources

GRDC Acid Soils Southern Region (https://acidsoilssa.com.au/)

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Notes

Leveraging seed treatments and management strategies to effectively minimise loss from Fusarium crown rot

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GRDC project codes: DAN00213, DAN00175

Keywords

- barley, fungicide seed treatments, wheat, yield loss.

Take home messages

- Current fungicide seed treatments registered for the suppression of Fusarium crown rot (FCR) inconsistently reduce the extent of yield loss from FCR.
- Victrato® had consistent, strong activity on limiting yield loss from FCR.
- However, under high infection levels, substantial yield loss may still occur in drier seasons. Victrato does not provide complete control of FCR, with efficacy likely reduced when prolonged dry soil conditions occur around the seed zone.
- Fungicide seed treatments, including Victrato, should not be considered standalone control options for FCR.
- Seed treatments should be used as an additional tool within existing integrated disease management strategies for FCR.

Introduction

Fusarium crown rot (FCR), caused predominantly by the fungal pathogen Fusarium pseudograminearum (Fp), is a major constraint to winter cereal production across Australia. A range of integrated management strategies including crop rotation, varietal selection, inter-row sowing, sowing time, stubble and fallow management are required to minimise losses. A number of fungicide seed treatments have been registered for the suppression of FCR in recent years, with a further product Victrato® from Syngenta likely to be available to Australian growers in 2024. Although chemical companies conduct their own widespread field evaluation across Australia, growers and their advisers value independent evaluation of the potential relative fit of these fungicide seed treatments within integrated management strategies for FCR.

What we did

A total of 15 replicated plot experiments (generally 2m x 10m with minimum of three replicates) were conducted across NSW from 2018–2021, with one additional field experiment conducted in Victoria (Horsham) and two in WA (Merredin and Wongan Hills) in 2018 only (Table 1). The winter cereal crop and number of varieties differed between experiments with wheat (W), barley (B) and/or durum (D) evaluated in each experiment (Table 1).

Six fungicide seed treatments: Nil, Vibrance® (difenoconazole + metalaxyl-M + sedaxane at 360mL/100kg seed), Rancona® Dimension (ipconazole + metalaxyl at 320mL/100kg seed), EverGol® Energy (prothioconazole + metalaxyl + penflufen at 260mL/100kg seed) and the unregistered product Victrato (Tymirium™ technology based on cyclobutrifluram at 40 and/or 80g active ingredient/100kg seed). All fungicide seed treatments were applied in 1kg to 3kg batches using a small seed treating unit to ensure good even coverage of seed. Note that not all six seed treatments were examined in 2020 and 2021.

All field experiments used an inoculated vs uninoculated randomised complete block design with inoculated plots infected by *Fp* inoculum grown on sterilised wheat grain added at 2.0g/m of row at sowing. This ensures high (>80%) FCR infection in inoculated plots, with uninoculated plots only exposed to background levels of *Fp* inoculum naturally present across a site. This design allows comparison between the yield effects of the various fungicide seed treatments in the presence and absence (background levels) of FCR. Yield loss from this disease is measured as the difference between inoculated and uninoculated treatments.

What did we find

Averaged across all cereal entries

Lower levels of in-crop rainfall between March and September generally lowered the yield potential at each site in each season, but also increased the extent of FCR yield loss. This was highlighted in the nil seed treatments where yield loss ranged from 11% to 48% in 2018, 14% to 20% in 2019, 11% to 37% in 2020 and 9% to 11% in 2021 (Table 1).

Table 1: Effect of various fungicide seed treatments on yield loss (%) associated with Fusarium crown rot infection in 18 replicated inoculated vs uninoculated field experiments – 2018 to 2021.

Year	Location	Crop[A]	Rainfall[B] (mm)	Yield[C] (t/ha)	%Yield loss from Fusarium crown rot[D]					
					Nil	Vibrance	Rancona Dimension	EverGol Energy	Victrato 40gai[E]	Victrato 80gai[E]
2018	Merriwagga, NSW	2W	63	1.44	44	nd[F]	nd	32	25	18
	Mallowa, NSW	2W	73	1.73	48	nd	nd	nd	26	24
	Gilgandra, NSW	2W	93	2.14	42	35	27	28	16	9
	Merredin, WA	2W	182	2.66	35	nd	nd	nd	23	13
	Horsham, Vic	2W	185	2.56	21	nd	nd	nd	+2[I]	+5
	Wongan Hills, WA	2W	291	3.27	11	nd	nd	nd	1	0
2019	Gulargambone, NSW	W/B	141	3.12	20	2	5	9	-[G]	+2
	Narrabri, NSW	W/B	200[H]	4.01	14	10	9	7	-[G]	6
2020	Boomi, NSW	3W/D	202	4.91	37	nd	28	nd	24	18
	Gurley, NSW	W/B	234	6.50	13	nd	nd	nd	-[G]	1
	Rowena, NSW	W/B	247	6.21	12	7	nd	4	-[G]	2
	Trangie, NSW	3W/D	412	4.13	26	20	23	19	4	2
	Gilgandra, NSW	3W/D	420	4.07	12	6	7	7	3	0
	Armatree, NSW	3W/D	425	4.37	11	nd	nd	7	3	+1
2021	Boomi, NSW	3W/D	349	5.74	10	-[G]	-[G]	-[G]	2	+1
	Armatree, NSW	3W/D	404	6.67	11	-[G]	-[G]	-[G]	2	1
	Wongarbon, NSW	3W/D	424	5.68	9	-[G]	-[G]	-[G]	6	4
	Rowena, NSW	3W/D	454	6.80	11	-[G]	-[G]	-[G]	1	0

[A] *Winter crop type variety numbers where W = wheat variety, B = barley variety and D = durum variety.*

[B] *Rainfall in-crop from March to September at each site. Critical time for fungicide uptake off seed and expression of FCR.*

[C] *Yield in uninoculated treatment (average of varieties) with nil seed treatment.*

[D] *Average percentage yield loss from FCR for each seed treatment (averaged across varieties) compared with the uninoculated/nil seed treatment.*

[E] *gai = grams of active ingredient. Victrato is an unregistered product.*

[F] *nd = no difference, % yield loss from FCR with fungicide seed treatment not significantly different from the nil seed treatment. Values only presented when reduction significantly lower than the nil seed treatment.*

[G] *All treatments not included at these sites.*

[H] *Included two irrigations at GS30 and GS39 of 40mm and 30mm respectively due to drought conditions.*

[I] *Results with a plus in front of them show that the treatment yielded higher than the uninoculated nil treatment (that is, the treatment reduced impact from both the added FCR inoculum as well as natural background levels of Fusarium present at that site.*

Vibrance and Rancona Dimension significantly reduced the extent of yield loss from FCR in six of fourteen experiments, whilst EverGol Energy reduced FCR yield loss in eight of fourteen field trials (Table 1). However, the unregistered product Victrato significantly reduced yield loss from FCR in 14 of 14 trials at the 40gai rate and 18 of 18 field experiments at the 80gai rate (Table 1). The reduction in yield loss was also generally stronger with this product compared with the other fungicide seed treatments and better at the 80gai than the 40gai rate (Table 1).

Significant yield loss (9% to 26%) still occurred with Victrato at drier sites. These dry conditions increased the yield loss from FCR (>35% in nil seed treatment). However, the 80gai rate at these disease conducive sites at least halved the yield loss compared with the nil seed treatment (Table 1). Yield loss from FCR was lower at the wetter sites (<26%). Victrato reduced yield loss to <6%, with increased yields at some sites due to the effects of background levels of FCR infection being reduced (Table 1). Moisture stress during grain filling exacerbates yield loss from FCR and favours the growth of *Fp* within the base of infected plants. Dry soil conditions throughout the season at the seeding depth, is likely to restrict the movement of fungicide actives off the seed coat and into surrounding soil and restrict uptake by root systems. This would reduce movement of the fungicides into the sub-crown internode, crown and tiller bases where FCR infection is concentrated. It is currently not clear if reduced efficacy of Victrato under drier conditions may be related to one or both of these factors.

What about durum

Durum wheat is known to have increased susceptibility to FCR compared with many wheat and barley varieties. The increased prevalence of FCR in farming systems aided by the adoption of conservation cropping practices, including retention of cereal stubble, has often seen durum removed from rotations due to this risk. The durum variety DBA Lillaroi was compared with three bread wheat varieties at four sites in 2020 (Table 1).

Table 2: Effect of Victrato seed treatment at two rates on the extent of yield loss[A] (%) from Fusarium crown rot in three bread wheat (W) and one durum (D) variety at three sites in 2020. Note: Victrato is not yet registered.

Variety	Boomi 2020			Trangie 2020			Gilgandra 2020			Armatree 2020		
	Nil[B]	Victrato 40gai	Victrato 80gai	Nil	Victrato 40gai	Victrato 80gai	Nil	Victrato 40gai	Victrato 80gai	Nil	Victrato 40gai	Victrato 80gai
LRPB Lancer (W)	29	23	20	30	10	8	13	2	0	9	4	+7[C]
Mitch (W)	39	18	11	13	+2	+5	9	2	1	5	0	0
LRPB Trojan (W)	34	22	18	20	4	2	12	1	0	14	2	2
DBA Lillaroi (D)	48	32	24	45	11	6	16	5	+2	14	6	+2

[A] *Average percentage yield loss from FCR for each seed treatment compared with the uninoculated/nil seed treatment for that variety.*

[B] *Nil = no seed treatment.*

[C] *Results with a plus in front of them show that the treatment yielded higher than the uninoculated nil treatment (that is, the treatment reduced impact from both the added FCR inoculum, as well as natural background levels of Fusarium present at that site).*

The extent of yield loss from FCR with nil seed treatment was generally higher in the durum variety (14% to 48%) compared with the three bread wheat varieties (5% to 39%). The bread wheat variety Mitch tended to have reduced yield loss from FCR compared with the other entries, apart from the Boomi site (Table 2). Yield loss from FCR was reduced with Victrato in both the bread wheat and durum varieties (Table 2). Even in the higher loss site at Boomi in 2020, the 80gai rate halved the extent of yield loss in the durum variety Lillaroi, with better efficacy in the other three sites.

Conclusions

Current fungicide seed treatments registered for the suppression of FCR can inconsistently reduce the extent of yield loss from this disease. Victrato, due to be registered in 2024, appears to have more consistent and stronger activity on limiting FCR yield loss. In the absence of fungicide seed treatments, average yield loss from FCR infection across the 18 sites over three seasons was 21.5%. The 80gai rate of Victrato significantly reduced the level of yield loss from FCR down to an average of 4.9% across these 18 field experiments. Under high infection levels, as created with artificial inoculation in these experiments, significant yield loss may still occur (up to 24% measured), particularly in drier seasons.

Dry soil conditions around the seeding depth throughout a season may reduce the uptake of fungicides applied to the seed coat. Drier seasons also exacerbate FCR expression, which would place additional pressure on fungicide seed treatments. However, even under these conditions, Victrato at the 80gai rate still at least halved the level of yield loss from FCR.

Fungicide seed treatments, including Victrato (once registered), should not be considered standalone control options for FCR. Rather, they should be used as an additional tool within existing integrated disease management strategies for FCR.

Integrated management of FCR

To manage the risk of yield losses in cereals, firstly identify paddocks at highest risk of Fusarium crown rot. High-risk paddocks generally include durum, bread wheat or barley crops being sown into a paddock with a history of stubble retention and tight cereal rotations (including oats). Other considerations are to use effective weed management programs to reduce grass weed hosts in-crop and fallow situations which serve as alternate hosts for the FCR fungus. Also remember, the larger the grass weed when controlled, the longer that residue serves as a potential inoculum source. Furthermore, given the recent Fusarium head blight epidemic in 2022, ensure that you are sowing seed free of Fusarium infection, as infected seed introduces FCR infection into paddocks.

All other management options are prior to sowing, so knowing the risk level within paddocks is important. This can either be through PreDicta B testing (SARDI) or stubble testing (NSWDPI).

If medium to high FCR risk, then:

- Sow a non-host break crop (for example, lentil, field pea, faba bean, chickpea, canola). A two-year break may be required if FCR inoculum levels are very high.

If still considering sowing a winter cereal:

- Consider stubble management options in terms of both impacts on FCR inoculum but also fallow soil moisture storage.
- ***Cultivation*** accelerates stubble decomposition which can decrease FCR risk (as the causal pathogen is stubble-borne) **but** it takes moisture and time. Cultivation also increases the spread of Fusarium crown rot inoculum across a paddock in the short term and increases exposure of below ground infection points (coleoptile, crown and sub-crown internode) in cereal plants to contact with stubble fragments infected with the FCR fungus. Cultivation close to sowing therefore increases the incidence of plants which get infected with FCR. Cultivation can also substantially reduce soil moisture storage during fallow periods.
- ***Stubble baling*** removes a proportion of the above ground inoculum from a paddock, potentially reducing FCR risk. The pathogen will then be concentrated in the shorter stubble butts and below ground in the previous rows. Hence, baling in combination with inter-row sowing is more likely to reduce FCR risk. Reduced ground cover after bailing and removal of cereal straw can reduce fallow efficiency.
- ***Stubble burning*** depending on the completeness of the burn, above ground inoculum is destroyed. Burning has no effect on the survival of the FCR fungus below ground in crown tissue, even with a hotter summer burn. Hence, the pathogen will be concentrated below ground in the previous rows, with survival between seasons dependent on the extent of summer rainfall. Burning of cereal stubble can considerably reduce fallow soil moisture storage, so a 'late-Autumn' burn is preferable to an 'early-Summer' burn. Stubble burning in combination with inter-row sowing is more likely to reduce FCR risk.
- ***Reducing cereal stubble height*** limits the length of stubble which the FCR fungus can vertically grow up during wet fallow periods, restricting the overall inoculum load within a paddock. When relative humidity is >92.5%, the FCR fungus can colonise vertically up retained standing cereal stubble in a process termed 'saprotrophic growth'. At 100% relative humidity, this saprotrophic growth can occur at a maximum rate of 1 cm per day (Petronaitis et al. 2020). The FCR fungus can therefore saprotrophically grow to the cut height of the cereal stubble under prolonged or accumulated periods of rainfall. Consequently, harvesting and leaving retained cereal stubble longer (for example, stripper fronts) leaves a greater length of stubble for subsequent potential saprotrophic growth of the FCR fungus. This is not a major issue in terms of FCR risk if the retained infected cereal stubble is left standing and kept intact. However, if the infected stubble is disturbed and redistributed across a paddock through grazing, mulching, cultivation or the subsequent sowing process, then this can increase the incidence of FCR infection. Recent research in NSW has also demonstrated that increased cereal harvest

height allowed saprotrophic growth of the FCR fungus above the harvest height of a following chickpea crop. This resulted in FCR infected cereal stubble being spread out the back of the header during the chickpea harvest process, increasing FCR risk for the next cereal crop (Petronaitis et al. 2022). Consider matching cereal stubble height at or after harvest in paddocks planned for a following shorter status break crop, such as chickpea or lentils, to prevent redistribution of retained FCR infected cereal stubble during the break crop harvest process.

- Select a cereal type and variety that has more tolerance to FCR ***and*** that is best suited to your region. Yield loss from FCR is generally durum>bread wheat>barley>oats. Recent research has shown that cereal type and varietal resistance has no impact on saprotrophic growth of the FCR fungus after harvest. Hence, cereal crop and variety choice does not have subsequent benefits for FCR risk within a paddock.
- Consider sowing a variety earlier within its recommended sowing window for your area. This will bring the grain filling period forward slightly and can reduce water and heat stress which exacerbates FCR expression and yield loss. However, this needs to be weighed against the risk of frost damage. Research across locations and seasons in NSW has shown that sowing at the start versus the end of a three-week recommended planting window can roughly half the yield loss from FCR.
- If previous cereal rows are intact, consider inter-row sowing to increase the distance between the new and old plants, as most inoculum is in the stem bases of the previous cereal crop. Physical contact between an infected piece of stubble and the coleoptile, crown or sub-crown internode of the new cereal plants is required to initiate FCR infection. Research across locations and seasons in NSW (30–35cm row spacings in stubble retained systems) has shown that inter-row sowing can roughly halve the number of wheat plants that become infected with FCR. Precision row placement can also provide greater benefits for FCR management when used in combination with rotation to non-host crops.
- Ensure nutrition is appropriate for the season. Excessive nitrogen will produce bulky crops that hasten moisture stress and make the expression of FCR more severe. Whitehead expression can also be made more severe by zinc deficiency.
- Consider a seed fungicide treatment to suppress FCR. Fungicide seed treatments are not a stand-alone treatment and must be used as a part of an integrated management approach.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. The author would also like to thank their advisers and acknowledge the ongoing support for northern pathology capacity by NSW DPI. National trials conducted in 2018 in Victoria (Horsham) and Western Australia (Merredin and Wongan Hills) were in collaboration with Dr Grant Hollaway (Ag Vic) and Dr Daniel Huberli (DPIRD) with biometric support from Clayton Forknall (DAFQ). Technical support provided by Chrystal Fensbo, Robyn Shapland, Tim O'Brien, Finn Fensbo, Patrick Mortell and Jason McCulloch (all NSW DPI) is gratefully acknowledged. A number of field experiments were contracted through AMPS Research (Matt Gardner) or NSW DPI (Peter Matthews) which is also gratefully acknowledged.

Useful resources

PreDicta®B sampling procedure (Sampling_protocol_Predicta_B_South_and_West_V2.pdf (pir.sa.gov.au))

Petronaitis T, Forknall C, Simpfendorfer S, Backhouse D (2020) (Stubble Olympics: the cereal pathogen 10cm sprint)

Petronaitis T, Forknall C, Simpfendorfer S, Flavel R, Backhouse D (2022) (Harvest height implications for Fusarium crown rot management)

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Notes

Bureau of Meteorology developments in long-term forecasting accuracy – the implications for autumn sowing

Jonathan How

Bureau of Meteorology – Agriculture Decision Support.

Keywords

- accuracy, climate, forecast, outlook.

Take home messages

- Research by the Bureau of Meteorology's new Agriculture Decision Support (AgDS) team and engagement with the grains industry has shown a need for insights that connect short-term weather forecasts to long-term climate forecasts.
- The team continues to improve the grains industry's understanding of long-term forecasts that look beyond 7 days, and aims to positively impact on-farm business management and grains-specific decisions such as autumn sowing.
- This paper provides one example drawn from the range of case studies developed by the team that demonstrate a service that is available to help inform key decisions. The case studies outline the value of the team's expertise in analysing day-to-day model performance, which in turn helps to ground truth the long-term forecast for improved accuracy.
- The AgDS team invite growers and advisers to keep up to date with the analysis of the forecasts by subscribing to the grains climate video briefings (Bureau of Meteorology Agriculture YouTube playlist), and by contacting the team via email, or in-person at field days and seminars.
- Additional work currently being developed within the Bureau will further assist in growers' long-term planning.

Background

The new AgDS team was established through the Agri-Climate Outlooks project with investment from GRDC and other rural research and development corporations. Research conducted by the AgDS team since early 2023 has found that there is a need for insights that bridge the gap between short-term forecasts (0–7 days) and long-term probabilistic climate forecasts, hereafter referred to as long-term forecasts (one week to months). Based on this need, the AgDS team aims to provide advisers and growers a comprehensive risk assessment for weather and climate decision making specifically. We achieve this objective through analysis and research that includes verification and case studies of weather and climate events utilising expertise within the Bureau.

This is demonstrated in a specific South Australian case study from December 2023 (see below). This case study demonstrates how the AgDS team bridges the gap between the Bureau's 7-day forecasts and the Bureau's long-term forecasts (that utilise the Bureau's single ACCESS-S – Australian Community Climate and Earth-System Simulator – model), by providing the agriculture sector with additional information to support on-farm high-value decisions.

The team is also connected to research work that the Bureau is conducting with outputs from the ACCESS-S model that may help to further bridge the gap between short-term forecasts and long-term forecasts in the 1–4-week period. This is being done for both temperature and rainfall, and proposed products show the range of possibilities up to 30 days out via 'box and whisker' plots.

Method

Agriculture decision support

The purpose of the AgDS team is to support adviser and grower decisions by providing weather and climate information that connects short-term weather with slower-moving climate drivers and long-term forecasts.

As professional meteorologists at the Bureau of Meteorology, members of the team aim to develop and understand the complex science of weather and climate, but with a dedicated agricultural lens. This gives us the best insight into connecting the physical interactions of the atmosphere with the computer-modelled scenarios. In the past nine months, AgDS have developed the following tools for the grains industry.

- Regular video briefings for each of the three GRDC grain-growing regions. In the period between February 2023 and December 2023, AgDS produced 29 grains videos, released to the Bureau's new dedicated Agriculture YouTube playlist. Every video briefing update explains how the short-term weather forecast will transition into the longer-term climate forecast to help bridge the gap between the two.
- Tailored video briefings – We have tailored video briefings to compare the Australian ACCESS-S climate model to international long-term climate models. This ensures we are providing a range of scenarios and providing insights on the most likely outcome based on verification and performance of the multi-models.
- Background discussions on rainfall probabilities – Analysis of how the rainfall probability distribution of the ACCESS-S model influences the forecast map output, and how to interpret this for decisions on the ground.
- Short-term weather alerts – Sending weather alerts for significant weather events that bridged the gap between short and long-term expectations beyond five days. This was done by utilising severe weather analysis experience within the team.
- Trialling various products – These include a conversational video explaining and myth-busting El Niño Southern Oscillation (ENSO) to uplift broader agricultural awareness and knowledge.
- Verification and case studies – Regular forecast verification, while also compiling regional-specific case studies from across the country.

Results and discussion

South Australia case study

An anomalously moving low-pressure system developed in early December 2023 over South Australia when harvest was well underway. This low-pressure system and associated surface trough dragged large amounts of tropical moisture from northern Australia over the region. Because of both the spatial and temporal differences in the short-term models in the lead-up to the rain event, Bureau forecasters used a blend of various models. These models came into alignment on 6 December and, as a result, the rainfall expectation significantly increased. At the same time, the ACCESS-S model forecast for December was showing near-median to below median rainfall for SA. These are shown in Figure 1 below, for forecasts valid 6 December 2023.

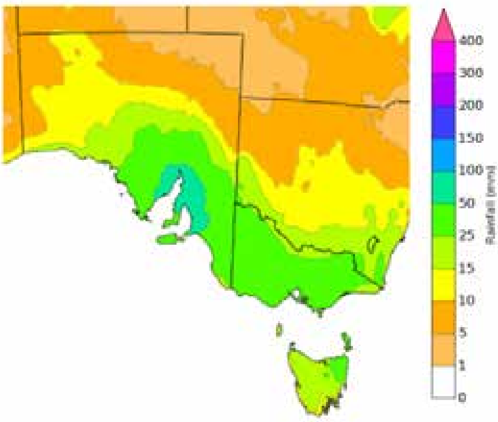
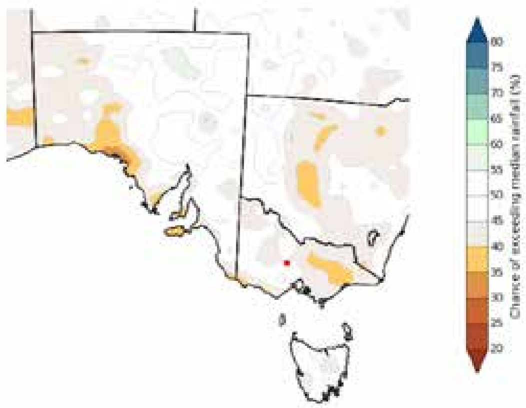
Bureau 7-day rain forecast (7–13 December 2023)	ACCESS-S December rainfall forecast
	

Figure 1. Comparison of the rainfall forecasts valid 6 December 2023. Maps taken from www.bom.gov.au

In the left panel of Figure 1, the Bureau's rainfall outlook was forecasting broad 7-day totals of 25–50mm through south-east SA as being the most likely scenario, with some areas of up to 100mm.

In the right panel of Figure 1, the ACCESS-S model was forecasting that the month of December, that the probabilities of rain would drier than median, n with a 35–45% chance of above median rainfall over much of SA, including the Eyre Peninsula. December is typically one of SA's driest months; the median December rainfall ranges from 20mm in Wudinna to 25mm in Adelaide.

This demonstrates how the overlap between short-term and long-term models can differ due to variations in computer model physics and resolution, discussed further below. In this particular example, the AgDS team used its severe weather expertise and knowledge of anomalously moving lows to send a 'weather alert update' to growers in SA ahead of the rain. Because of this, growers were able to increase harvesting efforts through the days before the rain, which broke records.

Insights into short-term and long-term models

The Bureau's rainfall outlook uses a blend of short-term forecast models, which can provide temperature or rainfall amounts in the coming days. On the other hand, long-term models cannot be this specific, due to small random changes that can amplify into different weather patterns. Rather, long-term forecasts, such as the ACCESS-model, being probability-based, are designed to be used as one of several planning tools within risk management and decision-making. The greatest benefits of using Bureau long-term forecasts will accrue from use over several seasons or years.

Further differences arise between short-term models and long-term models due to differences in computer power required in running millions of complex mathematical equations, both temporally and spatially. Differences also arise due to the analysis and comparison of various short-term models that is undertaken by meteorologists, rather than only considering one model output.

Simply, from the grower or public perspective, these two products displaying different solutions, and, in some cases, the Bureau's short-term rainfall outlook can appear to be at odds with the long-term probabilistic model forecast.

The AgDS team provides the analysis and insight regarding the short and long-term model outputs. The team's grains climate videos also include discussions around the spread of ACCESS-S rainfall probabilities. These probability distributions demonstrate how the output of the ACCESS-S model derived the specific percentage chance of above median rainfall. These background explanations help to provide context as to why the long-term model may be forecasting neutral conditions by looking at the spread of possible outcomes. Positive feedback from advisers and industry representatives has shown that the inclusion of these additional insights can help to explain outlooks by going beyond what is just presented on the maps.

Link to autumn 2024 outlook

As growers approach the autumn 2024 season, insights from the AgDS team may support weather and climate-based decisions for sowing, as an example. Our briefings and continued engagement with the grains industry into the autumn months will aim to provide an additional layer of analysis to support decisions that are rain and temperature sensitive. Further details of the autumn 2024 seasonal outlook will be made available at the oral presentation.

Conclusion and further work

With agriculture industry investment, the Bureau is working to improve the transition between the short-term and long-term forecasts. The Bureau's AgDS team will continue to convey key insights of foundational research as the Bureau considers opportunities to operationalise these findings based on the needs of grain growers and other farmers. The focus of the AgDS team is to understand the complex science of weather and climate as expert practitioners, and, in doing so, consider how it may influence high-value agriculture decisions. The AgDS team can use its experience to bridge the gap between short-term and long-term forecasts through video briefings, verification, and case studies.

The AgDS team will continue to engage with the agriculture industry in 2024 to provide direct relevant weather and climate analysis and advice. The team will support work to understand model bias, verification, and model physics in international climate models where appropriate. We would like growers and advisers to keep up to date with the team's analysis of the forecasts by subscribing to the grains climate video briefings, and by contacting the team via email, or in-person at field days and seminars.

Acknowledgements

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

The Bureau of Meteorology, in partnership with Agricultural Innovation Australia (AIA) are delivering the ACO project, which involves collaboration across 10 rural Research and Development Corporations.

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 Bureau would like to thank them for their continued support.

Useful References

Education on long term models (http://www.bom.gov.au/climate/ahead/about/)

Bureau of Meteorology Agriculture YouTube playlist (https://www.youtube.complaylist?list=PLbKuJrA7Vp7mdHq2MaI0tgIzznaZNbHUq)

Long-range weather and climate (http://www.bom.gov.au/climate/)

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Notes

Frost Learning Centre (FLC) for growers, advisers and researchers

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GRDC project: SAG2305-002OPX

Keywords

- frost, learning, mitigation, zoning.

Take home messages:

- Zoning farms and paddocks based on frost risk (red, amber and green zones) is the starting point for frost management.
- Planning prior to seeding improves the ability to mitigate frost risk. Tools to mitigate risk include varietal selection and mixtures, dual purpose cereals, attending to previous crop residues, or selecting crop/enterprise types that are either more tolerant to or able to avoid frost.
- The relationship between canopy size and grain yield in the presence of frost remains unclear, although the financial risk associated with crop inputs and frost needs to be evaluated closely.

Background

The South Australian Grain Industry Trust's (SAGIT) project, with GRDC co-investment, of the Frost Learning Centre (FLC) is the culmination of many years of frost research conducted in Mid North SA by Agrilink Agricultural Consultants. The FLC is a cereal focused trial with the site located in a paddock with an area at high risk of frequent and severe frosts (red zone) and an area relatively unaffected by frost (green zone). This enables comparison, with and without frost, for certain trials where it is considered important. Trials are focused on a range of frost intervention, prevention, and mitigation strategies to give growers and advisers options with frost management.

The Western Australian Department of Primary Industries and Regional Development (DPIRD), notably Dr Amanuel Bekuma, Dr Brendan Leske and Dr Ben Biddulph, have increased the understanding of the role of ice nucleating bacteria in plant freezing and frost damage. The FLC has increased the focus on the local impact and understanding of ice nucleating bacteria as the project has progressed.

Method

The key objectives of the FLC are to conduct applied research and extension into aspects of frost including avoidance, tolerance, mitigation, identification, and strategies to reduce yield, financial loss and stress from frost. This is complemented by investigation, creation and extension of new methodologies and the evaluation of existing and new technologies. Technology evaluation includes, but is not limited to, frost exclusion shelters, infra-red thermography, and remote sensing. The FLC has more recently focused on the role of ice nucleating bacteria, interactions of plant protection products and adjuvants and the investigation of frost mitigation and prevention products. Lastly, the FLC aims to provide a forum for growers and advisers to learn and discuss and as a collaboration site for other research endeavours.

Results and discussion

Zoning

The zone method for identifying frost risk enables growers and advisers to create and implement long term strategies and short term tactics in zones as defined below:

- **RED ZONE:** Where frost and related damage is either severe, frequent, or both. The financial impact is substantial.
- **AMBER ZONE:** Sometimes frosted, sometimes not, depending on the severity of the frost. In any frost that occurs, the amber zone can experience losses in a range from none to severe. Damage in the amber zone graduates in intensity from the green to the red zone.
- **GREEN ZONE:** Frost is not an issue – aim to maximise returns.

Zoning allows strategies and tactics to be tailored based on frost risk. Strategies to manage frost almost always result in reduced financial returns when compared to the optimum green zone management strategies, hence the importance to only use them where frost is an issue.

Zoning can be completed using knowledge of the landscape and paddock with relevant elevation, soil type, topography and yield maps assisting with identification.

The challenges of frost research

Replicating frost research results across seasons is a difficult task. The varied timing, severity, time of seeding (dry starts), very late season rain and absence of damaging frost events in 2022 has contributed to the challenge of drawing meaningful insights from the project data. The 2021 season had a dry start, with the opening rain not occurring until 25 May. An even later start occurred in 2022, with opening rains falling on 30–31 May. The 2023 season had a mid-April break, but germination of the trials didn't occur until follow-up rain on 20–21 May and 30 May. Table 1 shows the TOS 1 grain yields of a range of varieties grown across all three years of the FLC. Germination occurred from the 20 May to 1 June for all varieties across all three years in table one. The variability is driven by unpredictable timing of frost events, crop growth stage at the time of the event(s) and number and severity of individual frosts.

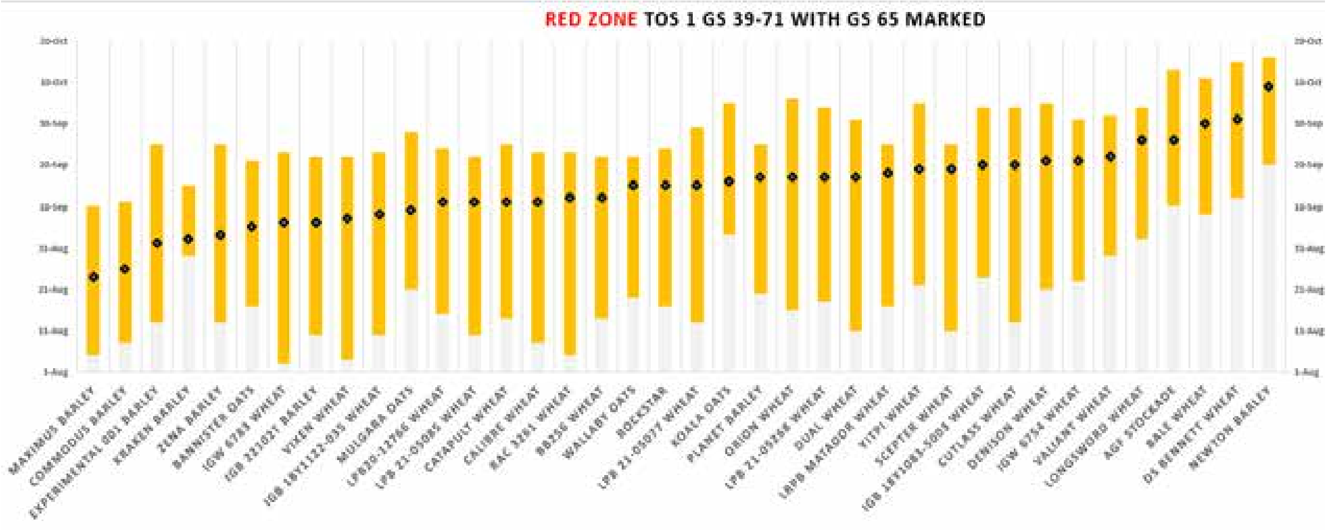
Table 1: Grain yield (kg/ha) of cereal varieties at an early time of sowing (TOS1) (germination late may -early June) across the three years of the FLC. Each season has been analysed separately with letters denoting significance at the p<0.05 statistical confidence level. GRDC Crop sowing guide 2024 variety maturity classes been listed on the table.

Crop	Maturity	2021		2022		2023	
CommodusA Barley	Very Quick- Quick			6696	c	5778	b
NeoA Barley	Quick					7358	a
RGT PlanetA Barley	Quick	5237	a	10253	a	7195	a
VixenA Wheat	Quick	4337	ab	9082	ab	4109	cd
BannisterA Oats	Quick			8741	b	5270	bc
CalibreA Wheat	Quick-Mid	4956	ab	8493	b	3601	de
DualA Wheat	Mid-Slow	3522	b				
DenisonA Wheat	Slow	5481	a	9075	ab	2265	ef
BaleA Wheat	Slow	4907	ab	7089	c	568	g
DS BennettA Wheat	Slow	5515	a	9038	ab	855	g

Temperatures quoted in this paragraph are recorded at 1.25m above ground level in a Stevenson screen. There is not a linear relationship between frost induced crop damage and the temperature measured either within the Stevenson screen or the ambient air temperature at canopy height during the critical period. The timing and frequency of major spring frost events varied between seasons:

In 2021, there were 17 nights during spring where the temperature was at or below 0°C. There were two major frost events on 11 October and 28 October where the minimum temperature reached -3.6°C and -2.8°C respectively, with time below 0°C being longer than seven hours on both nights. Late rains in early November, after these severe frost events, is suspected to have aided plant recovery in some trials/varieties.

- In 2022, there were six nights below 0°C in spring, with the coldest temperature being -2.56°C on 3 September and -2.5°C on 10 October, with both nights being below 0°C for at least seven hours. The barley cultivars were at head emergence and earliest wheat varieties were at the booting growth stage. There was limited damage observed. After the 10 October event, there were no further significant frost events and high grain yields resulted (table one).
- In 2023, there were eight nights during spring where minimum temperatures was below 0°C, with the coldest being the morning of 26 October, with a minimum of -5.5°C, with nine and a half hours below zero. Early maturing varieties in TOS 1 were sufficiently advanced (approximately soft dough Zadoks GS 85 and later) that severe grain yield loss didn't occur, although visibly frost affected grain was seen in some quick and quick-mid maturity varieties. There was major damage in the slow maturity varieties in TOS 1 and all varieties in TOS 2.



Phenology

Figure 1. Phenological development of wheat, barley and oat varieties sown in the red zone on 17 April 2023 (TOS1), showing Zadoks GS 39 at the base of the bar and GS71 at the top of the bar with GS 65 highlighted.

An understanding of phenology enables growers and advisers to make variety selections for their environment to target flowering during a period where abiotic factors (low radiation, frost damage, high temperatures, heat shock and water stress) are minimised. It is a strategy that weighs up the risk of these opposing factors and attempts to **avoid** the major frost window. The avoidance strategy can work for specific locations where there is greater degree of confidence that the dates of the last frost can be reasonably well predicted i.e where frost occurs at lower altitudes. The timing of frost differed between the years with early sown, fast maturity varieties in 2023 avoiding frost events and outyielding early sown, slow maturing varieties.

The three drivers for phenological development are temperature, photoperiod and vernalisation. Varieties that have vernalisation and photoperiod requirements feature strongly in the later flowering end of Figure one and two. While barley has a reputed higher tolerance to frost, all varieties, except the winter barley Newton[A], have early maturities that generally increase exposure to more frost events in winter and early spring. This may not normally be considered part of the frost window and exposure to this period is increased if the quick barley varieties are sown too early.

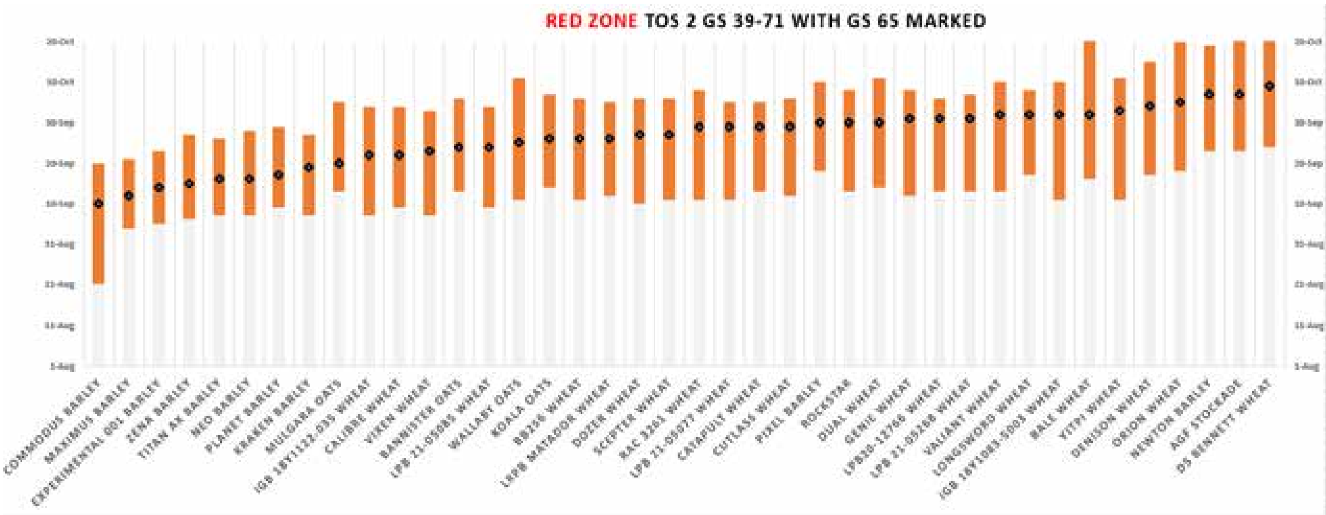


Figure 2. Phenological development of wheat, barley and oat varieties sown in the red zone on 17 May 2023 (TOS2), showing Zadoks GS 39 at the base of the bar and GS71 at the top of the bar with GS 65 highlighted.

Nitrogen and canopy

The nitrogen and canopy trial investigated the impact of canopy size and nitrogen rate on frost damage, with the canopy size being altered using seeding rate and nitrogen rate. This trial has been repeated for all three years of the FLC, with the same seeding rate treatments of CalibreA wheat and nitrogen rates applied. Canopy variation was produced by using seeding rates of 80 seeds/m2 and 300 seeds/m2 and manipulated with nitrogen rates of 0, 25, 50, 100, 200, 400kgN/ha. Timing of nitrogen application was during the vegetative growth period with the aim to produce a range of canopy sizes and not to assess frost damage response to timing of application.

Table 2: Impact of nitrogen (N) application and seed rate on grain yield and net returns of Calibre* wheat. Results are recorded over three years of the FLC with statistical significance noted at the ($P<0.05$) confidence level. Statistical analysis was completed within a season across all seeding rate and nitrogen treatments. GY = Grain Yield, NR = Net Revenue after nitrogen expense. Assumptions used: Grain price $350/t and Nitrogen price $1378/t.

			2021			2022			2023		
Seed Rate(Seeds/m^2)	N Rate (kgN/Ha)	N Cost $/ha	GY (kg/ha)		NR ($/ha)	GY (kg/ha)		NR ($/ha)	GY (kg/ha)		NR ($/ha)
300 Seed	0N	$0	1533	bc	$537	7251	bcd	$2,538	528	b	$185
300 Seed	25N	$34	2014	bc	$671	8221	abcd	$2,843	638	ab	$189
300 Seed	50N	$69	2111	bc	$670	7635	abcd	$2,603	564	ab	$129
300 Seed	100N	$138	2607	abc	$775	8518	ab	$2,844	865	a	$165
300 Seed	200N	$276	3740	a	$1,034	8484	ab	$2,694	644	ab	-$50
300 Seed	400N	$551	4070	a	$873	8979	a	$2,592	525	b	-$368
80 Seed	0N	$0	1092	c	$382	6758	d	$2,365	656	ab	$230
80 Seed	25N	$34	1433	bc	$467	6988	cd	$2,412	583	ab	$170
80 Seed	50N	$69	1796	bc	$560	7582	abcd	$2,585	568	ab	$130
80 Seed	100N	$138	2092	bc	$595	7938	abcd	$2,641	574	ab	$63
80 Seed	200N	$276	2611	abc	$638	8078	abcd	$2,552	678	ab	-$38
80 Seed	400N	$551	2677	ab	$386	8350	abc	$2,371	561	ab	-$355

There were no clear trends observed across the three seasons. All three years of this trial were sown into faba bean stubbles, with starting soil nitrogen levels, sampled from 0- 120cm depth, of 46kgN/ha in 2021, 121kgN/ha in 2022 and 52kgN/ha in 2023. In 2021, there was a significant yield response to the high seeding rate and high nitrogen rate treatments. Late season rains in 2021 are suspected to have aided recovery from frost in high nitrogen treatments due to later order tillers producing substantial grain.

In the 2022 trial, there was negligible frost impact on the trial, and high starting soil nitrogen resulted in a low yield response to applied nitrogen. In 2023, there was extremely severe frost and no clear trends in the data due to the severity of the effects across all treatments.

The financial risk associated with applying nitrogen is critical to consider in red zones. While high nitrogen rates produced the highest yields in 2021 and 2022, generally net returns either didn't increase as nitrogen rates increased and, at some rates, decreased. In 2023, a similar outcome was produced, except that returns were much lower due to the severe frost damage. This indicates variability of return and high level of financial risk that is associated with applying nitrogen in a frost-prone area. In these areas, an appropriate strategy may be to soil test to evaluate nitrogen levels, apply a rate at the low end of the appropriate rate range to reduce the amount of financial loss in the event of a frost, while not severely limiting returns in the absence of severe frost. This approach to red zones could be balanced with a more aggressive nitrogen strategy in green zones. If a salvage hay cut operation is available, then growing acceptable dual-purpose cereals and applying nitrogen earlier in the season can maximise dry matter production. In the event of frost, there may be a profitable return by cutting for hay, albeit this strategy is not without risk.

Additional research activities

Additional research activities conducted at the FLC in 2023 included:

- delay and reset of cereal phenology including a PGR assessment
- impact of crop residue on frost outcomes
- wheat and barley varietal mixtures
- impact of use of frosted seed, variety and time of seeding on frost outcomes
- impact of PGR use on wheat and barley frost outcomes
- impact of use of frost protection products on frost outcomes
- dual purpose cereals
- assessment of biological agents on frost outcomes
- limited assessment of herbicide and adjuvant application on frost outcomes.

Conclusion

Frost mitigation begins with knowing the areas on farm that are impacted by frost and delineating zoning based on the frequency and severity of the frost. This enables appropriate strategies to be implemented to mitigate frost risk and the associated financial implications, but risk cannot be eliminated completely, as seen with 2023 FLC results. Minimising financial exposure to frost events is critical for business sustainability, so having an alternative crop use, managing nitrogen expenditure and being cautious of investing in products promising improved frost outcomes may help to minimise this risk.

Acknowledgements

The support of South Australian Grain Industry Trust (SAGIT) and additional financial support from GRDC is acknowledged for this project. The dual-purpose cereal research is supported by Agrifutures and Balco Australia.

The authors would like to thank frost-affected growers for their valuable support, particularly the businesses that provided suitable trial sites. We would also like to acknowledge the involvement of SARDI for co-locating innovative pulse research, the MNHRZ committee for the organisation of many field days and workshops, suppliers of the products used in the trials and Dr Philip Brewer for his assistance with plant growth regulator selection. Lastly, we would like to acknowledge the support of DPIRD, especially Dr Amanuel Bekuma, Dr Brendan Leske and Dr Ben Biddulph for the laboratory testing of ice nucleating bacteria activity.

Useful resources

Frost management (https://grdc.com.au/resources-and-publications/resources/frost-management)

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Notes

Redlegged earth mite (RLEM) and pesticide resistance: the latest in best practice management and new decision-aid tools

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GRDC code CES2010-001RTX

Key words

- redlegged earth mite, RLEM, insecticide resistance, integrated pest management, social research, invertebrate pests

Take home messages

- Rising RLEM resistance issues are prompting a re-evaluation of the dependence on insecticides for control
    - New tools for better management:
      - A new interactive tool summarises RLEM management strategies in canola for users, analysing impacts on RLEM, other pests, beneficials, and resistance development
      - A predictive tool for estimating hatch timing improves the timing of RLEM autumn monitoring
      - TimeRite® strategy revisions have led to earlier estimated TimeRite dates as RLEM responds to climatic changes.

Background

The redlegged earth mite (Halotydeus destructor, RLEM) is a destructive and economically important pest in Australia's grain and pasture crops. The repeated use of limited chemical control options for RLEM has resulted in resistance issues across large areas of Western Australia and parts of south-eastern Australia. Many RLEM populations in these areas are resistant to synthetic pyrethroids (SPs), organophosphates (OPs), or both. This rise in resistance demonstrates a need to change the way insecticides are used to minimise the risk of further resistance in RLEM.

In this update, we will:

1. present data on the current resistance status of RLEM in Australia;
2. present the new seasonal risk tool for RLEM and other pests in canola;
3. demonstrate the new RLEM hatch timing tool; and
4. present research on updating the TimeRite® strategy.

The current resistance status of RLEM in Australia

Resistant RLEM populations have been detected across Western Australia, South Australia, and Victoria since resistance surveillance began in 2006. Screening undertaken between 2006 and 2023 found SP resistance to be widespread across the southern regions of Western Australia and in some parts of South Australia (Arthur et al. 2021). Organophosphate resistance has been detected in the southern regions of Western Australia and parts of South Australia and Victoria. Presently, no neonicotinoid resistance has been detected, but resistance monitoring is being conducted.

Within Western Australia, the current distribution of SP and OP resistance is widespread, covering the southwest, great southern, south coastal and wheatbelt regions (Figure 1).

In South Australia resistance to OPs and SPs was first discovered in 2016 with new detections continuing to accumulate. Approximately 60% of the RLEM possessing resistance in eastern Australia were collected from pasture seed sites. More recently, resistant populations have been detected in the mid-north region.

Resistance to OPs in Victoria was first detected in 2018, at Wanalta in north central Victoria (Arthur et al. 2021). Since then, several OP resistant populations have been detected in Victoria in the north central region and Minimay in the Wimmera region. There has been no SP resistance detected within Victoria to date.

In New South Wales, there have currently been no cases of resistance detected.

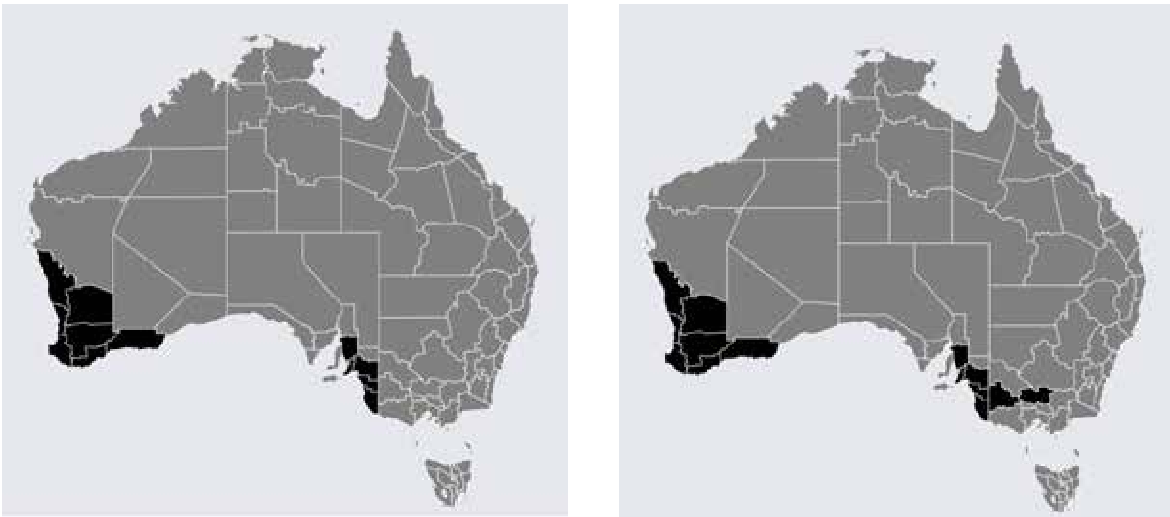

Figure 1. The current distribution of RLEM resistance to pyrethroids (left) and organophosphates (right). Regions with known resistant populations are shown in black.

Seasonal risk tool for RLEM and other pests in canola

Understanding management options for RLEM control is complicated by the wide range of pest and beneficial insects that can inhabit a single paddock. For example, a pesticide used for one pest can be toxic to other insects, which has consequences for resistance evolution and beneficial insects. To help improve management decisions, we developed an interactive seasonal risk tool for RLEM in canola. The tool allows users to explore the impact of various management options to reduce RLEM risk and their consequences on other pests, beneficials, and resistance evolution. The tool is currently in beta release, so users are encouraged to access the tool https://agpest.com.au/seasonal-pest-risk and submit any feedback through the feedback button on the right side of the tool.

The expected user journey for the tool is shown in the figures below but follows these general steps:

1. Users selects their location
2. Users select pests of interest to their situation (pests are filtered by location)
3. Known risk factors and management tactics for selected pests are presented
4. Users select the applicable risk factors and tactics
5. Based on risk factors and tactics applied, a calendar of estimated pest risks is returned
6. Users can experiment with hypothetical management programs to understand the effect on pest risk
7. Action thresholds for pests are provided (where available) and pesticide options can be explored if further action is required
8. Known resistance issues and beneficial toxicity information are summarised for each pesticide option

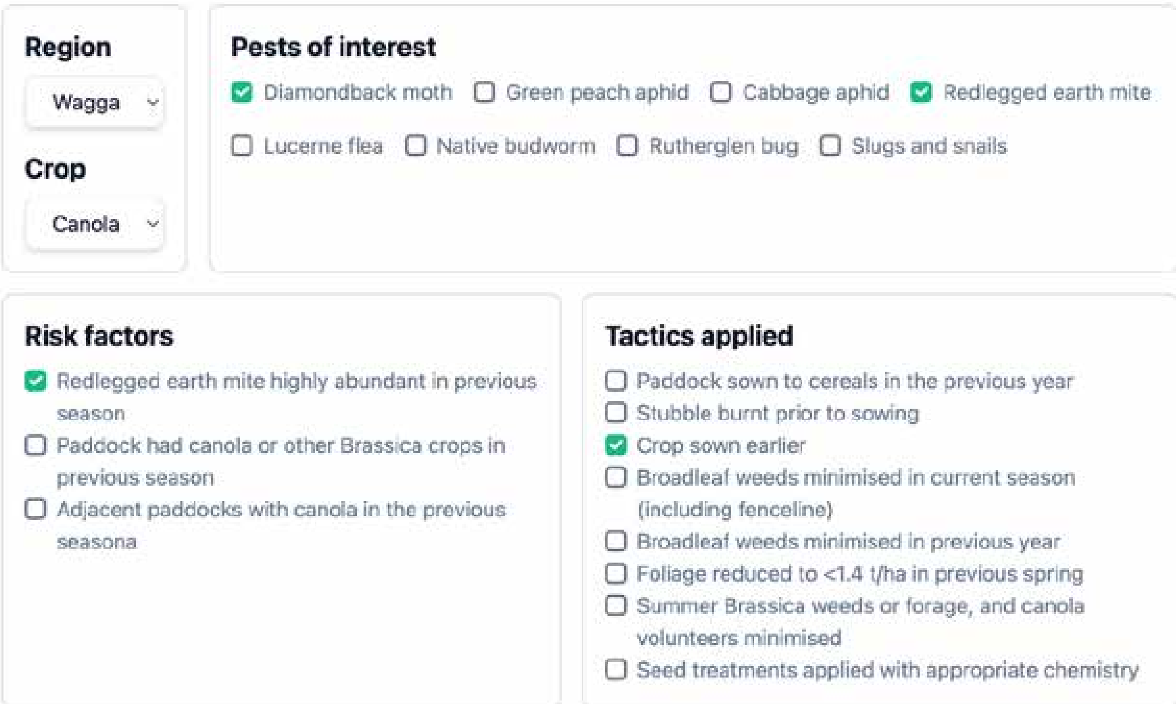

Figure 2. Relevant canola pests for a given location are retrieved and then for the selected pests of interest (e.g. redlegged earth mite and diamondback moth) risk factors and available management tactics are shown. The effects of these risk factors and tactics on pest risk are shown in the next figure.

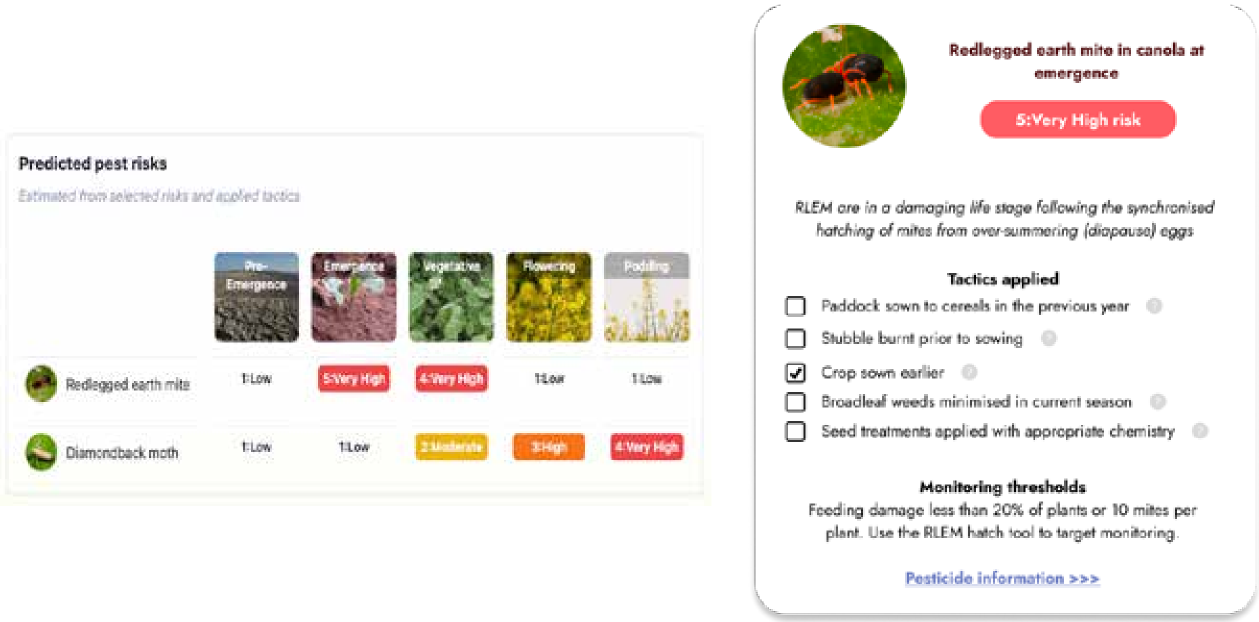

Figure 3. A crop calendar of risks for selected pests is shown based on the user-selected risk factors and management tactics. Clicking on a risk estimate shows a popup with further monitoring and management information. Users can experiment by selecting different tactics to see how pest risks change.

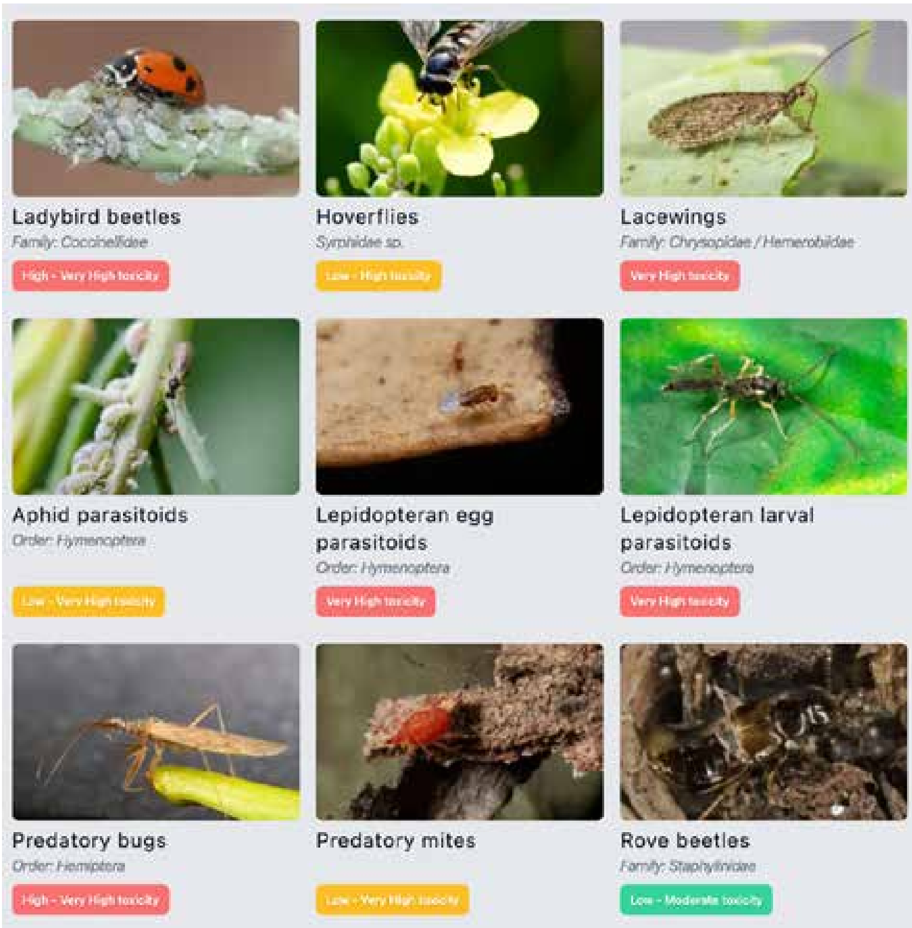

Figure 4. As an illustrative example, pyrethroid pesticides (Group 3A) toxicity is retrieved for beneficial insect groups. This helps users understand off-target impacts associated with pesticide usage. Ratings for toxicity are based on International Organisation for Biological Control (IOBC) protocols for laboratory studies and reflect percent mortality of insects within a particular beneficial group exposed to each chemical. A rating of L represents <30% mortality, M 30–79%, H 80–99% and VH >99% mortality. Further information on the toxicity status for each beneficial group can be accessed by clicking on the beneficial of interest.

Figure 5. As an illustrative example, pyrethroid pesticide (Group 3A) resistance information is retrieved for pests of Australian grains. This helps users understand which pest species have resistance to a particular class of chemical in Australia. Further information on the resistance status of each pest can be accessed by clicking on the pest of interest. This data was developed through GRDC's Australian Grains Pest Innovation Initiative (AGPIP).

RLEM hatch timing tool

The ability to predict when RLEM eggs will hatch can help growers understand crop risk during the autumn period and optimise monitoring for RLEM pressure at crop emergence. We developed a tool that predicts the hatch status (unhatched, soon-to-hatch, and hatched) of RLEM. The tool also provides historical estimates so users can understand typical hatching patterns for their region.

We extended a previous study on predicting hatch dates from regional temperature and rainfall conditions (McDonald et al. 2015) to an easy-to-use web interface that will provide the predicted hatch date for a user-defined location. This includes an option for real-time weather data for the current growing season, or long-term average conditions.

The model was validated against field collected mites and available data from the literature. Comparison of the observed hatch dates with predicted hatch dates revealed that the model error was no more than 15 days across all samples, with a mean error (and standard error) of -4.68 (4.03) days.

The tool was successful in predicting mite activity before the most economically injurious life stage (i.e., the adult phase), which should allow sufficient time for intervention where necessary.

The final version of the hatch tool (Figure 6) is available here: https://cesaraustralia.com/resources/redlegged-earth-mite-hatch-timing-tool/.

The app has two tabs, 'Estimate' and 'About'. The 'Estimate' tab (Figure 6 - left) shows a simple output of the hatch estimate, while the 'About' tab (Figure 6 - right) shows additional information, including historical hatch dates and current climatic data for the season up to the current day.

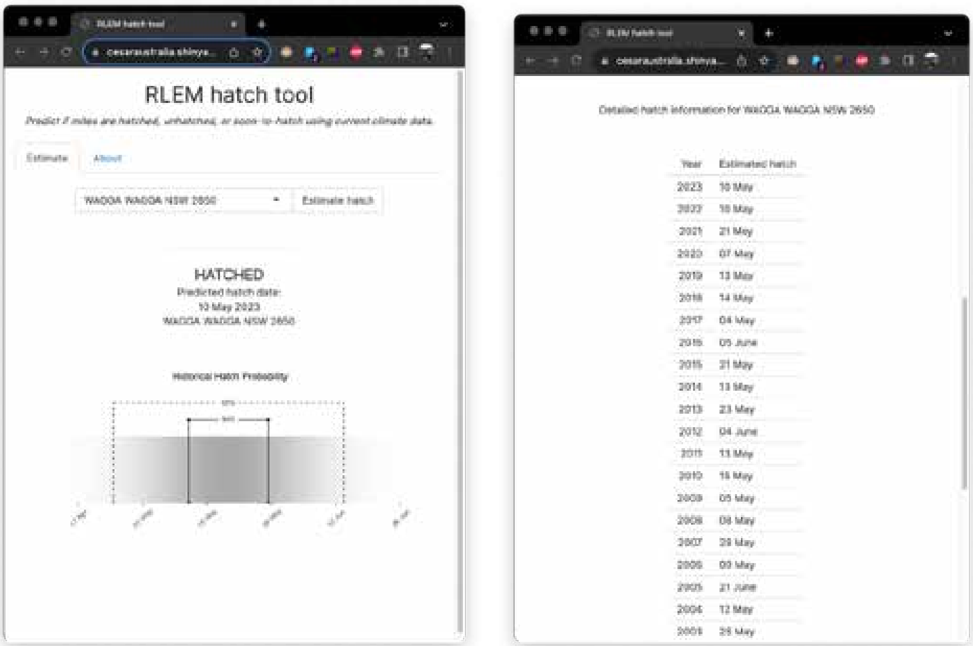

Figure 6. User interface for the hatch prediction app, showing the 'Estimate' (left) and 'About' (right) tabs. The location selector in the 'Estimate' tab allows users to easily select their location of interest.

Updating the TimeRite® strategy

Pest management strategies may need to change to adapt to new climatic and environmental conditions. TimeRite has been a widely used tool among Australian growers, which has helped improve control outcomes for RLEM and avoid unnecessary pesticide applications. However, the strategy has remained unchanged since its development more than two decades ago.

We aimed to update and improve the TimeRite strategy in several key areas:

1. improved model accuracy through the incorporation of changing climates,
2. increased flexibility of control programs through a better understanding of control efficacy before and after TimeRite, and
3. improved accessibility through a modern and easy-to-use online interface.

It is envisaged the updated TimeRite tool will be made available to users in mid-2024 at wool.com/land/TimeRite/ where the original TimeRite tool is housed. For example, at Wagga Wagga, NSW, the original TimeRite date was calculated at 29th September, while the updated date is estimated at 7th September reflecting an earlier date for optimal control. Figure 7 shows how the efficacy of control is expected to diminish before and after the TimeRite date. In addition to Wagga Wagga, Table 1 summarises the old and new TimeRite date for other illustrative regions including Port Lincoln, SA, Bendigo, VIC, and Esperance, WA.

Table 1. Comparison of previous TimeRite dates with the new updated TimeRite model predictions. Note that the new model automatically updates as climatic trends shift so should be check every couple of years.

Location	State	Old TimeRite date	New TimeRite date (2024)
Wagga Wagga	NSW	29th September	7th September
Port Lincoln	SA	18th September	13th September
Bendigo	VIC	28th September	11th September
Esperance	WA	26th September	10th September

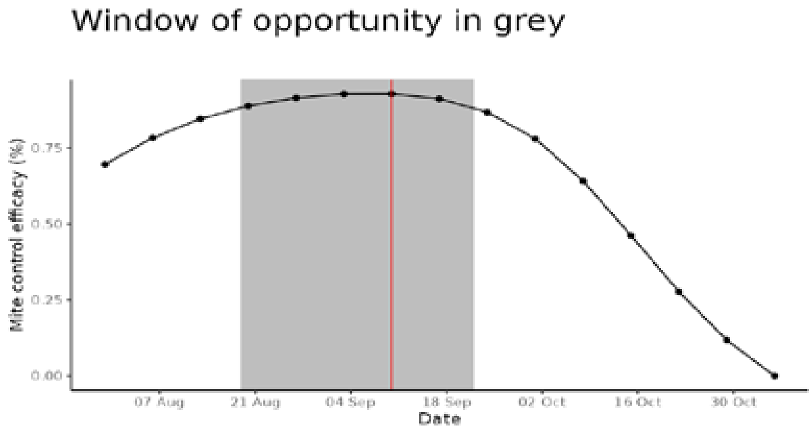

Figure 7. Updated TimeRite estimate for Wagga Wagga, NSW predicts an earlier date for optimal control timing of 7th September compared with original TimeRite date of 29th September. The vertical line denotes the optimal control date, while the grey region denotes the period where efficacy remains at least 95% of the optimum.

Figure 8. shows that future climate scenarios are likely to bring about further shifts in optimal control to earlier in the season. Generally warmer and drier forecast conditions are expected to cause RLEM to enter diapause earlier in spring and so TimeRite dates are likely to continue to shift earlier in the season.

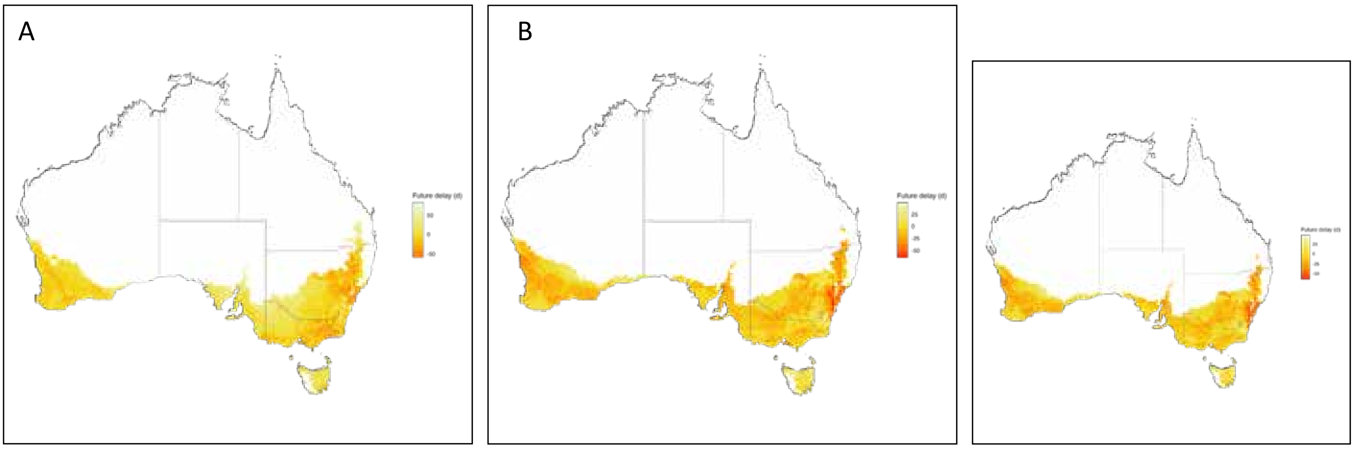

Figure 8. Predicted shifts in the point of 90% diapause by 2050 under the SSP245 warming scenario (A) and the more extreme SSP585 scenario (B). The shaded regions show the estimated delay in a population reaching 90% diapause. A positive delay represents diapause occurring later in the year relative to 2020 historical data, while a negative delay represents earlier diapause.

Conclusion

The research presented here highlights significant advancements in the understanding and management of RLEM, a critical pest in Australian grain crops. The escalating issue of pesticide resistance, particularly in regions of Western Australia, South Australia, and Victoria, underscores the need for a strategic shift in our approach to managing RLEM.

The introduction of new decision-aid tools, such as the interactive seasonal risk tool for canola and the RLEM hatch timing predictor, represent a major step forward. These tools enable growers to make more informed decisions about pest management, reducing reliance on chemical controls and their impacts on beneficial invertebrates and resistance evolution. Lastly, the revisions to the TimeRite strategy, which include (generally) earlier estimated dates for RLEM management, will help to maintain the effectiveness of this widely adopted management strategy amid changing environmental conditions.

Acknowledgements

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Notes

Back to nitrogen basics – soil testing and nitrogen budgeting fundamentals

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- N budgeting, nitrogen fertiliser rate, soil test.

Take home messages

- Nitrogen (N) fertiliser rate decisions based on soil test data and a formalised decision process are more profitable than fixed rates or decisions based on 'gut feel'.
- This article goes back to basics on N budgeting and is designed to help young agronomists make better N fertiliser recommendations.
- The article simplifies a lot of complex topics and should just be a starting point for learning about N management in southern Australian farming systems.

Background

Nitrogen (N) management has a big impact on farm profit, and being able to effectively advise growers on fertiliser N inputs is an extremely important skill for agronomists to have. Fertiliser N makes up a large component of variable costs of cropping and return on investment in N fertiliser is not certain, which makes decisions on N application rate risky. The GRDC Riskwi$e investment aims to help growers and advisors make better decisions where risk is a factor, and the initial focus is on N management decisions. Previous research has shown that choosing an N rate that uses soil test data and a formal decision-making process is far more profitable than 'gut feel' or flat application rates.

This article is a back to basics guide to N fertiliser budgeting and is targeted at early career agronomists to help improve decision making. It tries to provide enough science background to assist effective management but simplifies a lot of complex topics. If you want to further understand the complexities, please read the GRDC publication 'A nitrogen reference manual for the southern cropping region'. Some of the complexities around yield uncertainty are also expanded on the article written by Peter Hayman and Barry Mudge in these proceedings, and the articles are complementary.

Why is N so important for crops?

Nitrogen (N) is the nutrient required in the largest amount by grain crops. Grain crops require about seven times as much N as they do phosphorus (P), which is the next highest nutrient required by mass. Plants use N to make amino acids and proteins, and it is an important constituent of chlorophyll (the pigment that makes most plants look green) and RuBisCO (the enzyme used in carbon fixation), which are both important components of photosynthesis. N deficiency makes plants look less green because they contain a lower concentration of chlorophyll. N deficiency means that plants cannot photosynthesise (turn carbon dioxide into dry matter) as well as N sufficient plants, which means they cannot grow as much. Because crop grain yield is determined by the amount of growth that occurs during the critical period of yield determination, which occurs about 30 days before the start of grain fill in most crop species, N deficiency during this time causes large reductions in grain yield. Conversely, an oversupply of N can in some cases reduce grain yield in cereal crops. This yield reduction is often referred to as 'haying off', but the exact mechanisms of yield loss due to excessive N uptake are not known.

N taken up by crop plants is translocated to grains during grain filling to form proteins, and this is why N deficient cereal crops have low grain protein. Wheat or barley with protein of less than 11.5% is likely to have been N deficient and not achieved the best yield that it could.

Because most plant N is translocated to grain, large amounts of N (about 20kg/ha N per 1t/ha cereal yield or 40kg/ha per 1t/ha canola or legume yield) are exported from paddocks in grain at harvest. Sustained crop production requires inputs of N from fertiliser, legumes or organic wastes that equal or exceed offtake in grain. Most N (55 to 70%) is supplied to crops from the soil, but fertiliser can be used to supplement soil N supply, though this can usually only provide 30 to 45% of plant N uptake at the most. It is best to view fertiliser as a replacement for soil N that has been removed in grain, rather than the primary resource of N for crop growth.

Commercially, N deficiency can have a big impact on farm profitability. Ensuring that crops have sufficient N to achieve water limited potential yield, but not excessive amounts of N, can often mean the difference between profit and loss for a farm business.

What do we need to know to calculate a fertiliser N rate

N budgeting is an effective way to calculate a fertiliser N rate. To calculate a fertiliser rate using an N budget, we need to know the likely N requirement (or demand) of the crop we are managing, and the amount of N that is supplied by the soil. In basic N budgeting, fertiliser N requirement is calculated as the difference between the crop N demand and the soil N supply. When soil N supply exceeds crop demand, no additional fertiliser is required. When crop N demand exceeds soil N supply, additions of fertiliser N are required to avoid N deficiency and yield loss.

Estimating crop N demand

N is different to most other nutrients in that N requirement is proportional to grain yield. To effectively manage N, we need to understand crop yield. The yield concepts of Fischer (2015) are helpful in achieving this and are described below.

Farm yield (FY) – the yield achieved by growers in their fields. This can be measured individually in a sub-field unit (e.g., 3 ha), single field or is often aggregated up into larger areas.

Potential yield (PY) – the measured yield of the best cultivar, grown with optimal agronomy and without manageable biotic (for example, weeds, pests and diseases) and abiotic stresses, under natural resource and cropping system conditions representative of the target area. This is determined by solar radiation and temperature and is a useful benchmark in irrigated production systems and regions with very high rainfall.

Water-limited potential yield (PYw) – the yield obtained with no other manageable limitation to the crop (as for PY) apart from the water supply. This is a more useful metric in rainfed or dryland regions of crop production that commonly occur in Australia, and what we will use in the example at the end of this article.

Economic yield (EY) – the yield attained by growers with average natural resources when economically optimal practices and levels of inputs have been adopted while facing all the vagaries of weather. This metric recognises the law of diminishing returns; as inputs required to achieve high yields (fertilisers, biocides) are increased, returns decrease to the point where they become unprofitable. Economic yield is estimated as 80% of PYw, and this is what we use in the example below to calculate N demand.

In the case of wheat and barley, a robust rule of thumb is that 40kg/ha of N (soil mineral N and fertiliser) is required per 1t/ha of EY to ensure N sufficiency. In canola, approximately 80kg/ha of N supply is required per 1t/ha of grain yield. Only about half of this N supply is taken up by the crop and translocated to grain, the rest remains in the plant residues or soil.

Estimating economic yield

Because N is either applied at sowing and/or in crop, EY is unknown at the time that N application rate needs to be decided. In irrigated systems, or environments with very consistent rainfall, estimating N demand is easy because EY does not vary. In southern Australian dry land systems, EY varies enormously with the regions' highly variable August–October rainfall. It is this variability that makes it difficult to get N fertiliser rate 'right'.

There are lots of ways of estimating EY, including with complex crop simulation models like APSIM and its commercial web interface Yield Prophet®. In water limited environments like most of SA, a simpler way is to use known relationships between crop evapotranspiration (water use, WU) and an upper limit of grain yield. This relationship between crop water-use and grain yield was first described in SA by French and Schultz (1984) in their seminal work on water-use efficiency (WUE) and has most recently been updated by Harries et al. (2022) based on commercial crops in WA , where water limited potential yield for different crops can be calculated as follows:

Wheat PYw = (WU – 45)*25
Barley PYw = (WU – 50)*24
Canola PYw = (WU – 80)*15

This method of calculating PYw has a lot of assumptions and simplifications, but it is robust enough to make it useful for N management. EY is simply calculated as 0.8*PYw.

Measuring evapotranspiration is difficult in commercial crops, but it can be estimated from rainfall records, assuming that 25% of rain that falls during the summer fallow period (Nov–Mar), and all the rain that falls during the growing season (Apr–Oct) is used by crops for evapotranspiration (none leaches, runs off or is left behind by the crop). Therefore:
WU (mm) = (0.25*Nov–Mar rain) + Apr–Oct rain

If a decision on N rate is being made in April for the purposes of ordering urea after soil test results are available, Nov–Mar rainfall is known, but Apr–Oct needs to be estimated based on historic records. If a decision on N rate is being made in late July, Nov–Mar and Apr–Jul rainfall are known, but an estimate of likely rainfall needs to be used for Aug–Oct. Because Apr–Oct and Aug–Oct rainfall vary so much, basing a decision on the full range of possible outcomes, rather than assuming an average, can greatly improve decision making (please see the article by Peter Hayman and Barry Mudge in this proceedings). However, long term experiments have shown that simply using median rainfall for future months when estimating WU results in highly profitable N rate decisions is better than 'gut feel'.

Estimating N supply

Crops take up most of their N (55 to 70%) from the soil. N in the soil exists in two major pools – mineral N and organic N. Most N in cropping soils (tonnes per hectare) sits in the organic pool, which is not available to plants. It is contained in soil organic matter (SOM) with carbon (C) and other elements. Nitrogen cycles from the organic to the mineral pool through the process of mineralisation, and from the mineral pool back to the organic pool by the process of immobilisation. Both processes are the result of soil microbial activity. Mineralisation requires wet and warm soil, and in southern Australia mostly happens in summer when crops are not growing. Some mineralisation happens when the crop is growing (in crop mineralisation) and is highest in wet springs. In some systems N mineralisation and immobilisation are approximately equal resulting in no net change in mineral N availability to the crop.

Mineral N includes nitrate (NO_3) and ammonium (NH_4) which can both be taken up by plants but are much less abundant than organic N (tens to hundreds of kg per hectare). Nitrate is most readily taken up by plants and is usually the most abundant form of mineral N in the soil. It is also the form of N most readily lost to the environment by leaching and denitrification. Nitrate and ammonium are what we measure in soil tests to estimate soil N supply. Mineral N that we measure in a soil test at the start of the growing season has either not been taken up by the previous crop or has mineralised from soil organic matter or crop residues during the summer fallow period.

Taking effective soil tests

To estimate N supply, effective soil tests are required. These are best taken in the month or so prior to sowing, and before any fertiliser N is applied to the paddock. Mineral N is spatially variable, and estimates are highly prone to error. Multiple cores are taken in a single paddock to try and reduce error.

How many cores should I take

Accuracy of the estimate of soil mineral N increases with the number of cores that are taken. Most operators take 6–8 cores within a production zone and bulk them before sending for analysis. This typically gives a reasonable probability (~80%) of being within 20kg/ha N of the true mean. This is usually good enough for commercial N management. If bulking cores, it is extremely important to mix the soil very well before sub-sampling. There is a big advantage in not bulking cores and analysing them separately, as this avoids having to mix cores and helps to understand the paddock variability better. However, it increases the number of samples and the costs of analysis.

Where should I take cores

In a uniform paddock with a uniform yield map (I've been told they exist), a transect across the paddock is the best sampling strategy, avoiding any headlands, areas within 60m of trees, or unusual features. In paddocks with obviously variable soil types or topography, or variable yield maps with consistently high and low yielding zones, it is best to divide them into different production zones and sample and manage them separately. It is best practice to GPS locate your sampling points and return to the same location each year.

How deep should I take cores

Ideally, cores should be taken to maximum rooting depth of crops, which is usually at least 1.5m in SA and can be much deeper, particularly for canola. However, taking cores this deep is practically difficult, and most N is concentrated in the surface layers of soil, so an acceptable compromise is to sample to 0.6–1.0m depth. If you do not sample to full rooting depth, you are underestimating soil N supply.

How should I segment my cores

A big increase in accuracy of soil tests can be achieved by segmenting cores into different layers. This is because mineral N concentration decreases greatly at depth, so segmenting avoids mixing soils with very high and very low concentration, which is prone to sampling error in the laboratory. If sampling to 60cm, as a bare minimum, segment 0–10cm, 10–60cm and bulk the cores within these segments and analyse separately. It is even better to segment 0–10cm, 10–20cm, 20–40cm, and 40–60cm.

How should I handle my cores

Soil samples need to be always kept cool and arrive at the lab as quickly as possible or mineralisation will occur and inflate the amount of mineral N in the sample. Keep samples in an esky in the field, and transfer to a fridge or cool room before sending via express post or courier. Send samples early in the week so they are not stuck in transit over the weekend. You can tell if mineralisation has occurred if NH_4 concentration is higher than about 2mg/kg. If this is the case, ignore NH_4 in the estimate of soil N supply and just use NO_3.

Calculating N supply

The number you get back from the soil test is nitrate and ammonium concentration in mg/kg. To convert this to kg/ha of N, you need to multiply by soil bulk density and the depth of the soil that was sampled. An example of how to do this is provided below.

In-crop mineralisation also supplies N to the crop, but I prefer not to include this in estimates of N supply because it is highly variable (can be negative in a dry year) and difficult to estimate, and allowing for it in N budgets contributes to mining of soil organic N.

Putting it all together

The following is an example of calculating a fertiliser N rate using the N budgeting approach and the estimate of PYw estimated by Harries et al. (2022). It is for a hypothetical wheat paddock in the MRZ of SA that is sown on time and has no other agronomic constraints. The calculation of the N rate is being made at the end of July. Rainfall for the previous season and year to-date is in Table 1, median rainfall for the future months of August, September and October are in Table 2.

Table 1: Recorded rainfall for the summer fallow period and first 4 months of the growing season for the example wheat paddock in the medium rainfall zone of SA.

	Previous year		**Current year**						
Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Rainfall (mm)	72	43	18	3	23	37	35	60	25

Table 2: Long term median rainfall for the final three months of the growing season for the paddock location using data from the nearest BoM website for a representative BoM weather station.

Month	**Aug**	**Sep**	**Oct**
Rainfall (mm)	49	42	32

Crop water use (rounded up to the nearest mm) is then calculated as:
WU (mm) = (0.25*Nov–Mar rain) + Apr–Oct rain
WU (mm) = (0.25*(72 + 43 + 18 + 3 + 23)) + **(37 + 35 + 60 + 25)** + (*49 + 42 +32*)
WU = 320mm

The rainfall numbers in the equation above in bold are measured rainfall for Apr–Jul for the current year (Table 1). The numbers in italics are median values for Aug, Sep and Oct taken from long term rainfall records (Table 2).

Wheat PYw is then calculated as:
Wheat PYw (kg/ha) = (WU-45)*25
Wheat PYw (kg/ha) = (320-45)*25
Wheat PYw = 6875 kg/ha
Wheat EY is then calculated as:
Wheat EY (kg/ha) = PYw*0.8
Wheat EY = 5500 kg/ha

This can be converted into t/ha by dividing by 1000.
Wheat EY = 5.5 t/ha

Crop N demand is then calculated as:
N demand (kg/ha) = 5.5*40
N demand = 220 kg/ha N

Based on the assumption of median rainfall for Aug–Oct, this crop will require an N supply of 220 kg/ha to not be N deficient and achieve economic yield.

The soil test results for the paddock are in Table 3 assuming a segmented soil test to 1m.

Table 3: Soil test results for the paddock from cores taken prior to sowing.

Depth increment	NO_3 (mg/kg)	NH_4 (mg/kg)
0–10cm	12	2
10–40cm	6	1
40–70cm	3	1
70–100cm	1	1

Soil mineral N at each depth is calculated as:
Mineral N (kg/ha) = (NO_3 in mg/kg + NH_4 in mg/kg)*bulk density (mg/m^3)*depth increment (where 1 decimetre, dm = 0.1m = 10cm)

An estimate of different soil bulk densities is provided in Table 4. For this example, we will assume a loam with bulk density of 1.3 mg/m^3.
Mineral N 0–10 cm = (12 + 2) * 1.3 *1 = 18 kg/ha
Mineral N 0–10 cm = (6 + 1) * 1.3 *3 = 27 kg/ha
Mineral N 0–10 cm = (3 + 1) * 1.3 *3 = 16 kg/ha
Mineral N 0–10 cm = (1 + 1) * 1.3 *3 = 8 kg/ha

Total mineral N for the soil profile down to the sampling depth is calculated by summing all the depths:
Total mineral N to 1m = 18 + 27 + 16 + 8
Total mineral N to 1m = 69 kg/ha

Table 4: Range and average of bulk density for soils of different texture class.

Soil Type	Bulk Density Lower (mg/m^3)	Average Bulk Density (mg/m^3)	Bulk Density Upper (mg/m^3)
Coarse Sand	1.3	1.55	1.8
Fine Sand	1.3	1.3	1.3
Light Sandy Clay Loam	1.3	1.45	1.6
Loam	1.1	1.25	1.4
Sandy Clay Loam	1.3	1.45	1.6
Clay Loam	1.3	1.45	1.6
Clay	1.3	1.4	1.5
Self Mulching Clay	1.2	1.25	1.3

Crop N supply is calculated as:
N supply (kg/ha) = total soil mineral N + N in fertiliser applied to-date (80kg/ha MAP in this example at 10% N)
N supply (kg/ha) = 69 + 8
N supply = 77 kg N/ha

N fertiliser requirement is calculated as:
N fertiliser requirement (kg/ha) = crop N demand – soil N supply
N fertiliser requirement (kg/ha) = 220 – 77
N fertiliser requirement = 143 kg/ha N

To calculate a urea rate, divide this number by 0.46 (which is the proportion of urea that is N) = 311 kg/ha urea.

Final words

This is a basic and simplified approach to N budgeting, but evidence has shown that it is effective at calculating N fertiliser rates that are highly profitable over the long term. Many growers and agronomists use other methods of N budgeting that are just as valid and just as effective.

Questions often get asked about the validity of the approach when crops achieve high yield when a soil test indicates that the crop should have been N deficient. The reason for this can be found in the simplifications used in the technique which can underestimate soil N supply. More soil N is available below sampling depth, soil tests can easily be out by 20–40kg/ha N or more if not done well, and in wet springs, crop mineralisation can supply the crop with >80kg/ha N in soils with high soil organic matter. Continually growing N deficient crops not only reduces profitability, but also mines soil organic matter, releasing CO_2 into the atmosphere, damaging soil structure, and reducing the soil's ability to supply N to a crop.

The future

Researchers in Riskwi$e are evaluating new ways of deciding N rates, including N banks (which still require a soil test) and data from header mounted protein and yield maps, and more information about these will be available in the future from the GRDC Riskwi$e investment.

Acknowledgements

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

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Notes

Pod-set in faba bean – benchmarks and physiology

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GRDC project codes: UOA2202-006RSX; UOA2204-RTX

Keywords

- biomass, critical period, harvest index, pulses.

Take home messages

- Pod number can be used to estimate grain yield in southern Australia: every 100 pods/m^2 (that contain grain at maturity) equate to approximately 1t/ha for cultivars released since 2013.
- Grain yield, grain number and pod number are associated with growth during the critical period, which is at pod emergence in faba bean.
- Pod-set is highly coordinated across a faba bean plant, so avoid drawing conclusions from pod numbers at individual nodes.

Background

Increased profitability of faba bean in Australian farming systems can be achieved through an increase in grain yield, grain price or both, and/or a reduction in production cost. This paper will focus on grain yield. Grain yield is correlated with pod number, and over several weeks faba bean plants produce many flowers but most do not set a pod. This has led industry and researchers to identify 'pod-set', that is, the successful conversion of flowers into pods that contain marketable seeds at maturity, as a target for crop improvement. Physiological theory and evidence can provide clarification on the significance of this trait.

Physiological theory explains yield in terms of crop behaviour, which complements agronomic theory that explains yield in terms of grower management. Agronomic theories are practical, but relying on them solely does not account for the inherent crop response that generates the observable traits that we measure, such as pod-set. Understanding of the underlying crop physiology helps growers ensure the agronomic theories and practices used are appropriate for the given crop.

In this update paper, we will:

- provide a benchmark for faba bean grain yield from pod number
- outline the key drivers of grain yield and pod-set at the crop, plant and node levels
- use this knowledge to address frequently asked questions in a physiological context.

Key concept: life is organised by scale

To explain faba bean pod-set systematically, let's start by acknowledging that biological units are organised in a hierarchy of scales: cells **within** tissues **within** organs **within** individuals **within** populations, and so on (Figure 1). In a cropped paddock, the crop is the population level, the plants occupy the individual level, and the flowers, pods, leaves, and other structures occupy the organ level.

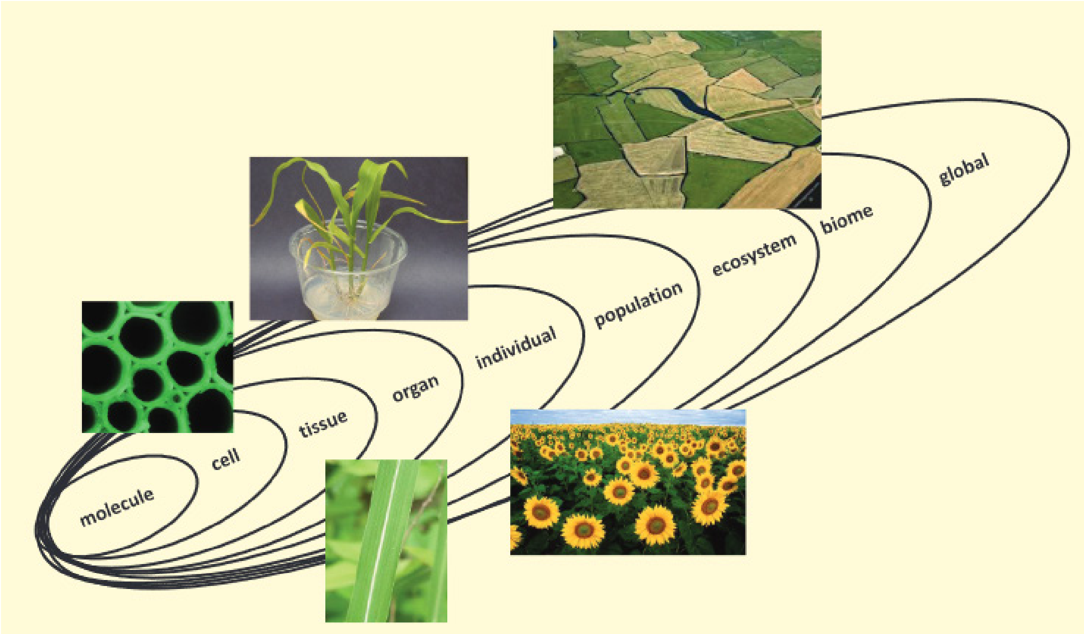

Figure 1. Life is organised by a hierarchy of scales. Source: Sadras and Richards 2014.

It is important to think about scales explicitly to define our terms. When 'yield' is defined as tonnes of grain harvested per hectare, this is a crop (population) trait. Pod-set can be described at both crop (pods/m^2) and plant (pods/plant) scales.

It is also important to think about how higher and lower scales relate to each other. For example, behaviours of plant organs (flowers, pods) are coordinated by the plant as a whole, so it is expected that pod-set will be connected to other plant functions. Furthermore, plants compete and/or cooperate, so it is expected that plant interactions are a factor for crop-level growth and reproduction.

The next sections work through crop, plant and organ scales to explain pod-set.

Results and discussion

Grain yield and pod-set at the crop scale

Most of the variation between high and low grain yields associates with variation in grain number (grains/m^2). This has frequently been shown in cereals, oilseeds and pulses, and holds true across climates, soils and management (Figure 2). It is also true for faba bean (Figure 3a), where pod number shows a similar, but more scattered, correlation with yield (Figure 3b). This shows that faba bean crops are responding to good and bad conditions mostly by changing these traits. Grain weight (mg/seed) has a small effect and is important for grain quality and some agronomic scenarios (for example, decisions for late-season crop inputs), but grain number is key for yield variation.

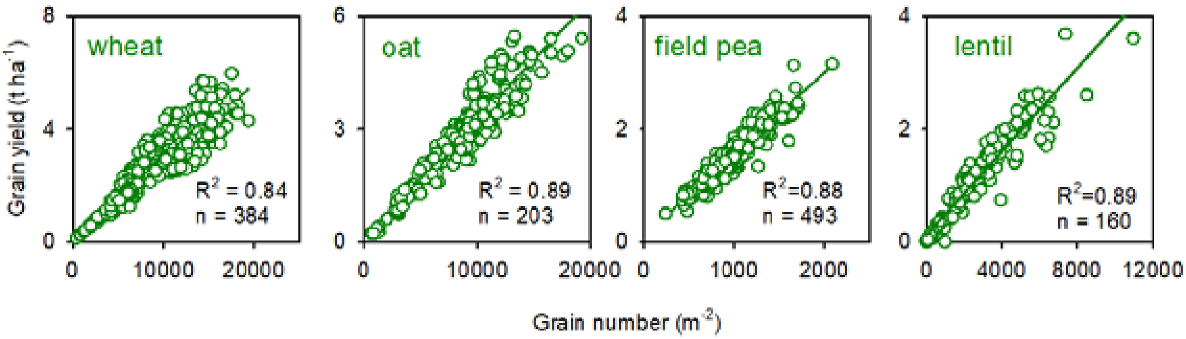

Figure 2. Crop yield is primarily related to grain number. Source: Sadras 2021.

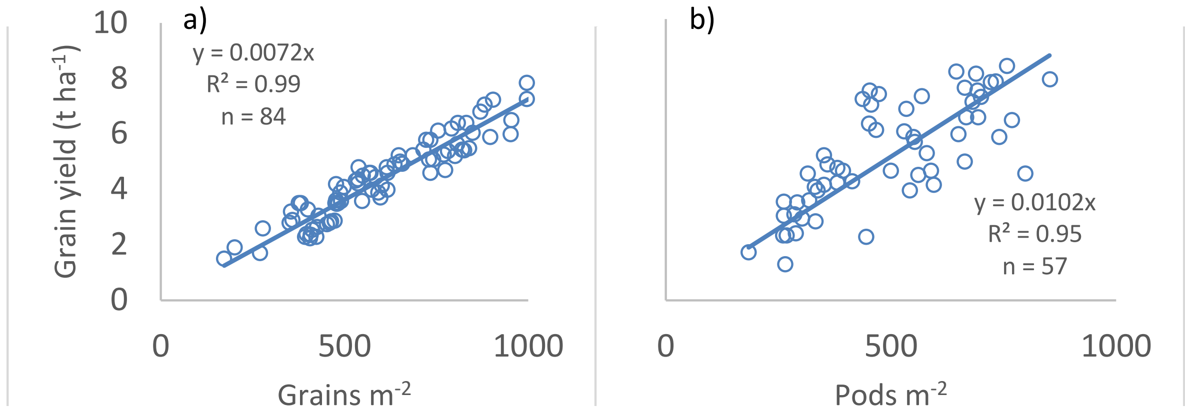

Figure 3. Grain yield is related to (a) grain number and pod number in faba bean. The cultivars are PBA Amberley$^{\phi}$, PBA Bendoc$^{\phi}$, PBA Samira$^{\phi}$ and PBA Zahra$^{\phi}$, and management sources of variation include plant density, sowing date and row spacing. Data are from (a) nine or (b) 12 disease-free site-years, and two (a, b) moderately diseased site-years in southern Australia.

Grain number is determined during a 'critical period', during which a change in growth has a large effect on grain number and yield, and outside of which a change in growth has a smaller effect on yield. The critical period is during booting in cereals, and centres on pod emergence in pulses and canola, including faba bean (Figure 4). Yield could be increased by a longer critical period (for example, better matching of phenology to the environment), faster growth during the critical period (for example, adequate groundcover to capture all radiation) and greater allocation to seeds during the critical period (for example, more efficient genotypes). At the end of a season when interpreting pod number and/or grain yield achieved, the key question to ask is 'What happened during the critical period?' Then, the answer to this question can be linked to other factors for yield (see the FAQs section below for examples).

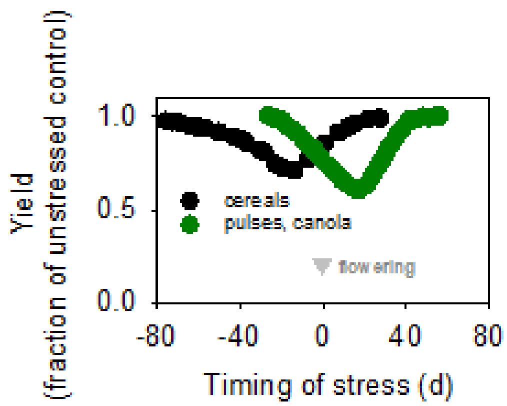

Figure 4. Species-specific critical windows for grain number and yield. Source: Sadras and Dreccer 2015.

Pod-set at crop and plant scales

Since grain yield was defined as a population trait above, we are only interested in yield per plant if it is correlated with yield per hectare, and this is not always the case. For example, when plant population density changes in response to sowing rate or crop establishment, crop yield and plant yield move in opposite directions (Figure 5a). The same is true for pod number (Figure 5b).

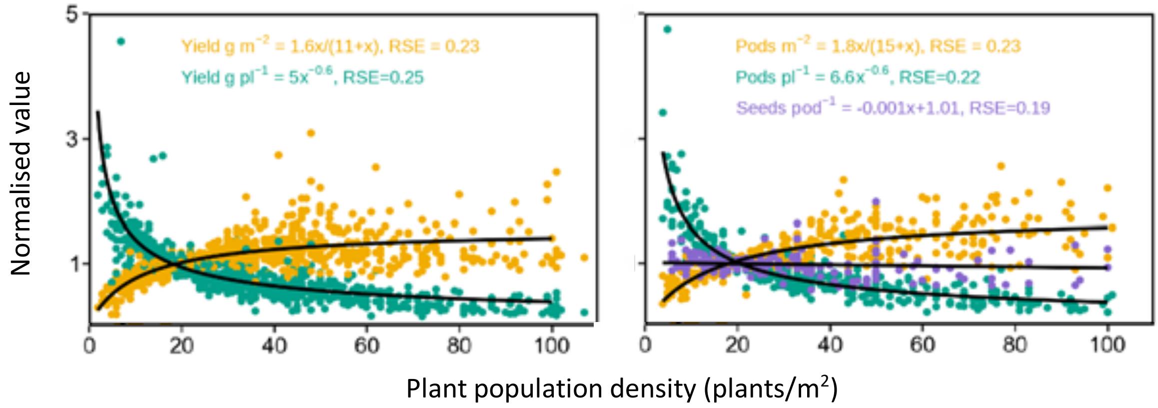

Figure 5. Faba bean crop and plant responses of (a) yield and (b) pod number to plant population density, from a database of 204 responses (126 of which are from Australia). Traits are normalised by their value at 20 plants/m^2 (for example, '3' is three times larger than the response's 20 plants/m^2 value). Yellow symbols are traits with area-based units (/m^2), green symbols have units of /plant1, and purple symbols have other units. Curves are Michaelis-Menten models for /m^2 traits, power models for /plant traits, and a linear model for seeds/pod. RSE is residual standard error of the normalised trait.

When plant population density is the same across seasons, pods/m^2 and pods/plant are correlated. However, plant density can vary between seasons and within a paddock so pods/m^2 is the most reliable indicator for yield estimation. Figure 3b showed that in the southern region, approximately every 100 pods/m^2 is roughly equivalent to 1t/ha of grain yield for cultivars released since 2013 (PBA Samira⫚). Pods should be counted from a measured area, or converted from pods/plant using the plant density where the count was taken. The estimate could be performed during late pod-set, when growers are confident they can identify the pods that are likely to reach maturity.

Pod-set at plant and node scales

Faba bean plants have a distinct pattern of pod distribution along the stems that can be described as 'pear-shaped' or 'bottom-heavy'. The first panel of Figure 6 ('1Control') illustrates this pattern in a typical faba bean crop, PBA Samira⫚ grown at Freeling, SA in 2022 at 25 plants/m^2. After a few failed flowering nodes, most pods are formed on the lower, older flowering nodes with a sharp decrease in pods for younger nodes higher on the stem. This basic shape is universal in faba bean; it applies across widely different soils, climates and genotypes. Panels 2, 3 and 4 of Figure 6 show that when the crop was thinned from 25 plants/m^2 to 5 plants/m^2, giving each plant much greater access to light and water, it was the lower nodes that responded, even as late as grain-fill. In the field, do not assume that pod number at an individual node reflects an isolated event because these findings show that pod-set is coordinated by the whole plant and the responsiveness of the nodes overlaps significantly.

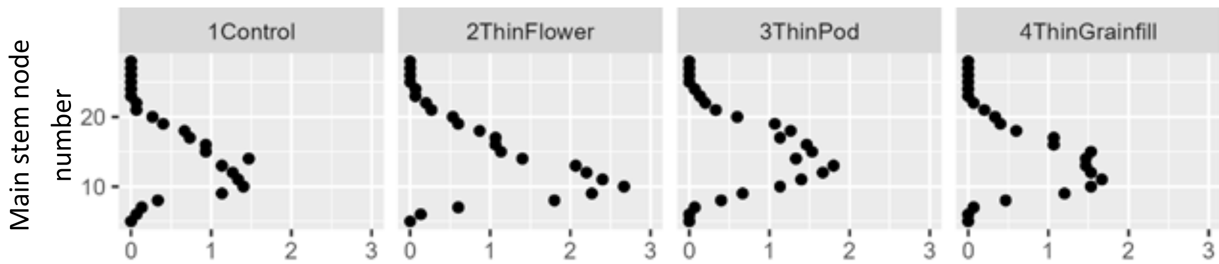

Figure 6. Vertical distribution of pods along faba bean main stems, grown at Freeling, SA in 2022. Panel 1) Control, PBA Samira⫚, 25 plants/m^2. Panel 2) Thinned to 5 plants/m^2 at flowering. Panel 3) Thinned at pod emergence. Panel 4) Thinned during early grain-fill. Points are the mean of three replicates, four plants per replicate.

The pattern of faba bean pod-set within a plant is an example of how all flowering plants reproduce. Flowering plants overproduce flowers and cull them according to a range of factors, such as resources, pollination status, and so on. One estimate for faba bean is that if every ovule in every flower formed a normal-sized seed, it would equate to a yield of 38 t/ha. Overproduction of florets occurs in wheat, too, but it isn't visible (Figure 7, red line).

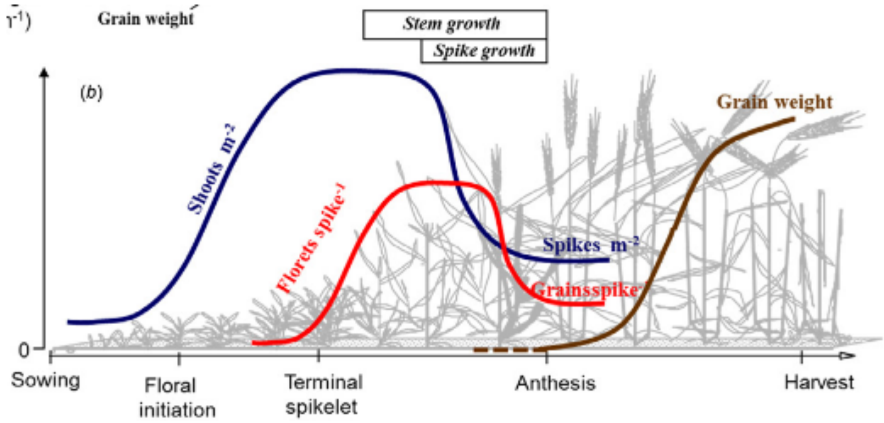

Figure 7. Generation of yield components over time in wheat. Source: Slafer et al. 2014.

It is also common for a hierarchy to develop among growing offspring on a plant where some seeds are larger and/or more likely to develop to maturity - a phenomenon called 'dominance'. This would explain the vertical distribution of pods in faba bean: the older, larger pods dominate the younger, smaller ones, including when plant resources are increased during reproduction. Experiments on faba bean in 2023, where the first flowers or first pods were removed, showed that younger nodes higher on the stem can form pods to compensate for lost pods lower down the stem. This suggests that the pattern of pod-set in faba bean is partially the result of a buffering system that can accommodate some pod abortion earlier in the season.

Pod-set FAQs

With this physiology in mind, we can address some frequently asked questions about faba bean pod-set. Given the importance of critical period growth to grain yield, it will help to distinguish growth-dependent effects from growth-independent effects.

How does self-shading influence pod-set?

Some self-shading always occurs in plants, but excessive self-shading might lead to reduced growth during the critical period, with the plants aborting more flowers as a result (a growth-dependent effect). Alternatively, the altered light conditions might signal the plant to conservatively abort flowers (a growth-independent effect), leading to a 'de-coupling' of crop growth rate and yield, as has been observed in field pea. The reasons lead to different research pathways to find solutions, and the measurements have been taken in field trials 2022 and 2023 to distinguish them.

However, during the triple La Niña events of recent years, where rainfall and growth were higher than average and radiation was lower than average, pod-set and yields were high where disease was kept under control. This would suggest that moisture supply is an important factor that may be the true cause of an apparent de-coupling of growth and yield. Further research is required, but in the meantime, care should be taken to distinguish self-shading from lodging and disease effects in seasons with high biomass.

How do diseases influence pod-set?

Faba bean diseases, such as chocolate spot, affect both leaves and flowers. Loss of photosynthetic area could increase flower abortion (growth-dependent effect), while diseased flowers might be killed (growth-independent effect). The same solution applies in either case: practice integrated disease management.

How does insect pollination influence pod-set?

Pollination may increase faba bean pod-set and yield, but the results are inconsistent. Both fully self-pollinating and partially pollinator-dependent genotypes have inconsistent responses to pollination. In some seasons, growth during the critical period might not be sufficient for pollination to show a large effect (growth-dependent effect). Pollination can even lead to pod abortion, because sometimes pollen grains clog the stigma, leading to flower abortion (growth-independent effect).

Pollinator numbers are declining worldwide, which has been shown to cause some plant species to become more reliant on self-pollination, and this could be the case for faba bean. Furthermore, in the first stages of the Australian breeding program, plants are kept in bee exclusion cages to eliminate cross-pollination, so there is some selection pressure for self-pollination.

If beehives can be placed near faba bean crops at an acceptable cost, then this can be seen as an insurance against unnecessary losses, but it is unlikely to be a major driver of grain yield in Australian conditions.

How does heat stress influence pod-set?

Heat stress is a major constraint to faba bean production. It could reduce yield by shortening growth during the critical period or reducing its growth rate, leading to reduced pod-set (growth-dependent effect). It can also disrupt normal reproductive functions, such as causing pollen sterility (growth-independent effect). The difference has breeding implications, but for growers the same strategy of timely sowing is required.

Conclusion: should we focus on pod-set to improve faba bean grain yield?

Expanding faba bean production into lower rainfall areas might require an increase in both biomass and harvest index. However, in the higher rainfall regions where they are grown most, faba bean crops can, and often do, produce large amounts of biomass and are prone to diseases and lodging. For these environments, increasing faba bean grain yield through increased harvest index is preferable. This will require either an increase in pods per plant or seeds per pod (not discussed in this paper, but similar principles apply).

However, the need for greater harvest index does not automatically imply that flower, pod or seed 'failure' is the problem that requires specific attention. A range of growth-dependent and growth-independent factors contribute to pod-set in faba bean, and the growth-independent effects are inconsistent (pollination), require more research (self-shading), or do not change grower practice (disease, heat). Consequently, growers should focus on the key drivers of yield: matching phenology and growth during the critical period to their target environments and protecting the crop from diseases and weeds.

Acknowledgements

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Notes

Yield potential of synthetic auxin herbicide tolerant field pea

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Keywords

- field pea, herbicide tolerance, pulse legumes, yield potential.

Take home messages

- New pulse varieties with improved tolerance to synthetic auxin herbicides are being trialled.
- Herbicide tolerance traits don't have to come with a big yield penalty.
- A 27% increase in grain yield is possible through a single gene regulating plant architecture.
- Plant molecular biology PhDs can have applied outcomes.

Background

Herbicide tolerant crop varieties provide novel weed control options, increased crop safety, and offer more flexible crop rotations. Weed control is particularly important in the pulse phase because pulses have poor early crop competition, few registered herbicide options, and are sensitive to soil residues of herbicides used in previous seasons. Many herbicide tolerant crops have been developed, but these traits tend to come at the cost of grain yield potential. Triazine tolerant canola has an inherent yield penalty of 20–30% (Robertson et al. 2002) and a similar penalty is seen in metribuzin tolerant lentils (McMurray et al. 2021). While this can be an acceptable trade off in some situations, it is important to understand and minimise yield penalties where possible.

Molecular genetics research provides an opportunity to understand the molecular and physiological basis for key agronomic traits. For example, understanding the effects of herbicide tolerance traits on plant development may reveal strategies to overcome associated yield penalties. This PhD project sought to characterise and understand the effects on plant development and grain yield of new synthetic auxin herbicide tolerance traits developed by SARDI and UoA (GRDC projects DAS00131 and UOA2007-010RTX).

Synthetic auxin herbicides like clopyralid (Lontrel®) act through the plant's hormone signalling pathways, where they mimic the phytohormone auxin, leading to an overactivation of auxin responses and plant death (Todd et al. 2020). Target-site tolerance is possible through mutations in an auxin receptor gene; however, if the mutation alters the function of the gene too severely, there are potential implications for the normal developmental processes regulated by this hormone signalling pathway.

As part of the previous GRDC-funded projects, ethyl methanesulfonate (EMS) mutagenised field pea (*Pisum* sativum) lines with improved clopyralid tolerance were identified through bulk screening of a PBA Wharton$^{\Phi}$-derived mutant population. Through those projects and this PhD research, 14 unique tolerance mutations have been identified in the *Auxin Signalling F-box Protein 4/5* (*AFB4/5*) auxin receptor gene (in-press; this work). Different mutants show varying degrees of altered plant architecture, delayed phenology, and reduced grain size in greenhouse and field conditions.

Here, we report that the seed size of a herbicide-tolerant mutant can be completely rescued by a second mutation in a gene that acts downstream of auxin signalling. Furthermore, while most clopyralid tolerant mutants have an inherent yield and seed size trade-off, one mutant line substantially outperformed PBA Wharton^{A}, with up to 21% higher average grain weight and 27% higher yield in optimal field conditions.

Method

Field trials were conducted in the South Australian mid-north region (Table 1). A preliminary assessment of 90 mutant lines (unreplicated) alongside check rows of PBA Wharton⁽ᴰ⁾ was conducted in 2020 and observations compared with a similar trial conducted simultaneously by the National Field Pea Breeding program (Agriculture Victoria Research). Short rows were hand harvested to ensure seed purity.

For trials in the 2022 and 2023 seasons, experimental plots (12m x 1.5m) were arranged in a randomised complete block design with four replicates. Seeding rate treatments were based on a target plant density of 45 plants/m^2.

Controlled environment experiments were performed in growth rooms at the University of Adelaide, Waite Campus. Seeds were sown in 20cm diameter 4.5L pots of BioGro potting soil (90% composted pine bark + 10% river sand) and growth conditions were maintained at 24/15°C day/night, 14-hour day length and maximum light intensity of 700µmol/m^2/s. The *smxl7-1* mutant line (Kerr et al. 2021) was kindly provided by Dr Elizabeth Dun (University of Queensland) and double mutants were generated by crossing with the *afb4/5-8* null mutant.

Statistical analyses were performed using the ASREML package (Butler 2022) in R Statistical Software (v4.2.0; R Core Team 2022), and GraphPad Prism version 9.0.0 for Windows (GraphPad Software, Boston, Massachusetts USA, www.graphpad.com)

Table 1: Field trial sites. Locations are approximate.

	Turretfield 2020	Mallala 2022	Kapunda 2022	Kapunda 2023
Location (latitude, longitude)	-34.549, 138.795	-34.475, 138.563	-34.389, 138.889	
Mean annual rainfall (mm) Growing season (Apr–Oct)	371.6 (274.9)	381.4 (256.1)	491 (335.2)	
Actual rainfall Growing season (Apr–Oct)	336.8 (284.4)	533.8 (353.6)	689.8 (510.3)	407.2 (272.7)

Results and discussion

Preliminary field assessment

Plants carrying predicted null (complete loss of function) mutations in the auxin receptor/herbicide target-site gene consistently showed severe growth defects including reduced plant height, increased shoot branching, delayed phenology and reduced seed size, while those with substitution mutations causing a small change in the predicted protein sequence had a range of intermediate phenotypes that varied between the control and null lines (Figure 1A). Two clopyralid-tolerant mutant lines with growth habit and thousand grain weight similar to PBA WhartonP were selected in consultation with the breeder for further evaluation (Figure 1B). Line 17KAHCL038 had only minor changes in plant height and phenology (data not shown) but 16% lower average seed weight ($p<0.01$, Student's independent T-test). Line 17KAHCL050 had slightly reduced plant height and delayed phenology but seed size was not reduced ($p=0.36$).

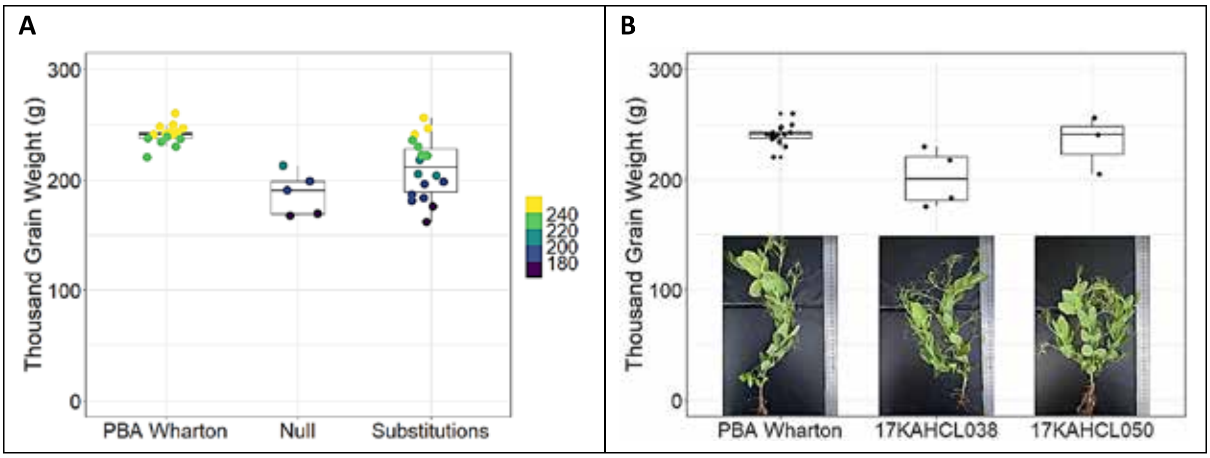

Figure 1. Preliminary field assessment reveals reduced seed size in clopyralid tolerant field pea mutants. Five null and 18 substitution mutant lines showed contrasting effects on thousand grain weight (A). Two mutations of interest for breeding were replicated within the 2020 field trial (B).

2022 field trials

Field sites were selected to represent low-medium rainfall (Mallala; 256mm mean growing season rainfall) and medium-high rainfall (Kapunda; 335mm mean growing season rainfall) zones, based on a growing season of April–October. There was unusually high rainfall in 2022, with annual rainfall in the 95^{th} percentile at both sites, resulting in a delayed harvest and extended growing season. Actual growing season rainfall (April–November) was 460.4mm at Mallala and 645.5mm at Kapunda (Australian Government Bureau of Meteorology).

At Mallala, 17KAHCL038 showed an 18% reduction in grain yield compared to PBA Wharton$^{\phi}$ at the 0.5x seeding rate (p=0.04) but no significant difference at the 1x seeding rate (p=0.89). In contrast, 17KAHCL050 showed a substantial yield improvement of 22% (p=0.01) and 27.5% (p=0.003) at the 0.5x and 1x seeding rates, respectively (Figure 2A). These yield differences were driven partly by seed size, with 17KAHCL038 showing a 7.6% reduction in hundred seed weight (100SW) compared to PBA Wharton$^{\phi}$ at the lower seeding rate, while 17KAHCL050 had a 17% and 25% increase in 100SW at the reduced and standard seeding rates, respectively (Figure 2B).

Due to poor emergence, waterlogging, and weed pressure, the Kapunda site performed poorly and had large variances in grain yield between replicates. Mean grain yields followed the same pattern as Mallala, however none of these differences met the threshold for statistical significance (Figure 2C).

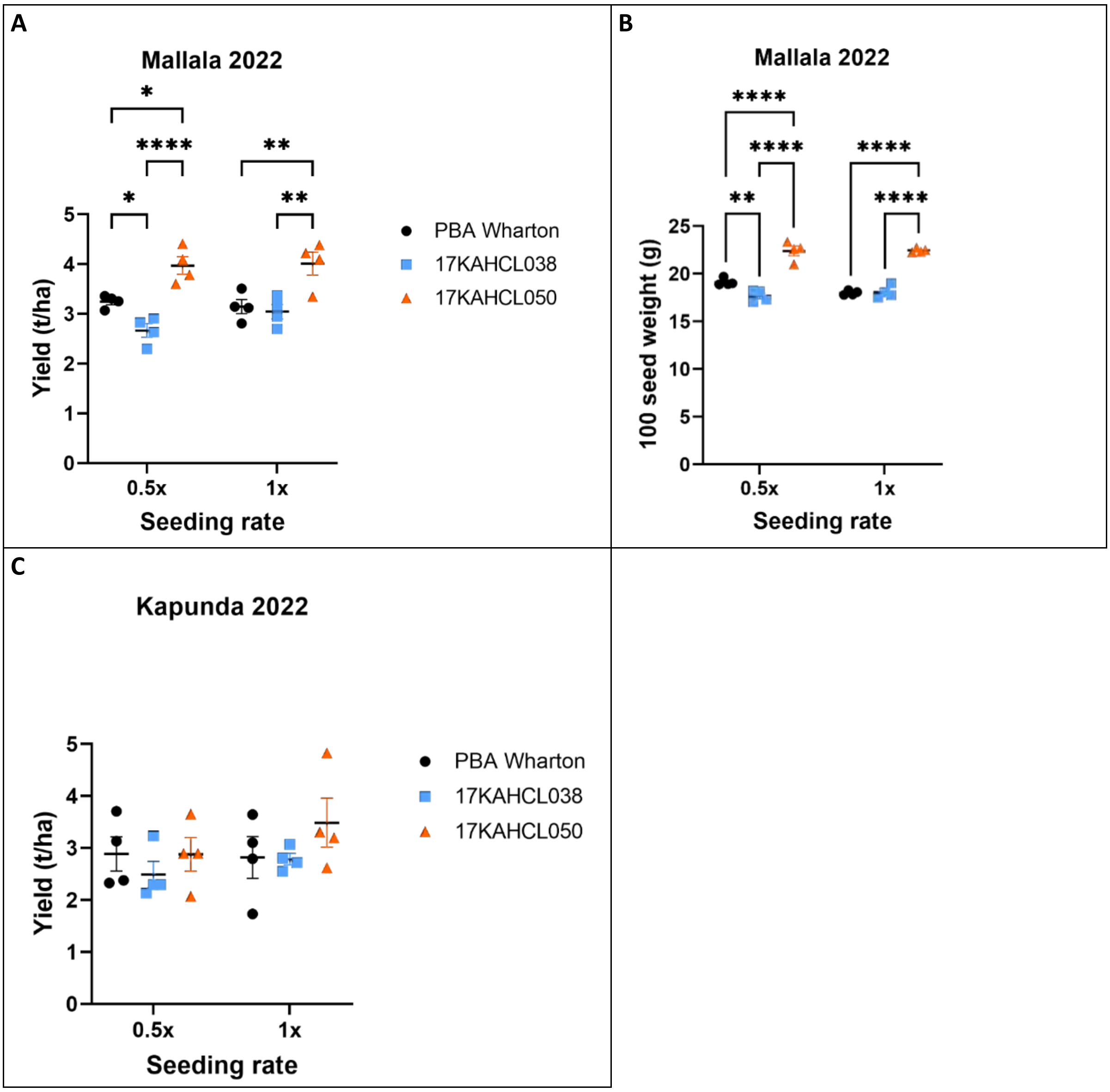

Figure 2. Performance of two herbicide tolerant field pea lines compared to the susceptible variety PBA Wharton$^{\phi}$ in field trials at Mallala (***A, B***) and Kapunda (C) in 2022. No significant effect of seeding rate was detected in a 2-way ANOVA. Genotypic differences marked with asterisks are significant at p<0.05 (*), p<0.01 (**), p<0.005 (***) and p<0.0001 (****) (Tukey's multiple comparisons test).

2023 field trials

To test whether the increased yield of 17KAHCL050 could be replicated in more limiting field conditions, two times of sowing (TOS) were included, ~5 weeks apart with the aim to compare normal conditions to a shortened growing season. The 2023 year was drier than average, with growing season rainfall (April–October) totalling 272.7mm, compared to the long-term mean of 335mm. A hot, dry spring resulted in a harsh finish to the season and harvest was 5 weeks earlier than in 2022.

Line 17KAHCL050 performed well at the 1x seeding rate at TOS1, with no significant reduction in mean grain yield (p=0.17), however a significant yield penalty of 10% was observed at the reduced seeding rate (p=0.05; Figure 3A). TOS2 yield was lower for both genotypes. Line 17KAHCL050 showed a 12% yield penalty (p=0.0006) at the 1x seeding rate and 11% at the 0.5x rate (p=0.006; Figure 3B). The average seed weight of the herbicide tolerant mutant was ~7–10% larger than that of PBA Wharton$^{\phi}$ in all treatments (Figure 3C-D).

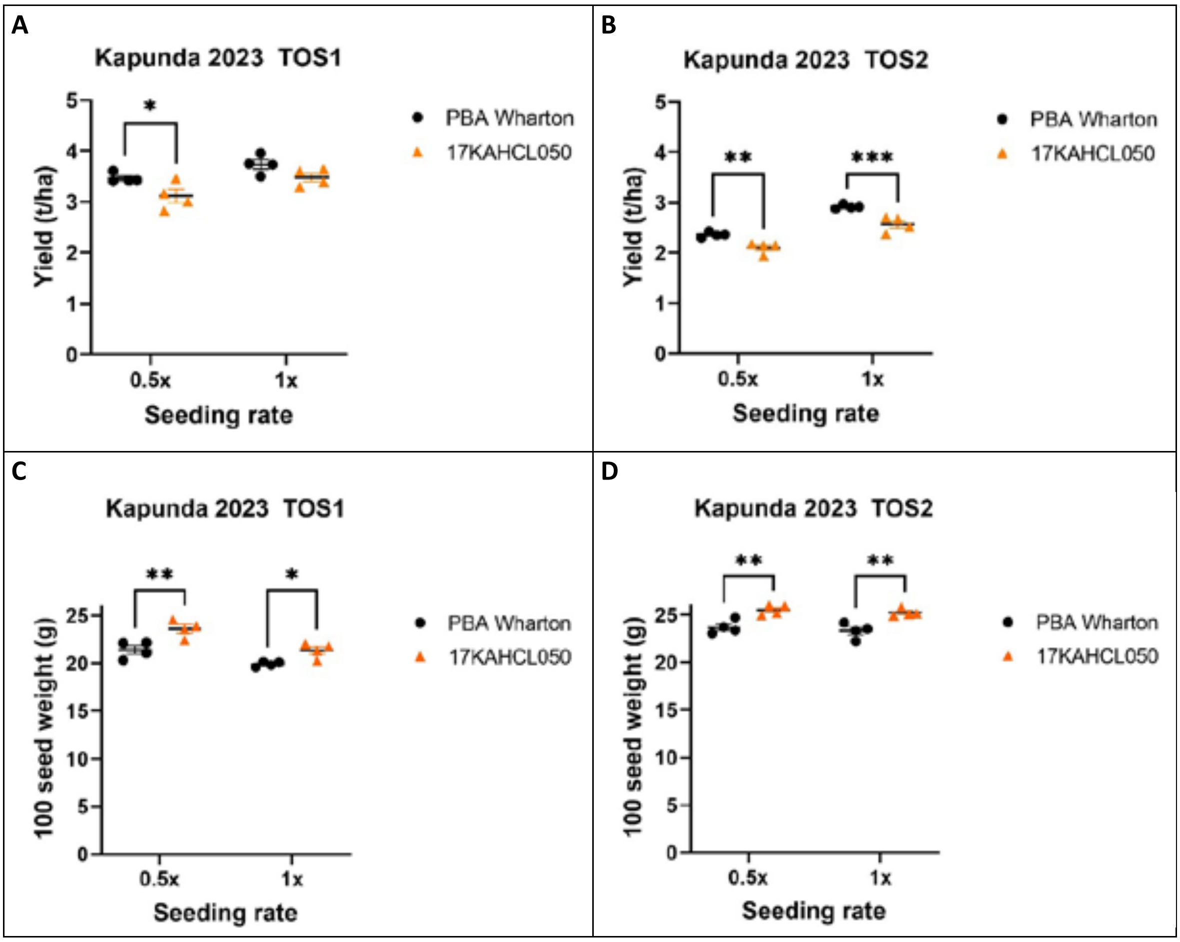

Figure 3. A yield penalty associated with the 17KAHCL050 clopyralid herbicide tolerance trait is apparent with delayed sowing and at reduced seeding rates. Grain yield (***A, B***) and 100 seed weight (***C, D***) were measured for two times of sowing (TOS). Seeding rates targeted 0.5x and 1x standard plant density of 45 plants/m^2. Differences marked with asterisks are significant at p<0.05(*), p<0.01 (**), and p<0.005 (***) (2-way ANOVA and Bonferroni's multiple comparisons test).

SMXL7 regulates seed size

Auxin regulates diverse processes in plant growth and development through a complex network of receptors, co-receptors and auxin response factors controlling expression of hundreds of genes. In shoot branching regulation, strigolactones are another hormone that act downstream of auxin to repress lateral bud growth. In garden pea, Kerr et al. (2021) described a mutant of SUPPRESSOR OF MAX2-LIKE 7 (SMXL7) which restores branching regulation in strigolactone signalling mutants. They demonstrated that the *smxl7-1* mutation partially rescues branching regulation and plant height in an *afb4/5-1* auxin receptor mutant. To test if the reduced seed size of the 17KAHCL065 null mutant (*afb4/5-8*) is due to reduced strigolactone response via SMXL7, we crossed the herbicide tolerant line with the *smxl7-1* mutant and identified single and double mutants in the F3 generation.

All *afb4/5-8* single mutants were dwarfed, highly branched and had a 35% decrease in average seed weight compared to wildtype F3 lines. The *afb4/5-8 smxl7-1* double mutants had partially restored shoot architecture, as expected, and seed size was completely restored (Figure 4). This finding suggests that SMXL7 plays an important role in seed development downstream of auxin signalling and shows that *smxl7* mutants may be able to minimise yield and grain quality trade-offs when breeding for synthetic auxin herbicide tolerance.

Conclusion

A yield penalty is associated with some synthetic auxin herbicide tolerance mutations in field pea, but the magnitude of the penalty varies between mutation events and with environmental conditions. We demonstrated that the reduced seed size observed in some clopyralid tolerant mutants (namely, 17KAHCL065, afb4/5-8) can be rescued by a mutation in another single gene in the auxin-strigolactone hormone signalling pathway (namely, *smxl7-1*). Additionally, we identified a mutant line with a 27% increase in grain yield compared to PBA Wharton$^{\phi}$ in favourable (long-season) field conditions, but a small (0–12%) yield penalty in more limiting conditions.

Through exploring novel large-scale genetic diversity and understanding the molecular biology underpinning key agronomic traits, we showed that it is possible to develop herbicide tolerant crops that offer valuable weed control options while minimising the trade-off in crop productivity. Furthermore, we showed that there is an exciting opportunity to achieve a step-change in yield potential through targeting plant architecture in grain legumes.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support. This research is supported by an Australian Government Research Training Program (RTP) Scholarship.

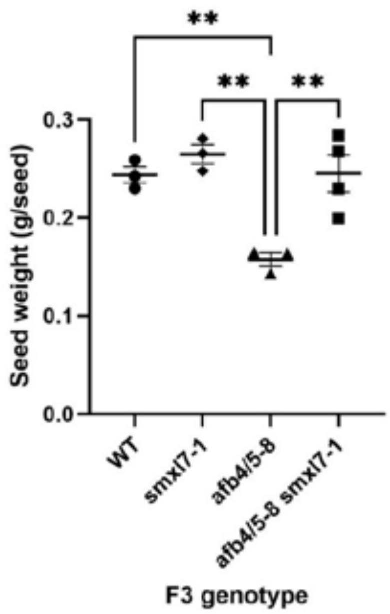

Figure 4. Reduced seed weight of the afb4/5-8 null mutant is rescued by smxl7-1. Data points are average seed weights from individual F3 plants grown in controlled environment. Differences marked with asterisks (**) are significant at p<0.01 (1-way ANOVA and Tukey's Multiple Comparisons Test).

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Notes

Strategies for optimising glufosinate and tackling efficacy challenges

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Keywords

- glufosinate, herbicide translocation, humidity, temperature.

Take home messages

- Glufosinate is a charged herbicide, which influences its absorption.
- Translocation of glufosinate is the limiting factor for control. Translocation is decreased with lower temperatures after application.
- High humidity at application is essential for glufosinate uptake and hence, performance.

Chemistry of glufosinate

In understanding the issues with glufosinate efficacy, it is useful to start with a discussion of the chemistry of the herbicide. Glufosinate has structural similarities to glyphosate and, like glyphosate, is a charged herbicide (Figure 1). Like glyphosate, the charge on the herbicide will change with the solution pH. The pKa described is for the second pKa for each herbicide. While it is possible to reduce the overall charge on glyphosate by reducing the pH of the spray solution, the spray solution for glufosinate will have to be below pH 2.9 to achieve this.

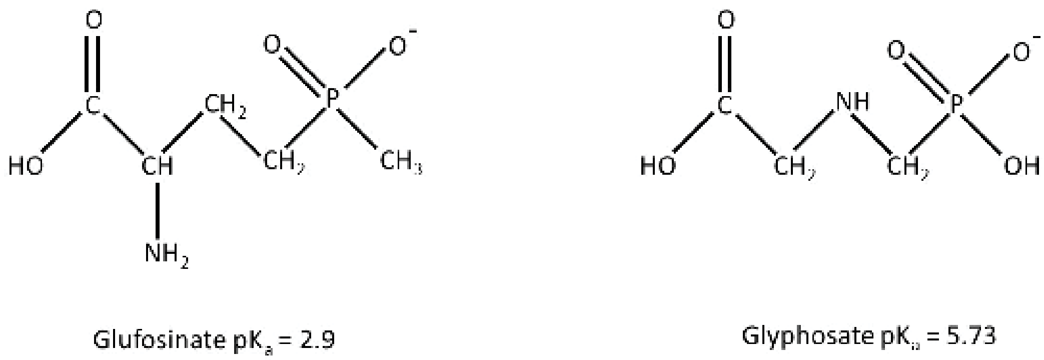

Figure 1. Chemistry of glufosinate compared to glyphosate.

Charged and polar herbicides are unable to pass through the wax layer of the cuticle. Instead, they enter the leaf through pectin strands within the cuticle. These pectin strands contain negative charges, making it harder for negatively charged herbicides to enter the leaf.

Absorption of glufosinate is important for efficacy

Absorption of glufosinate, like glyphosate, into leaves is relatively slow (Figure 2). Temperature makes a small difference to glufosinate absorption; however, humidity is a much more important factor. Light also increases absorption of glufosinate. Low humidity conditions reduce the amount of water associated with the pectin strands within the cuticle, making it harder for negatively charged herbicides like glufosinate to enter the leaf. Low humidity is normally not a problem in winter in southern Australia and high humidity only needs to be present for the first 24 hours after application for most of the herbicide to be absorbed.

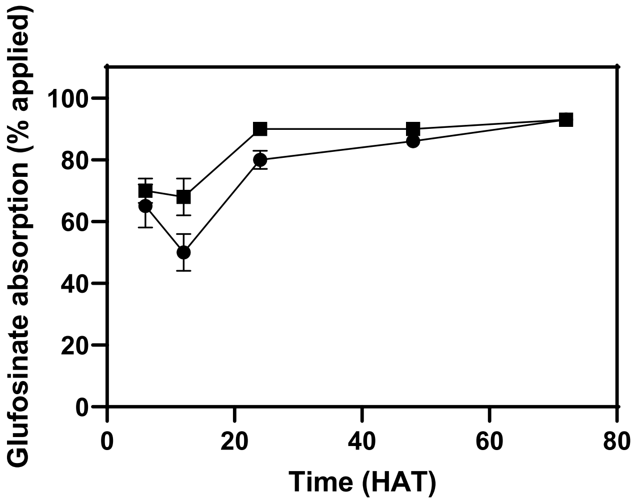

Figure 2. Absorption of glufosinate into wild radish plants grown under controlled conditions at two temperatures of 5/10°C (circles) or 20/25°C (squares). From Kumaratilake and Preston 2005.

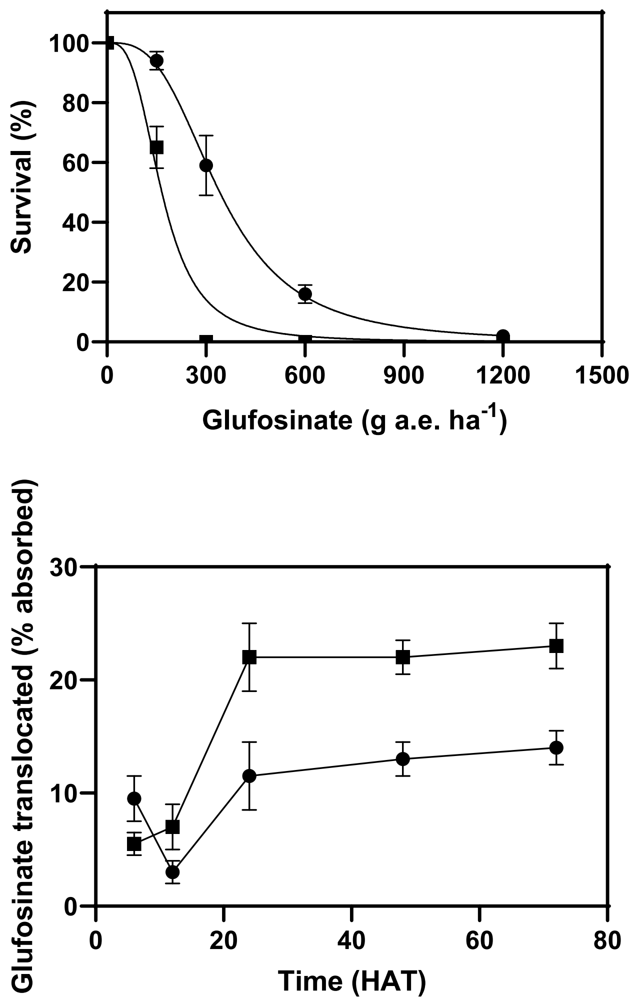

Figure 3. Left – survival of annual ryegrass (circles) and wild oats (squares) following treatment with glufosinate under controlled conditions. Right – translocation of glufosinate from the treated leaf to the rest of the plant in annual ryegrass (circles) and wild oats (squares). From Kumaratilake et al. 2002.

Translocation of glufosinate is the limiting factor for efficacy

Unlike glyphosate, which is rapidly translocated around plants after being absorbed, translocation of glufosinate is much slower. This makes translocation the main limiting factor for efficacy. Experiments on annual ryegrass and wild oats under controlled conditions show that glufosinate controls wild oats more easily than annual ryegrass (Figure 3). The reason for this difference in control is because glufosinate translocation from the treated leaf is much lower for annual ryegrass than for wild oats.

The amount of translocation of glufosinate is much lower than is typically seen with glyphosate, so any factor that will reduce translocation of glufosinate is likely to lead to greater survival. One of those factors is temperature. Experiments with wild radish under controlled conditions show that wild radish can be controlled at warmer temperatures, but there is very poor control at cool temperatures, even with high rates of herbicide. The reason for the poor control at low temperatures is that almost no glufosinate is translocated from the treated leaf to the rest of the plant. At higher temperatures, significantly more glufosinate is translocated from 48 hours (Figure 4).

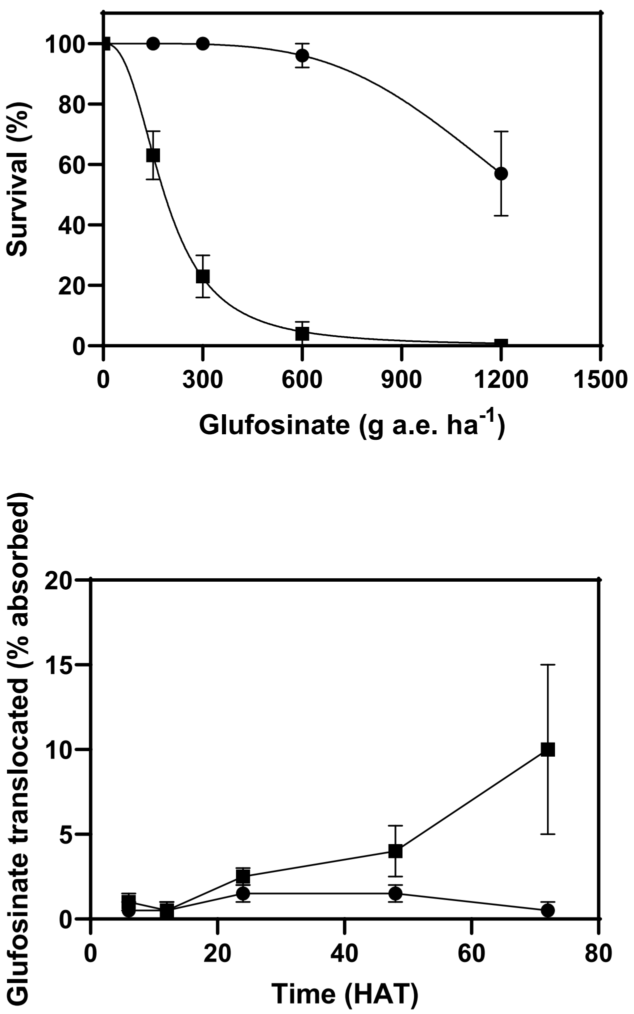

Figure 4. Left – survival of wild radish treated with glufosinate grown under controlled conditions at two temperatures of 5/10°C (circles) or 20/25°C (squares). Right – translocation of glufosinate from the treated leaf to the rest of the plant in wild radish at two temperatures of 5/10°C (circles) or 20/25°C (squares). From Kumaratilake and Preston 2005.

Mode of action of glufosinate

Glufosinate is an inhibitor of glutamine synthetase and exerts its herbicidal effect through inhibiting the recycling of carbon intermediates required for carbon fixation. This results in reactive oxygen species (ROS) generated out of the photosynthetic electron transport chain that produce the characteristic bleaching and wilting symptoms.

The rapid development of symptoms is unlike glyphosate, which has slow development of symptoms. This means that the action of glufosinate can reduce translocation of the herbicide by trapping the herbicide in damaged tissue.

This does happen as translocation to other leaves is greater when the treated leaves are covered, than when they are exposed to light (Figure 5). While rapid action of glufosinate does reduce glufosinate translocation, it is not the reason for the lack of substantial systemic effect of glufosinate. The low amounts of herbicide translocation in many plant species is the limitation for glufosinate activity.

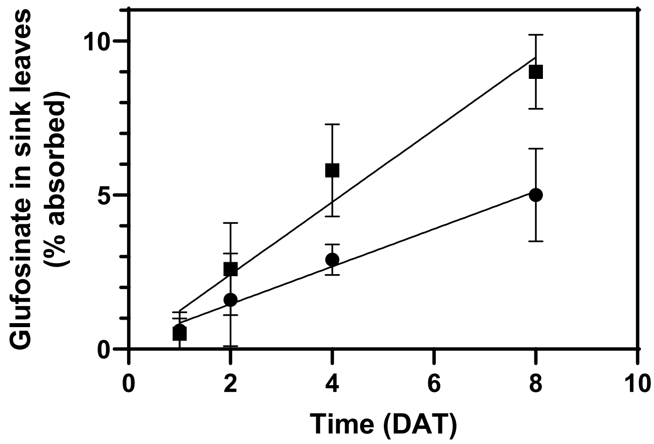

Figure 5. Translocation of glufosinate to source leaves in palmer amaranth when the source leaves were covered with foil (squares) or left uncovered (circles). From Takano et al. 2020.

Obtaining better control with glufosinate

As translocation is the limiting factor in glufosinate control of weeds, the main strategies should be to minimise the factors that reduce translocation of the herbicide. The main factor is temperature in the days after application. Therefore, applying glufosinate when there is warmer weather predicted should improve control over conditions when there are cooler temperatures, particularly at night. Like many herbicides, avoiding frosty conditions will improve control.

The other way to increase the amount of glufosinate translocated is to increase the amount of herbicide absorbed. Using the highest rate available, rather than a lower rate will provide increased control by increasing the amount of glufosinate absorbed. Applications in the morning, when humidity is often higher, rather than in the afternoon should increase absorption and hence, the amount of glufosinate translocated. Obtaining good coverage and application to small weeds, particularly for hard-to-control weeds, such as annual ryegrass and wild radish, will improve control.

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Notes

Fungicide resistant wheat powdery mildew – mildewcide success at Malinong

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GRDC project code: TRE2204-001RTX

Keywords

- disease management, fungicide resistance, wheat powdery mildew.

Take home messages

- Fungicide resistance surveys indicate increasing levels of QoI fungicide resistance and saturation of the mutation associated with DMI fungicide reduced sensitivity.
- DMI and QoI fungicides failed to reduce wheat powdery mildew at Malinong in 2023.
- Mildewcide products reduced wheat powdery mildew to manageable levels at Malinong.
- The application of group 11 QoI fungicides increased the frequency of resistance mutation G143A at the QoI target at three trial sites where resistance was present at low levels prior to fungicide application.
- APVMA permits have been issued for the use of Legend® (quinoxyfen) (PER93197), Vivando® (metrafenone) (PER93198) and Talendo® (proquinazid) (PER93216) for the control of wheat powdery mildew. These products have provided high levels of powdery mildew control in wheat trials from 2020–2023, when applied prior to development of severe infection.

Background

Similar to 2022, wheat powdery mildew (WPM) was widespread across south-eastern Australia in the 2023 season. It was easily identified in most wheat growing regions, expanding its area of incidence compared with historical occurrence. There are a range of interacting factors that have caused this, including the predominance of SVS varieties grown in most regions over a long period of time, conducive environmental conditions for developing large crop canopies and for disease development, and inoculum source carrying over from previous seasons.

Difficulty achieving high levels of disease control with what were considered robust and well-timed fungicides is continuing to be reported in many regions. Fungicide resistance testing, funded by SAGIT project TC120 and GRDC project TRE2204-001RTX, has revealed resistance to group 11 (QoI) and reduced sensitivity to group 3 (DMI) fungicides as an important factor in these control failures. GRDC project TRE2204-001RTX continues to quantify the extent and speed of resistance development across the regions and identify management strategies for WPM, given resistance development.

Method

Fungicide resistance paddock survey

A field survey to determine frequencies of the mutations G143A at CytB (QoI fungicide resistance) and Y136F at Cyp51 (DMI reduced sensitivity) was undertaken in 2022. This included 145 paddocks sampled across SA and Vic, including the Eyre Peninsula, SA Mallee and Upper SE of SA. An additional 51 paddocks, predominantly from the Yorke Peninsula, were sampled in 2023. However, results from these resistance tests were not available at the time of publication. The 2022 and 2023 samples add to the database of 73 paddocks sampled from the Yorke Peninsula and Mid North SA in 2021 and NE Vic and southern NSW in 2020.

Field trials

Small plot trials were established at three locations in 2023, at Wards Hill and Malinong, SA and Katamatite, Vic. These trials investigated post-emergent fungicide efficacy, pre-emergent fungicide efficacy, fungicide timing and varietal resistance interactions. A moderate to high level WPM infection occurred at Malinong (fungicide efficacy and variety resistance trials) in 2023 and this paper primarily focuses on these results. Very low levels of WPM infection occurred at the Wards Hill and Katamatite sites in 2023.

Fungicide efficacy trials

The fungicide efficacy trial at Malinong was sown to Scepter⍉ wheat on 9 May 2023. The fungicide treatments shown in Table 1 were applied at GS32 (2nd node) on 17 July 2023 and GS41 (flag leaf sheath extending) on 21 August 2023. Product rates were selected based on maximum label rate, unless specified otherwise. Wheat powdery mildew was scored as pustule counts on 21 August and 20 September 2023. Twelve middle tillers were selected from each plot and pustules were counted on the stem, flag-3 and flag-2 on 21 August and flag and flag-1 on 20 September. Statistical analysis was conducted using the transformation 1-1/sqrt(pustule count + 1) using mixed linear models in R. Where large pustules occurred or merged, a count of 1 was given for each $2mm^2$ of pustule area. Septoria assessments were conducted by estimating the leaf area infected on the flag and flag-1 of the same tillers as for the WPM assessment. Plant samples were collected from selected treatments to determine changes in frequencies of the G143A at CytB and Y136F at Cyp51 mutations in response to fungicide application.

Variety trial

The variety trial at Malinong was sown on 9 May 2023 and compared six wheat varieties: Valiant⍉ (VS), Scepter⍉ (SVS), Mace⍉ (MSS), Grenade CL Plus⍉ (MS), Calibre⍉ (S) and Brumby⍉ (R). Three fungicide strategies were applied to Valiant⍉, Scepter⍉, Mace⍉ and Grenade CL Plus⍉. Fungicide strategy 1 was only applied to Calibre⍉ and Brumby⍉. Depending on the strategy the fungicide treatments were applied on the following dates: GS32 on 17 July, GS41 on 21 August and GS55 on 20 September 2023.

- Strategy 1 = Epoxiconazole 125[h] @ 500mL/ha GS32
- Strategy 2 = Epoxiconazole 125[h] @ 500mL/ha GS32 *fb* Maxentis® @ 600mL/ha GS41
- Strategy 3 = Epoxiconazole 125[h] @ 500mL/ha GS32 + Vivando[k] @ 300mL/ha *fb* Maxentis @ 600 mL/ha + Vivando @ 300mL/ha GS41 *fb* mildewcide at GS55

[h]Epoxiconazole 125 label rate for powdery mildew is 250mL/ha, 500mL/ha is maximum label rate for wheat for control of leaf rust, stripe rust and Septoria nodorum blotch. It has been applied standalone in this trial for research and demonstration purposes.

[k]Vivando applied under APVMA permit PER93198. This permit states to apply at or before BBCH31 and reapply 21–28 days after the first application and no later than BBCH61.

Wheat powdery mildew and Septoria assessments were conducted as outlined in the fungicide efficacy trial above.

Both trials were harvested for grain yield on 21 December.

Results and discussion

Wheat powdery mildew fungicide resistance survey

The mutation frequency for Y136F at Cyp51 is a gateway mutation that indicates reduced sensitivity to group 3 fungicides. It does not infer that the DMI fungicides will be ineffective, but the pathogen may be less sensitive. From the paddock survey of 145 samples collected in 2022 from the Eyre Peninsula, SA Mallee, Upper Southeast and Victoria, the incidence of this mutation averaged 98.6% (data not shown). This shows the Y136F mutation is near saturation within the WPM population. The survey results also revealed there is little geographical trend in the Y136F mutation frequency. For example, the minimum mutation frequency value of 57% was sampled at a site near Nundroo. However, a paddock approximately 14km away had a value of 98%.

Mutation frequency for G143A at CytB confers resistance to group 11 QoI fungicides such as azoxystrobin. For the samples collected in 2022, there was a geographical trend for the mutation to increase in frequency from the west to the east (Figure 1). The highest values were sampled in higher rainfall areas in Victoria (mean 64%, range 23–100%), which also corresponds with where detections of the G143A mutation were first discovered in Australia in 2016. Surprisingly, the mutation was detected at moderate frequencies in the SA Mallee (mean 18%, range 0–43%), where use of strobilurin fungicides has historically been low, which suggests that the resistance has not developed locally in the Mallee but moved there over time from an area with the resistance mutation. The Upper SE also had moderate to high mutation frequencies (mean 26%, range 0–71%). Mutation frequency was lower on the EP (mean 3.4%, range 0–50%), indicating that the strobilurins may still provide useful activity in many paddocks in that region. However, the mutation is still present in 6% of paddocks sampled on the EP at moderate levels. This will increase with strobilurin use. Despite the overall trend of declining resistance mutation from east to west, higher levels of resistance were detected in the northern YP region in 2021 (mean 33%, range 2–90%). This may be due to the high levels of WPM present on the northern YP over the last 5-10 years resulting in greater selection for the resistant mutation.

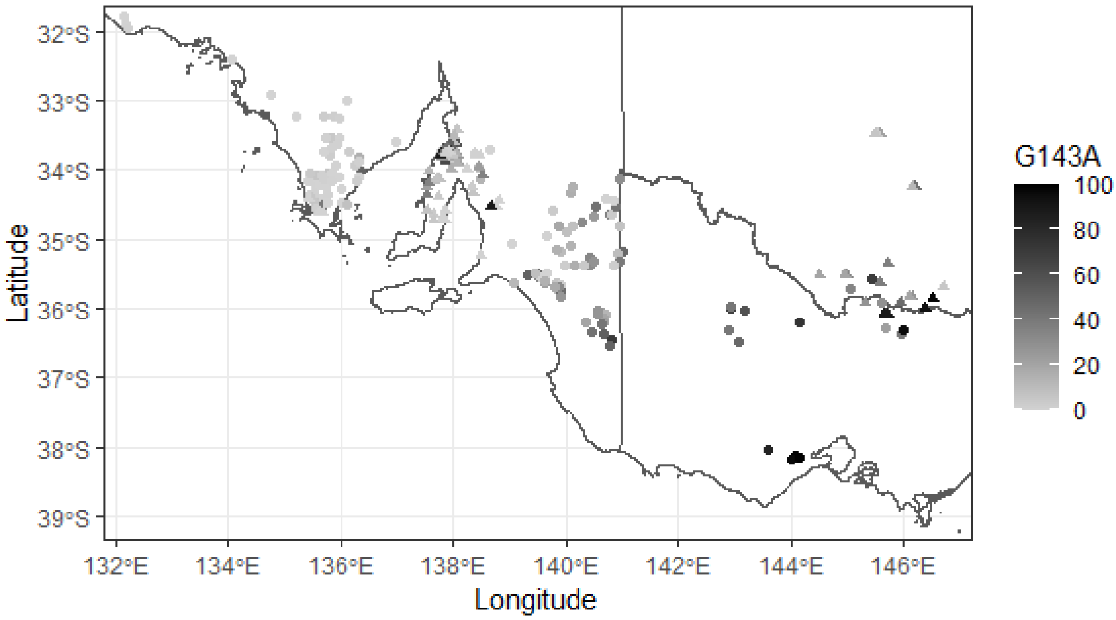

Figure 1. Frequency of wheat powdery mildew G143A mutation at CytB for survey paddocks sampled 2022 (circles) and 2021 (triangles).

Field trials – wheat powdery mildew fungicide resistance and post-emergent fungicide performance

Mutation frequency for Y136F at Cyp51 was high at all survey locations in 2022 averaging 99% (data not presented). Data presented in Table 1 shows the application of any standalone DMI fungicide did not reduce WPM infection compared to the control. However, it is important to note that tebuconazole and Proviso® (prothioconazole) are not registered for control of WPM when applied alone. When the three DMI fungicides tebuconazole, prothioconazole and Opus® (epoxiconazole) were combined, a 60% reduction in WPM was achieved at the early assessment. However, control is below expectation for such a robust treatment.

Septoria tritici blotch impacted the trial site, with some treatments providing better control than others. Within the standalone DMI treatments, greater levels of Septoria control were generally related to higher WPM pustule counts and this needs to be considered when interpreting results.

The group 11 QoI fungicides did not reduce WPM infection compared to the control (Table 1). Azoxystrobin applied alone is not registered in wheat but has been included in this trial as a demonstration and provided no control of WPM. Where azoxystrobin was applied in combination with a DMI active (Amistar® Xtra, Tazer® Xpert and Maxentis®), no additional control of WPM was achieved compared to where the DMI mix partner was applied alone. The fungicide Opera® contains the QoI fungicide pyraclostrobin (plus the DMI epoxiconazole) and similar to the dual active products containing azoxystrobin, this product provided no control of WPM at Malinong in 2023.

The group 7 SDHI fungicides are the only other registered fungicide group for WPM control in wheat. In this trial, Aviator® Xpro® was applied at maximum label rate. As observed in previous trials, the SDHI component in Aviator Xpro, bixafen, provided no additional control compared to the DMI mix partner prothioconazole (Trengove et al. 2022).

Table 1: Wheat powdery mildew (pustule number), Septoria tritici blotch (% Flag-1 % infection) and grain yield of Scepter[(]) wheat in the fungicide efficacy trial at Malinong, SA, 2023. WPM data has been transformed for analysis, fungicide treatments sharing the same letter within a column are statistically similar.

Product	Rate (mL/ha)	Total WPM pustules	1-(1/sqrt(1 + pustule count)	Total WPM pustules	1-(1/sqrt(1 + pustule count)	Septoria % F-1	Grain yield (t/ha)
		21 August 2023 (Stem + flag-3 + flag-2)		20 September 2023 (flag + flag-1)			
Nil		10.9	0.71 a	3.7	0.53 de	63 a	5.1 c
[g]Tebuconazole 430	290	9.4	0.69 a	1.9	0.39 bcd	64 a	5.2 bc
[h]Opus®	500	10.1	0.7 a	10.4	0.68 e	28 cd	6.0 a
[f]Proviso®	250	13.8	0.74 a	5.4	0.52 de	19 defg	5.9 ab
Prosaro®	300	6.3	0.63 ab	3.9	0.5 de	50 b	5.6 abc
[g]Tebuconazole 430 + [h]Opus+ [f]Proviso®	290 + 500 + 250	4.4	0.57 abc	0.9	0.25 abc	16 efgh	6.3 a
[c]Azoxystrobin 625	256	10.1	0.7 a	8.5	0.62 de	31 c	5.8 abc
Amistar Xtra	800	4.9	0.59 abc	4.7	0.46 cde	16 efgh	5.8 ab
Tazer Xpert	2000	24.0	0.8 a	6.1	0.6 de	9 ghi	6.1 a
Maxentis	600	8.2	0.67 a	3.7	0.49 cde	8 hi	5.9 ab
[m]Opera	1000	7.7	0.66 a	12.1	0.68 e	12 fghi	6.1 a
Aviator Xpro	500	13.8	0.74 a	6.9	0.63 de	5 i	5.8 abc
[j]Talendo + [h]Opus	250 + 500	1.2	0.33 cd	0.1	0.05 a	20 def	5.8 abc
[l]Legend + [h]Opus + Uptake®	250 + 500 + 0.5%	1.7	0.39 bcd	0.2	0.09 a	20 def	5.6 abc
Pr (>F)			<0.001		<0.001	<0.001	<0.001

[c]Azoxystrobin (Mirador® 625) is registered in wheat only when mixed with a DMI mix partner. It has been applied standalone in this trial for research and demonstration purposes.

[g]Tebuconazole applied alone is not registered for the control of wheat powdery mildew. It has been applied standalone in this trial for research and demonstration purposes.

[h]Opus (Epoxiconazole 125) label rate for powdery mildew is 250mL/ha, 500mL/ha is maximum label rate for wheat for control of leaf rust, stripe rust and Septoria nodorum blotch. It has been applied standalone in this trial for research and demonstration purposes.

[f]Proviso (prothioconazole) is not registered in wheat when applied stand alone. It has been applied standalone in this trial for research and demonstration purposes.

[j]Talendo applied under APVMA permit PER93216.

[l]Legend applied under APVMA permit PER93197.

[m]Opera label rate for powdery mildew is 500mL/ha, 1000mL/ha is maximum label rate for wheat for control of leaf rust. It has been applied standalone in this trial for research and demonstration purposes.

As a result of the dry spring, WPM infection reduced significantly after the last assessment and grain yield results were mostly unaffected by the presence of WPM (Figure 2). Grain yields ranged from 5.1–6.3t/ha, with Septoria being the largest contributor to grain yield loss. This highlights the importance of managing all diseases present and is the reason mildewcide products should always be applied with a robust fungicide package to target other diseases.

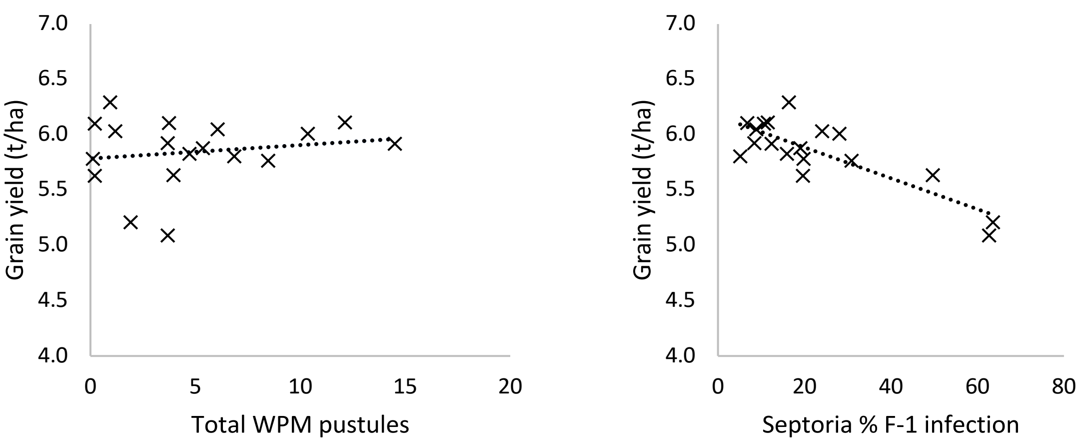

Figure 2. The impact of WPM (left, $y = 0.0122x + 5.7841$, $R^2 = 0.0282$) and Septoria tritici blotch (right, $y = -0.014x + 6.165$, $R^2 = 0.6775$) on grain yield. Diseases were assessed on 20 September at Malinong SA in 2023.

Response to single season selection pressure in group 11 resistance

Mutation frequency for G143A at CytB ranged from 1.2% to 24% in the control across four trial sites in 2022 (Table 2). The results also show treatments containing the group 11 fungicide azoxystrobin generally increased this frequency across the sites. This is expected, where the continual use of group 11 QoI fungicides maintains selection pressure on the population. This finding is also consistent with previous results from Bute in 2021, where treatments including azoxystrobin increased mutation frequency from 19% to 49% (Trengove et al. 2022).

Table 2: Frequency of G143A mutation at CytB (conferring resistance to group 11 QoI fungicides) in four fungicide trials, 2022. Letters denote treatments that are significantly different with the same column.

Treatment (group)	Bute		Katamatite		Malinong	Port Neill	
Nil	1.2	c	24	C	4.2	2.0	b
Epoxiconazole (3)	4.9	b	38	bc	6.8	2.2	b
Azoxystrobin[c] (11)	9.2	a	45	bc	10.6	4.1	a
Tazer Xpert (3 + 11)	5.8	ab	70	ab	12.3	1.6	b
Tebuconazole[g] (3)			53	ab			
Veritas® (3 + 11)			79	a			
Prothioconazole[f] (3)	2.4	bc					
Maxentis (3 + 11)	5.3	b					
Aviator Xpro (3 + 7)	3.1	bc					
Pr (>F)	0.002		0.022		0.107	0.011	

[c]Azoxystrobin (Mirador® 625) is registered in wheat only when mixed with a DMI mix partner. It has been applied standalone in these trials for research and demonstration purposes.

[g]Tebuconazole applied alone is not registered for the control of wheat powdery mildew. It has been applied standalone in these trials for research and demonstration purposes.

Samples collected from selected treatments in 2023 are being analysed and are expected to show a similar increase to the other sites where group 11 fungicides have been applied.

Mildewcides - permits and summary of trial performance

The APVMA has issued permits for three fungicides for the control of powdery mildew in wheat. Legend and other registered products with 250g/L quinoxyfen (group 13, PER93197), Talendo (group 13, PER93216) and Vivando® (group U8, PER93198) are currently able to be used for WPM control until 31 July 2024. These products represent two fungicide modes of action not previously registered for use in wheat in Australia.

Critical use comments that are common to all three of these permits include:

- Apply as a protectant only
- Do not apply more than 2 applications per crop
- Apply in accordance with the current CropLife Fungicide Resistance Management Strategy.

Critical use comments specific to each permitted fungicide are detailed in Table 3.

Table 3: Critical comments for permitted products Legend (PER93197), Talendo (PER93216) and Vivando (PER93198) for control of powdery mildew in wheat.

Product	Legend (quinoxyfen)	Talendo (proquinazid)	Vivando (metrafenone)
Use rate (mL/ha)	200–300	250	300
Timing	Not after BBCH39	BBCH25–BBCH49	Not after BBCH61
Water rate (L/ha)	50–100	100–200	200
Application interval (days)	21	14	21
Grazing withholding	4 weeks	4 weeks	4 weeks
Harvest withholding	Not required	Not required	35 days

The products Legend and Talendo were included in the product efficacy trial at Malinong in 2023 and provided high levels of WPM control where other products failed. Vivando was included in the variety trial at Malinong and provided excellent control in SVS or better varieties. These results are consistent with previous trials where these products were applied prior to WPM establishing in the canopy. Performance of the permitted products varied across six trials, with timing of application relative to disease build up considered a very important factor in performance (Table 4).

Mildewcide permit product performance was lower when the WPM was established prior to fungicide application. This occurred at Bute in 2020 and at Malinong in 2022 (Table 4). Wheat powdery mildew was first detected at GS14 at Bute in 2020 and was already at moderate levels before fungicide application at GS32. Moderate control was achieved in this instance. Similarly, at Malinong in 2022, WPM infection was well established in the trial prior to fungicide application at GS39, in this case no effective control was achieved with these products.

The mildewcide products performed well at Bute in 2021 and 2022, all but eliminating the WPM infection (Table 4). This is similar to the control achieved at Malinong in 2023. In these four trials, the WPM infection did not develop until after the first fungicide application. This highlights the importance of using these permitted mildewcide products as protectants only.

Table 4: Performance of permitted products against WPM in trials at Bute and Malinong on wheat varieties rated SVS, letters denote significant differences within a column.

Treatment	Bute 2020	Malinong 2022	Bute 2021	Bute 2022	Malinong 2023	Malinong Var 2023
	Total pustules stem, F-2, F-3 (GS45)	Total pustules F-1 (GS65)	Total pustules F-1 (GS65)	Total pustules F-1,2,3 (GS55)	Total pustules stem, F-2, F-3 (GS41)	Total pustules stem, F-2, F-3 (GS41)
Nil	28.7 a	13.4 a	4.1 a	16.4 a	10.9 a	9.2 a
Tebuconazole	8.4 b	13.5 a	1.6 ab	8.9 b	9.7 a	
Legend	10.1 b	14.9 a	0.1 c	0.1 c	1.7 b	
Talendo	9.0 b			0.7 c	1.2 b	
Vivando	8.4 b					1.8 b
Pr (>F)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Varietal resistance to wheat powdery mildew

A number of wheat varieties performed similarly at Malinong, despite their variation in WPM resistance ranking. This is in contrast to previous seasons where WPM infection has generally followed the resistance ratings closely, with MS performing better than MSS which performed better than SVS (Trengove et al. 2021, Trengove et al. 2022, Trengove et al. 2023). At Malinong in 2023, the VS variety Valiant$^{\phi}$ had the highest WPM infection. Both Mace$^{\phi}$ (MSS) and Grenade CL Plus$^{\phi}$ (MS) did not perform any better than the SVS variety Scepter$^{\phi}$ (Figure 3). Anecdotal reports from growers and consultants in the area also observed this in paddocks. There has potentially been some breakdown of resistance or local pathotypes that are more virulent on those varieties. However, more research in the area is required to understand this further.

The newer variety Calibre$^{\phi}$, rated S, has consistently performed better than the rating suggests. In all previous trials at Bute, it has performed similarly to Mace$^{\phi}$ or Grenade CL Plus$^{\phi}$. In this season, it has outperformed those two varieties significantly, with minimal WPM infection following a single application of epoxiconazole, which failed to control WPM in the adjacent product efficacy trial. The levels of WPM infection on Calibre$^{\phi}$ over the last three seasons indicate that the S rating is not appropriate for this variety.

Brumby$^{\phi}$ was released with an R rating and, prior to 2023, was generally performing at that level. The rating in the 2024 South Australian crop sowing guide has been revised to R/S, to indicate an S rating to a rarer strain of WPM which is likely present at the Malinong site. In the 2023 Malinong trial, Brumby$^{\phi}$ performed similarly to Calibre$^{\phi}$ and there were several reports of WPM infection in Brumby$^{\phi}$ at low levels around the area and on the Yorke Peninsula.

The variety Valiant$^{\phi}$, rated VS, had the highest level of WPM infection under all three fungicide strategies. This includes Strategy 3 which received two applications (prior to WPM assessment) of the mildewcide Vivando and was only able to reduce the pustule number to the level observed in Strategy 1 and 2 for Scepter$^{\phi}$, Mace$^{\phi}$ and Grenade CL Plus$^{\phi}$. Vivando was able to provide high levels of WPM control in Scepter$^{\phi}$, Mace$^{\phi}$ and Grenade CL Plus$^{A\phi}$ (Figure 3). These results highlight the pressure VS varieties are putting on fungicides and fungicide resistance development. Varieties rated VS should be avoided in areas where WPM is a concern.

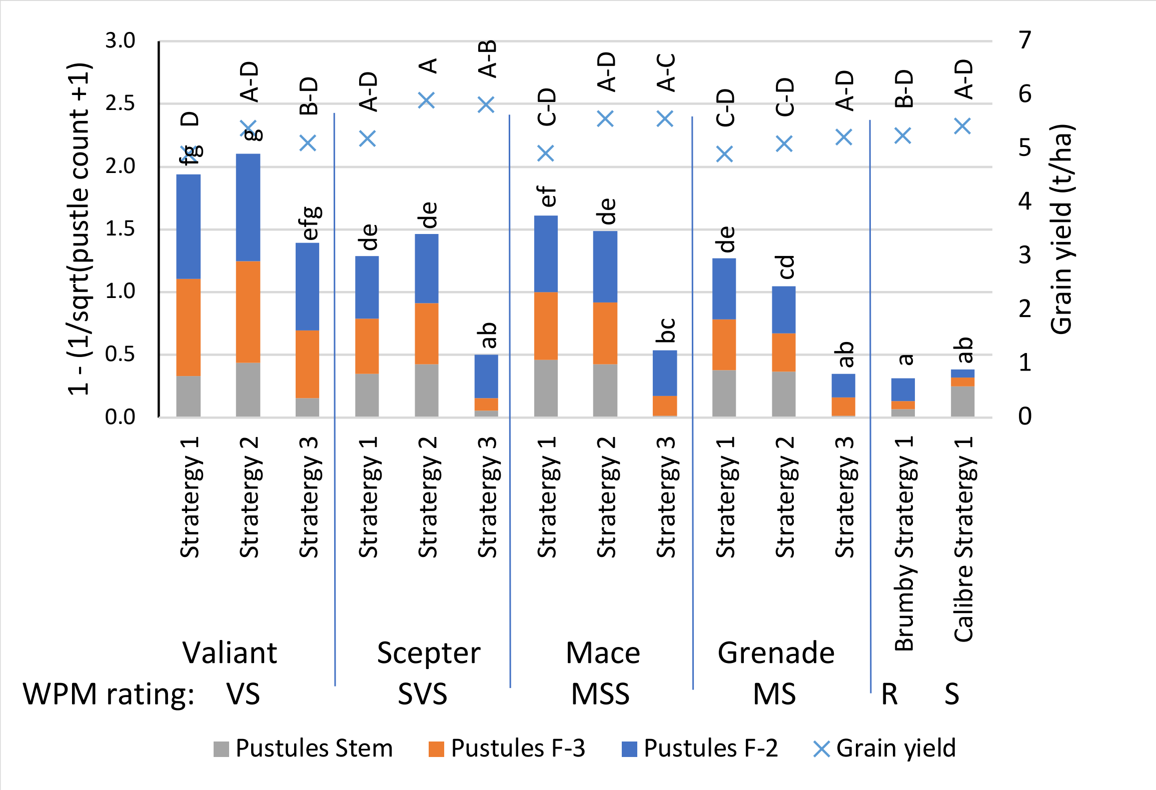

Figure 3. Wheat powdery mildew infection (21 August 2023) and grain yield for Malinong variety × fungicide trial, lower- and upper-case letters denote significant differences P<0.005 for WPM infection and grain yield respectively. Fungicide strategies are described in the methodology.

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. PER93197, PER93216 and PER93198 are a result of SAGIT and GRDC investments, field studies and regulatory, and the support of Grain Producers Australia (GPA) as the permit holder. The research input during this project from Nick Poole, Ben Morris and Tara Garrard is gratefully acknowledged.

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Notes

GRDC

GRAINS RESEARCH & DEVELOPMENT CORPORATION

Final session
Day 1

Fast Graphs for slow thinking– an example using nitrogen

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[1]SARDI Climate Applications; [2]Mudge Consulting.

GRDC project code: CSP2303-015BGX, RiskWi$e

Keywords

- climate, nitrogen, risk.

Take home messages

- N budgeting using 40kg N/t of wheat is simple, widely used, and robust. However, the rule is usually applied to a single target yield and only considers the year of application. The single target yield makes it hard to think clearly about risk and the annualised focus ignores carryover and /or long-term rundown of N.
- When choosing a single target yield, a grower has one chance in 10 of selecting the right rainfall decile. Concern about applying too much N contributes to conservative rates which have been identified as an important cause of the gap in actual and potential yield and profit.
- The N theme in RiskWi$e is working with farming systems groups in a co-learning exercise to better understand the risk-reward relationship of different approaches to N fertiliser decisions over the 5-year project. Some groups are examining a long-term strategic approach using N Bank that considers the N requirement of the farming system in the context of its soil and climate. This has the attraction of a simpler set and forget approach to N management rather than tactically responding to the economics and climate of a single season.
- For growers and advisers who do want to consider a seasonally responsive approach to N management, we have developed the Fast Graphs for Slow Thinking spreadsheet (Figure 2), which uses the 40kg N/t wheat rule to consider the upside and downside by budgeting across all 10 deciles. We also encourage users to vary the rate of N carryover and see how this changes the risk and reward outcome.
- Seasonal climate forecasts are best understood as increasing the likelihood of some deciles and decreasing the likelihood of other deciles. This contrasts with the media headlines of 'El Niño outlook for a dry spring' and the quest for a forecast of a single decile. The Fast Graphs for Slow Thinking spreadsheet has been designed to examine the shift in probabilities.

Introduction

Annie Duke was a professional poker player who then pursued an academic career in decision making. She famously said, "How life turns out is determined by luck and the quality of our decisions". Notably we can only control the quality of our decisions and this paper provides an example of a decision-making process used to improve the quality of decision making where both chance and skill are involved. To illustrate this example the authors have used the decision of nitrogen application.

Overview of Riskwi$e and N theme

RiskWi$e (RiskWi$e - GRDC) runs from 2023 to 2028 and seeks to understand and improve the risk-reward outcomes for Australian grain growers by supporting grower on-farm decision-making. RiskWi$e was a response to grain growers drawing attention to the increase in risk associated with grain production. RiskWi$e is working through Action Research Groups (ARGs). In South Australia, grain growers from Eyre Peninsula are involved via the AIR EP ARG. The Central ARG is led by Hart Field Day Site and includes the Mid North High Rainfall Zone (MNHRZ); Murray Plains Farmers (MPF);

Northern Sustainable Soils (NSS); and Upper North Farming Systems (UNFS). The Mallee and South-East are covered by the ARG led by the Birchip Cropping Group and include Mallee Sustainable Farming (MSF) and the Coomandook Ag Bureau.

Groups are addressing a range of themes including sowing decisions, enterprise agronomic and financial decisions and managing the resource capital. Nitrogen decision is a common theme for all groups. The N theme of RiskWi$e is one of several GRDC investments in N because getting decisions about N management more right, more often will improve grain grower enduring profitability. Evidence from the GRDC paddock survey project, along with analysis of protein levels in wheat and barley receivals, indicate that N deficiency is an important contributor to the yield gap for Australian grains. While it is rarely economic to chase maximum yield, there is good reason to suspect that N deficiency is causing a profit gap as well as a yield gap. In RiskWi$e, the N decisions theme is working with the ARGs to take a whole-of-system approach to assess N decision strategies encompassing fertiliser and legume use. Part of the approach is to '**challenge the annualised thinking associated with N applications and budgeting that arguably amplify perceived risk**'. This paper complements a paper in these proceedings by James Hunt, (leader of N theme in RiskWi$e) who has written a clear summary of the basics of N budgeting.

The simple rule of 40kg N per tonne of wheat is useful 'bucket chemistry' which highlights the substantial upside of N in a good season. N budgeting involves estimating the demand of N from the crop (20kg plant N per tonne), the supply of N from the soil (50% efficiency in our example) to provide a total soil N supply required (40 kg soil N per tonne) and balancing any shortfall in soil N with added fertiliser N. Later in this paper, we will raise some problems with the ways that N budgeting has been applied. However, there is a lot to like about this simple rule. Using common units of kg N/ha for crop N demand and supply of N from soil and fertiliser makes budgeting possible. Prior to N budgeting, growers were confronted with a soil test of nitrate in parts per million, kg of fertiliser product and yield in t/acre or bags per acre. The simple maths of a budget is empowering. For example, if someone reports a 4-tonne crop (soil mineral N needed is 4t/ha x 40 kg soil N/t = 160 kg N/ha) coming from 50kg starting soil N and 50kg/N as fertiliser, agronomists and growers immediately question the source of the extra 60kg N/ha. The robust simplification of these biological based maths also provides for a simple economic assessment. When there is enough water for an extra tonne of wheat, 40kg of N is an excellent investment. If we assume a urea price of $700/t, one kg N is about $1.50 (700 *.46) and 40 kg N is $60. If we also assume $10/ha as application cost, then $70 N cost is a good investment for a tonne of wheat.

Estimating the supply of N can be challenging

Estimating the supply of N usually relies on deep N soil testing, although many agronomists use estimates based on paddock history. In the future, it is likely that protein monitors will be used with yield maps to provide a map of N removed from different parts of the paddock. The protein content of the grain, especially in a good season, is very informative with protein content below 11.5% often indicating N supply limited yield (G. McDonald, review published in Unkovich et al., 2020). In broad zonal terms, high yield high protein (>12.5%) is likely to have received more N than the crop required, low yield low protein (<11.5%) and high yield low protein (<11.5%) did not receive enough N to maximise yield, while an area with low yield high protein (>12.5%) maybe constrained by factors other than N. The N removal maps, sometimes referred to as N off-take maps can be loaded into spreaders to ensure N replacement accounts for the variability in N removal and sub-paddock yields can be improved.

Estimating N mineralisation can be challenging and is discussed in more detail by Hunt et al in these proceedings. One approach for paddocks with a long cropping history is to exclude in-crop mineralisation from the N budget because an over-reliance on in-crop mineralisation will rundown soil organic carbon. In addition, N mineralisation and N immobilisation often approximate each other (cancel out) in paddocks with a long cropping history. Other N budgeting approaches include Yield Prophet®, which will include mineralisation and immobilisation in the N limited yield or the rule of 0.15kg N/ha per mm of growing season rainfall (GSR). The exact number for the supply of N will be uncertain, especially with spatially variable soils.

Estimating the crop demand for N is difficult because of the uncertain finish to the season

Estimating the target yield of an irrigated crop is relatively easy. Picking a target yield for dryland grain crops is difficult. The water limited yield in medium rainfall zones ranges from less than 1t/ha in a poor season to close to over 8t/ha in a good season with a corresponding N requirement of 40 to 200 kg N/ha. In the low rainfall zone, these numbers might be adjusted to 0.5t/ha to 5t/ha, and in high rainfall, 4t/ha to over 12t/ha.

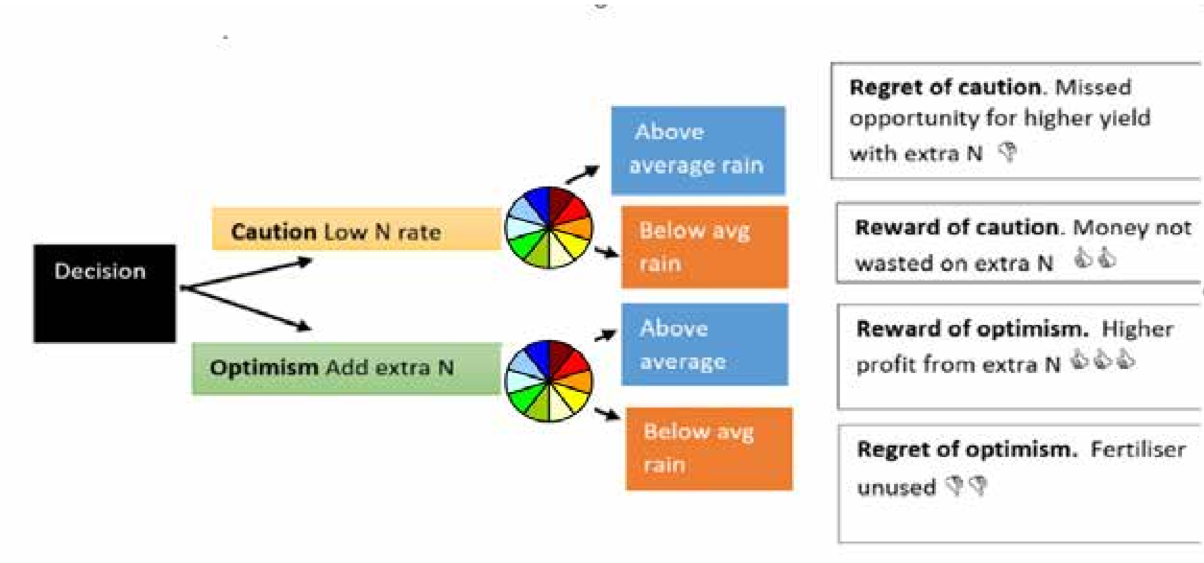


Figure 1. A simple N decision tree that considers an in season tactical decision to add extra N. In this example above and below average rainfall have equal probabilities of occurring but the rewards and regrets of optimism are greater than the rewards and regrets of caution.

When using a rainfall decile to estimate the target yield, there is one chance in 10 of being right. A grower can aim for decile 3 and receive a reward of caution for the lower N rate in a dry finish, but a regret of caution when missing out on the potential returns in an above average finish. Alternatively, a grower can be optimistic and pick decile 7 and enjoy the reward of optimism if the season turns out to be wetter than average but face a regret of optimism in a dry finish. Most of us are loss averse: we care more about losing money than gaining money. Some growers and advisers point to the time dimension, where the up-front cost (risk) of N is immediate and certain, whereas the gains (rewards) from N are uncertain and lie in the future. The longer-term costs of under fertilising and running down soil N and soil carbon are even more diffuse and lie further into the future.

Looking beyond the horizon of the year of application with N Bank

N budgeting is usually treated as a problem to be solved within the year of application. If 40kg N/ha are added with the hope of an extra 1t/ha and the season turns out drier and only 20kg/ha was needed for 0.5t/ha, cost of the unused 20kg of N is written off as a loss. This ignores the experimental evidence showing a portion of unused nitrogen is usually available for the next crop. A review of long-term experiments that used labelled 15N shows 66% of applied fertiliser N is recovered over a 3-year period, with 44% on average in year one and 22% on average recovered in the follow years (Vonk et al 2022). Therefore, in any one year the soil provides the bulk of the crop N requirement, and this highlights the need to pay attention to the soil N reserve and soil organic matter.

The planning horizon of this tactical approach is within the year of application and is part of the ‘annualised thinking’ that arguably amplifies the risk. An emerging alternative is a more strategic approach to nitrogen decisions, and one such approach is to use N banking. A grower using the N bank approach still needs an estimate of pre-sowing soil N and must make operational decisions about the timing of topdressing to ideally coincide with rain but is spared the angst of worrying about trying to get N exactly right each year by dealing with the uncertainty of the finish to the season. This is a simple rule with a ‘set and forget’ approach) and estimates the target winter mineral N bank that is necessary for your soil and climate. In this approach, fertiliser N is used to top up the winter mineral N pool to the N banking target. (Hunt et al 2023.

A grower and adviser can choose to be completely strategic (e.g., fertilise the farming system) and ignore what is happening in any season, or they can be completely tactical (e.g., single crop and year focus) and fine tune with as much information as possible from soil probes, models and seasonal forecasts along with the price of wheat, cost of nitrogen, the farm cashflow and interest rates. If being completely tactical, it is important for enduring profitability to keep an eye on the long-term N balance, which is often negative in many cropping systems (Norton and Elaina vanderMark 2016). Different growers will find the strategic or tactical approach more appropriate for their business and personality. It is also possible to set a longer-term strategic horizon and respond tactically in some years.). The rest of this paper addresses a tactical approach. If a grower chooses to be tactical, rather than choosing a single target yield, it is not much extra work to consider a range of outcomes and weigh the choice against these outcomes.

Getting tactical decisions more right, more often with decision analysis

The process of decision analysis is an established approach from applied economics for dealing with decision making under uncertainty. Although grain growers might not use terms like reward and regret of optimism and caution, they understand the concepts through lived experience. One response is that the decision tree shown in Figure 1 does little more than describe the dilemma of the post-seeding N decision with no solution. If we don't know whether the rainfall will be above or below average, we don't know which branch to take.

Decision analysis is a formalised way of weighing different futures. The simple decision tree in Figure 1 uses thumbs up and thumbs down to rank the four outcomes, but with a few assumptions these can be converted to profit or loss as $/ha. If the chance of above or below average is taken as 50%, we can then compare the probability weighted average for both branches of the tree. An argument that a decision can only be made with perfect knowledge of the future ignores the numerous ways that decisions are made in so much of modern life, including aviation safety, health, internet searches and artificial intelligence.

Not all decisions that grain growers are making can be squeezed into a numerical decision analysis framework. Many decisions are routine and best practice, such as summer weed control to conserve soil water and mineral nitrogen. Other decisions may be regarded as minor and are not worth the time and effort (e.g., fungicide seed dressing in high rainfall cropping systems). Some decisions are too **complicated**, such as crop sequences for a paddock with hard-to-control weeds and their seed bank. These could be solved with extensive numerical analysis but might be better completed by using a checklist and conversation with an advisor who has had to tackle this problem previously. Then there are other decisions where extensive numerical analysis is unhelpful, such as succession planning. These are **complex** because the solution depends on other humans. N budgeting offers a simple approach for tactical, post-seeding N decisions. The main reasons the decision is difficult is because (i) the climate uncertainty elevates the crop response uncertainty, and (ii) the nitrogen price is often a high proportion of gross margins which amplifies the economic uncertainty. Although we don't know what the coming season will be, grain growers have access to:

1. a robust N budgeting rule (e.g., 1 t wheat requires 40 kg of soil mineral N/ha, while 1 t of canola requires 80 kg N/ha),
2. local historical rainfall records, which are the envy of many other parts of the world,
3. robust water-use conversion functions for wheat, barley and canola (see paper by James Hunt in these proceedings).
4. Widespread understanding of deciles as a concept of probability and risk,
5. seasonal forecasts that are far from perfect but much better than guessing and are presented as probabilities.

Fast Graphs for Slow Thinking

Fast Graphs for Slow Thinking is a reference to the book 'Thinking Fast and Slow' by Daniel Kahneman (winner of Nobel Prize for economics). Kahneman distinguishes between fast thinking, which is instinctive, recognises patterns and jumps to conclusions, and slow thinking, which is more deliberative and logical. Fast thinking is efficient, and part of that efficiency is the quick creation of a coherent, plausible narrative. Comparing the upside and downside of a decision involves weighing a range of possible futures. This is mentally demanding, but relatively easy in a spreadsheet. Our idea is to get the information quickly into a graph that shows the upside and downside of the N investment (we estimate less than 20 minutes), so that we can then have a useful conversation about the risky decision. This follows the advice of Professor Bill Malcolm, the Farm Management economist from the University of Melbourne: 'simple figuring and sophisticated thinking'.

This version of Fast Graphs for Slow Thinking wasn't developed as another decision support system for nitrogen; the aim was to explore how the upside, downside and probability weighted average of N decisions are changed by the cost of N and price of wheat, levels of carryover N, and seasonal climate forecasts. In doing this, we were testing the usefulness of a simple decision analysis to run the N budget across deciles, rather than pick a single target yield.

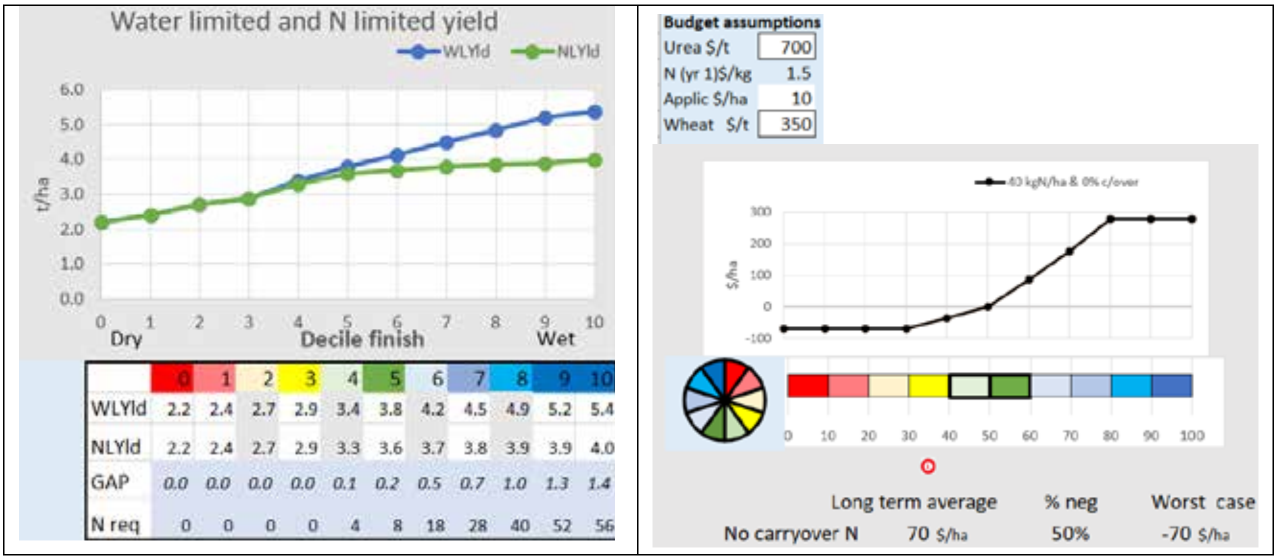
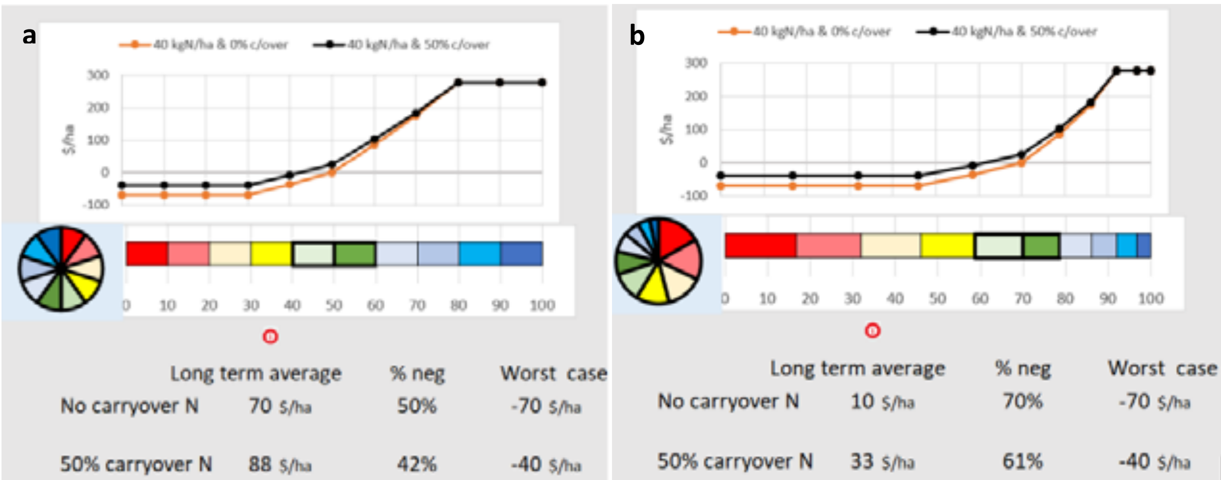


Figure 2. Screenshot of Fast Graphs for Slow Thinking, showing the water and nitrogen limited yield (left hand panel) and the profit by decile graph (right hand panel). The profit by decile graph is for the application of 40kg N, which is similar to aiming for decile 8 where the gap between the water and N limited yield is 1t/ha.

Using Fast Graphs for Slow Thinking, if we assume: (i) no carryover of N, (ii) urea $700/t, (iii) application cost of $10/ha, (iv) wheat price at $350/t and a rainfall decile 1 to 10 yield response for added fertiliser N from 2.2 to 4.0 t/ha (Figure 2), the worst case is a loss of $70/ha ($60 of Urea for 40kg N + $10 for application). The best case is 1t of wheat at $350 less $70, and a profit of $280/ha. The upside wedge is substantially better than the downside, and the probability weighted average profit is $70/ha (Figure 2 right hand panel at the bottom).



Figures 3a and 3b show the return (profit/ha y axis) from adding 40 kg N/ha assuming urea is $700/t, urea spreading is $10/ha and wheat is valued at $350/t. In Figure 3a the rainfall decile outcomes (coloured rectangles on the x-axis) are equally distributed. In Figure 3b the probability of receiving mean rainfall (coloured rectangles on the x-axis) is shifted from 50% (equally distributed deciles) down to 30% (skewed distribution of deciles to the dry end). In both graphs the orange line with orange circles shows returns ($/ha) from each decile assuming no N carryover into subsequent years. The black line with black circles shows the impact of 50% of applied N carrying over into the following year.

In the graphs the considerations for carry over N include (i) a proportion between 0% and 90% of the unused N will be available for subsequent crops, and (ii) the N carried forward to the next crop is valued as the saving in N fertiliser. Figure 3a and 3b show how carryover N of 50% reduces the loss in poor seasons but has no impact in good seasons because there is no unused N in rainfall deciles 8 and above. The long-term average improvement in this example for N carryover is $18/ha ($88/ha – $70/ha) where there is an equal distribution of rainfall deciles (figure 3a) and $23/ha ($33/ha – $10/ha) where there is skewed distribution of rainfall deciles toward the drier outcomes (figure 3b).

A shift in the odds from 50% chance of above median rainfall down to only 30% will adjust the shape of the upside and downside (Figure 3a compared with 3b). Importantly, a forecast doesn't change the position on the y-axis (e.g., possible profit). If the season finishes as a poor season in the drier deciles, there will be a loss; if the smaller chance (figure 3b) of a good season occurs, the grower will have a substantial return. A forecast doesn't change the future, it changes the likelihood of different future outcomes occurring. In other words, the forecast changes the width of the downside and upside wedge, not the height. If we assume 50% carryover of N, the climate outlook change from >50% of mean rainfall down to >30% of mean rainfall reduces the probability weighted average from $88/ha down to $33/ha (Figure 3a compared with 3b). The spend was $72/ha ($62 on urea plus $10 on spreading) so a profit of $88/ha where we have 50% N carryover represents a $1.00 dollar risks for $2.07 reward (income) and $1.07 profit using the long-term average (Figure 3a). In this scenario the loss is generated in 42% of the years experienced. The drier outlook (Figure 3b) represents a $1.00 risked for a $1.40 reward (income) and $0.40 profit where the loss occurs in 61% of years. This is explained by the scewed distribution of the seasonal decile outlook (figure 3b).

As the psychologist Paul Slovic says, 'our emotions are not good at arithmetic, we tend to think of future events as 100% or 0%'. Revising the likelihood of deciles based on a forecast is easily done in a spreadsheet and growers easily recognise patterns of shifts in graphs, especially if they were involved in providing the underlying information.

We started this paper arguing that N budgeting could benefit from looking beyond the horizon of a single year and considering a range of outcomes. Topdressing decisions in 2023 were difficult because many growers had removed a lot of grain in 2022, had a good start, followed by widespread rain in June but a forecast for increased chance of dry conditions and discussion of El Niño. Looking beyond the horizon of the single year, with the understanding that not all unused N will be lost and an appreciation of the benefits of building soil N, are enough for some growers to take a set and forget approach of N bank. Other growers are interested in the coming season as well as the long term. As with the example in Figure 3b, because an El Niño outlook doesn't eliminate the upside, the wetter deciles often contribute to a positive probability weighted average. This highlights the benefits of considering both the upside and the downside of N budgets.

Conclusion

The RiskWi$e project is about better understanding risk and reward in all parts of the grain farm and is therefore more than an initiative about N risk-reward. It does however provide a rich opportunity for conversations about the risk and reward of N use in our grain production systems. Because getting N topdressing exactly right is almost impossible due to the variable climate, it is better to consider the consequences of erring on the side of applying a bit extra N or too little N. The cautious approach of too little N can have a substantial cost of missing the opportunity of turning 40kg of N to 1t of wheat. The long-term cost of applying less N than is replaced by a legume phase is a run-down in soil N and soil carbon.

The strategic approach of using N banking is attractive as a robust 'set and forget' rule. The N bank method sets a winter mineral N target for your soil and climate combination and the grower simply tops the existing winter mineral N level up to the pre-determined mineral N target. If the carryover N from last season is high, then the mineral N top up is low and vice versa. A proportion of growers in a proportion of years will want to tactically adjust their N. Budgeting tactically across deciles takes a bit longer than budgeting for a single target yield, but we have found that once growers see the graph showing the upside and downside, decision making becomes easier.

'Fast Graphs for Slow Thinking' could complement N banking to adjust the target when there is a forecast for increased odds of dry (deciles 1 2 and 3) or wet (>= decile 7). The GRDC funded [Local Climate Tool (forecasts4profit.com.au)] shows that for many sites in South East Australia, El Nino or Positive IOD leads to a doubling of the chances of being in the bottom two deciles and La Nina or Negative IOD a doubling of the chance of decile 9 and 10. GRDC investment in projects with the Bureau of Meteorology have contributed to seasonal forecasts showing the chance of deciles rather than just above or below median.

The end point is more complete conversations about risk and reward which are improved by insights from the behavioural sciences. Our contention is that the applied economic tool of decision analysis has a role, not so much in the answer it provides, but in the conversations we have about probability, recency bias, loss aversion and planning for a single, most likely future. Fast Graphs for Slow Thinking is one approach to simulate thinking for improved decision making.

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Notes

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.

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Concurrent session Day 2

Strategies to improve crop establishment and yield on repellent sandy soils after amelioration

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GRDC project code: MFM2106-001RTX

Keywords

- amelioration, crop establishment, sandy soil, water repellence.

Take home messages

- Crop establishment can be improved following amelioration by adequately consolidating the seed-bed pre-sowing, which reduces seeder sinkage and excessive soil throw.
- Combining seed broadcasting with in-row seeding in vulnerable paddock zones can increase early ground cover and reduce in-crop wind erosion risks.
- When amelioration of water repellence is successful, sowing rates can be reduced, with seed cost-savings and no penalty to grain yield, providing adequate nutrition is supplied to meet the new crop potential.
- Despite successful amelioration of constraints (clay spreading, delving, spading), crop yields are rarely consistent across different soil types, both spatially and temporally, hence zone-based approaches to soil sampling and in-crop nutrition are still needed to achieve potential yields in different soil types.

Background

Sandy soils that have been deep tilled to eliminate water repellence often have soft seedbeds, face high wind erosion risks and have diluted or re-distributed nutrients through the profile. These consequences of amelioration can hinder crop establishment in the first year and limit grain yield and quality in subsequent years.

A paddock scale trial at Coomandook in the Upper Southeast of South Australia was set up on a water repellent sandy soil to test responses to different deep tillage types and seeding strategies. Results presented here outline the impact of treatments on barley crop establishment in the same year as amelioration (2022), and agronomic strategies to enhance canola yield in the second year (2023).

Data are also presented for two sites at Sherwood, also in the Upper SE. The first site sought to quantify the new yield potential in different paddock zones after amelioration (clay spread deep sand versus delved heavy flat) and to identify economically viable agronomic strategies to 'close the yield gap' in each zone. This site was established in 2022 and monitored for a second year in 2023 to measure legacy effects of different nutrient packages. The second site was set up in 2023 and sought to build on 2022 results by further exploring nitrogen demand and attainable yields in two paddock zones.

Method

Coomandook year 1

Two tillage-based soil amelioration treatments were contrasted against an unmodified control: topsoil inversion to 350mm depth (Plozza Plow, conducted on the day of sowing; the soil was at field capacity following rain); or chisel ploughing to 550mm depth with topsoil dilution from sublayer lifting (Bednar Terraland, conducted in dry soil 10 weeks prior to sowing, including 5 weeks of surface consolidation via grazing). Treatments were applied in strips 24m wide and 850m long, separated by controls; both tillage strips were rolled just before sowing using a 1.5m diameter straight-rib roller.

Commodus⊕ barley (medium coleoptile length) was sown on 22nd June 2022 at 73kg/ha using the following techniques.

- Furrow seeding: John Deere 1870 Conserva-Pak (30cm row spacing) operated at 8.5km/h, set for 3cm seeding depth in the control area and kept the same across the ripped/ploughed strips to monitor their impact.
- Seed broadcast: An additional 50kg/ha of seed was broadcast pre-seeding to 20m x 12m subplots over both tillage strips in an exposed section of a deep sandy rise. The broadcast seeds were then incorporated by the seeder during the sowing pass.

Sowing depth and crop establishment were recorded for both rear and front seeder rows (replicated x 3). Grain yield was measured using a plot harvester for each tillage type (replicated x 3).

Coomandook year 2

A small plot trial was sown across the Plozza, control and Bednar strips on 9 May 2023 in a semi-randomised split plot design, replicated three times. Three sowing rates of 44Y94CL canola (162 200 seeds/kg) were used: 1.6kg/ha, 2.8kg/ha and 4.0kg/ha, targeting plant populations of 20, 35 and 50 plants/m2 respectively, assuming 96% germination and 80% field emergence. Two nutrition strategies were applied to split plots: baseline nutrition, reflecting district practice (target yield of 1.8t/ha) and improved nutrition that was designed to accommodate the economic water limited yield potential of 2.3t/ha (Table 1), a target supported by pre-sowing soil test data.

Table 1: Nutrition treatments applied at Coomandook in canola in 2023. Nitrogen (N) was supplied as urea at three different timings, phosphorus (P) as MAP, potassium (K) as muriate of potash and copper (Cu) as fluid copper sulphate, banded below the seed. Note, sulphur (S) was supplied across the whole site pre-sowing as gypsum (800kg/ha = 100–110kg/ha of S).

Treatment	N kg/ha				P	K	Cu
	Sowing	1–4 leaf	Early stem elongation	Total	kg/ha	kg/ha	kg/ha
Baseline	8	40	46	94	16.4	10	0
Improved	30	80	40	150	16.4	15	1

Sherwood a, 2022 and 2023

Two identical small plot trials were sown across a delved flat and clay spread hill that had both been spaded in 2020. Nutrition treatments were designed to reflect district practice or to accommodate the economic water limited yield potential of 3.9t/ha (Table 2).

Table 2: Nutrition treatments applied to wheat at Sherwood in 2022.

Treatment		Nutrients supplied (kg/ha) from fertiliser				
#	Name	N	P	K	S	Cu
T1	Nil fertiliser	0	0	0	0	2
T2	District practice	100	18	0	11	2
T3	T2 + N	200	18	0	11	2
T4	T2 + P	100	27	0	11	2
T5	T2 + K	100	18	20	11	2
T6	T2 + N + P + K shallow	200	27	20	11	2
T7	T2 + N + P + K deep	200	27	20	11	2

Nutrients were supplied in either of two positions: banded with and below the seed (shallow); or banded with, below the seed and at 15–20cm (deep). Scepter⊕ wheat was sown on 24 May 2022 and the trials were oversown with 44Y94CL canola on 26 May 2023. In 2023, all plots received the same nutrient package to test the legacy effects of 2022 fertiliser additions.

Sherwood b, 2023

Two identical small plot trials were sown across a delved flat and clay spread sandhill that had both been spaded in 2021. Nitrogen rates of 0kg/ha, 50kg/ha, 75kg/ha, 100kg/ha, 125kg/ha, 150kg/ha and 200kg/ha were tested, along with a treatment allowing for starting soil N and K status, supplying 75kg N/ha and 20kg K/ha on the delved flat, and

125kg N/ha and 20 kg K/ha on the clay spread hill. The trials were sown to RockStar⟮D⟯ wheat on 26 May 2023.

Results and discussion

Crop establishment after amelioration at Coomandook, 2022

Average sowing depth in the control was 50mm (Table 3) and the crop established at 120 plants/m2 (71% of seed sown; Table 4). The seeder front rows were 9mm deeper than the rear rows due to soil throw. Under the Bednar Terraland treatment, which was consolidated by grazing prior to sowing, the sowing depth was similar (59mm), with no impact on crop establishment. Conversely, under the Plozza disc treatment, which still had a soft seedbed post-rolling, the sowing depth was strongly affected by seeder sinkage and excessive soil throw. The greatest impacts were measured on the seeder front rows (+94mm), leading to a reduction in plant population (-19 plants/m2). Even more plant losses would be expected if a shorter coleoptile variety and pre-emergence herbicides had been used.

Table 3: Barley seeding depth (mm) at Coomandook in 2022 by treatment and seeder row position.

Seeder row position	Unmodified control		Plozza		Bednar	
	mean	s.e.	mean	s.e.	mean	s.e.
Rear row	45.3	4.2	78.4	7.8	52.7	6.0
Front row	54.1	6.4	148.0	13.0	65.3	8.4
Average depth	**50**	**5.3**	**113**	**10.4**	**59**	**7.2**

Seed broadcasting combined with seeder sowing added an extra 41 plants/m2 on the Bednar plots (Table 4) and an extra 34 plants/m2 in Plozza plots and displayed greater protection during a high wind event in August that caused substantial drift damage in surrounding areas.

Table 4: Year 1 barley crop establishment (plants/m2) at Coomandook.

Seeder sowing	Unmodified control		Plozza		Bednar	
	mean	s.e.	mean	s.e.	mean	s.e.
Rear row p/m2	113	4.9	115	6.2	113	9.6
Front row p/m2	127	5.7	108	6.2	140	4.4
Average p/m2	**120**	**5.3**	**112**	**6.2**	**126**	**7.0**
% seed rate	71%	-	66%	-	74%	-
Combined seeder + broadcast sowing						
Mean row p/m2	-	-	123	5.8	121	3.1
Inter row p/m2	-	-	23	3.3	46	2.7
Average p/m2	-	-	146	4.6	167	2.9

Optimised year 2 agronomy at Coomandook

Treating water repellence at Coomandook via inversion or chisel ploughing in 2022 resulted in average canola plant populations of 18 plants/m^2, 32 plants/m^2 and 56 plants/m^2 in 2023, for the low, medium and high sowing rates respectively (Figure 1), achieving 72%, 73% and 90% field establishment. In contrast, the unmodified control only achieved 34–40% field establishment, with populations of 9 plants/m^2, 18 plants/m^2 and 25 plants/m^2 for the low, medium and high sowing rates respectively. Even with the highest sowing rate of 4kg/ha, the target plant population of 35 plants/m^2 was not achieved and produced only 1.43t/ha of grain with district practice agronomy, improving to 1.73t/ha of grain with extra N and K applied (Figure 2).

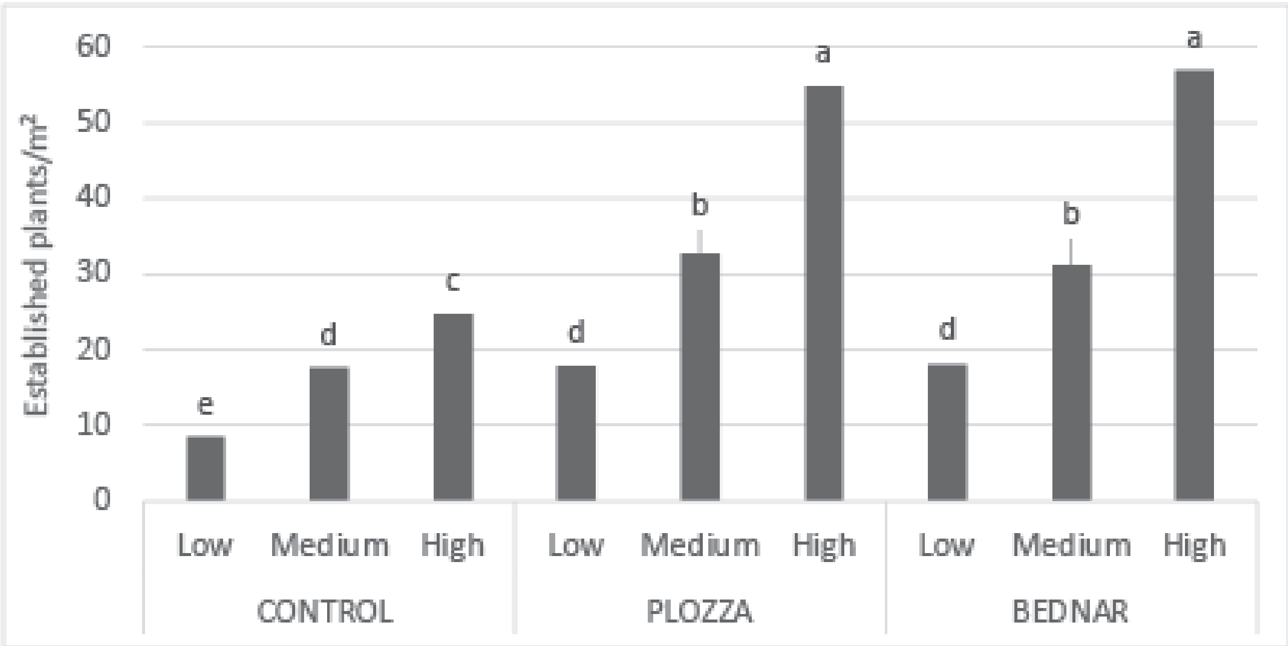

Figure 1. Canola crop establishment at Coomandook in 2023 for each tillage type and sowing rate (low=1.6kg/ha, medium=2.8kg/ha, high=4kg/ha), showing higher sowing rates are needed to achieve the target plant population (dashed line) when water repellence is present (control). Letters denote significance ($p<0.001$, Lsd=6.2).

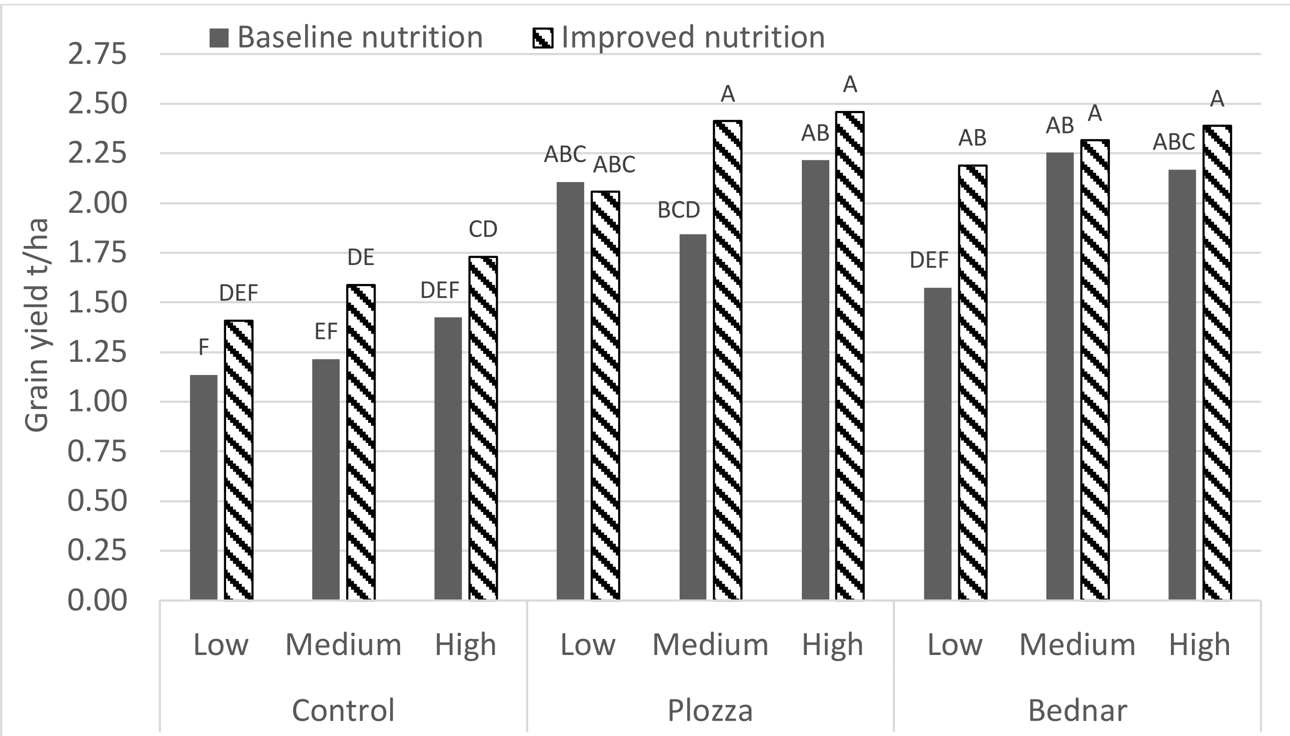

Figure 2. Canola grain yield at Coomandook in 2023 for each tillage type, sowing rate (low, medium and high, as per Fig. 1) and nutrition strategy (solid columns = baseline nutrition, N@93kg/ha; dashed columns = improved nutrition, N@150kg/ha). Letters denote significance ($p<0.05$, Lsd=0.40).

The improved nutrition treatments performed the most consistently across the Plozza and Bednar treatments, yielding 2.3t/ha on average (0.3t/ha above the district practice at 2.0t/ha; Figure 2). There was no benefit to increasing the sowing rate >2.8kg/ha. These results show that sowing rates can be substantially reduced when water repellence is treated and that yields can be improved, even with plant populations <20/m2. At $35/kg for the latest hybrid seeds, lower seeding rates can deliver substantial savings.

Nutrition response – Sherwood a 2022 and 2023

Nitrogen was the major driver of wheat yield responses to nutrition additions in 2022, achieving an average of 4.5t/ha on the delved flat and 3.9t/

ha on the clay spread hill for all treatments that contained 200kg N/ha, more than 1.3t/ha better than the district practice treatment (3.1t/ha and 2.6t/ha respectively; Table 5). Canola yields in 2023 were also consistently improved by the extra N applied in 2022, achieving 3.9t/ha and 3.2t/ha, more than 1t/ha better than district practice. There was no response to extra P or K fertiliser in either location.

Table 5: Wheat (2022) and canola (2023) yields (t/ha) at Sherwood, showing higher yields on the delved flat than on the clay spread hill in both years. A different letter in the Lsd group indicates a significant difference between treatments.

	Delved flat				Clay spread hill			
	Wheat 2022		Canola 2023		Wheat 2022		Canola 2023	
Treatment	Yield	Lsd group	Yield	Lsd group	Yield	Lsd group	Yield	Lsd group
Nil fertiliser	1.62	a	0.88	a	1.17	a	0.98	a
District practice	3.12	b	2.61	b	2.87	b	2.19	b
T2 + N	4.36	c	3.73	c	3.78	c	3.17	d
T2 + P	3.49	b	2.85	b	3.01	b	2.52	c
T2 + K	3.03	b	3.16	bc	2.98	b	2.49	c
T2 + N + P + K shallow	4.62	c	3.66	c	3.94	c	3.21	d
T2 + N + P + K deep	4.37	c	3.65	c	3.86	c	3.23	d
P Value	<.001	-	<.001	-	<.001	-	<.001	-
Lsd (0.05)	0.55	-	0.73	-	0.32	-	0.27	-

Nitrogen response – Sherwood b 2023

Wheat at Sherwood in 2023 yielded 4t/ha on the delved flat and 1.7t/ha on the clay spread hill with no N fertiliser applied, following beans in 2022 (Figure 3). The crop on the hill suffered severe moisture stress in late spring and no N response was recorded. Down on the flat however, yields were improved by >0.5t/ha with the addition of 100kg N/ha and maximised at 125kg/ha, resulting in improved grain quality via higher protein (Table 6). Although screenings were elevated, particularly for N rates >150kg/ha, all N treatments achieved a grade of AUH2. There was no benefit to grain yield by applying more than 125kg N/ha, but the data presented above (Sherwood a) show that residual N may benefit subsequent crops.

Results from these trials confirm that yields can be improved by matching N additions to water limited yield potential and starting soil chemistry, but that yield gaps still exist between different soil types/ zones both spatially and temporally, even after amelioration. Adopting strategic zone-based soil sampling and variable rate fertiliser technology is the next step to enhance grain yields and optimise economic returns after amelioration.

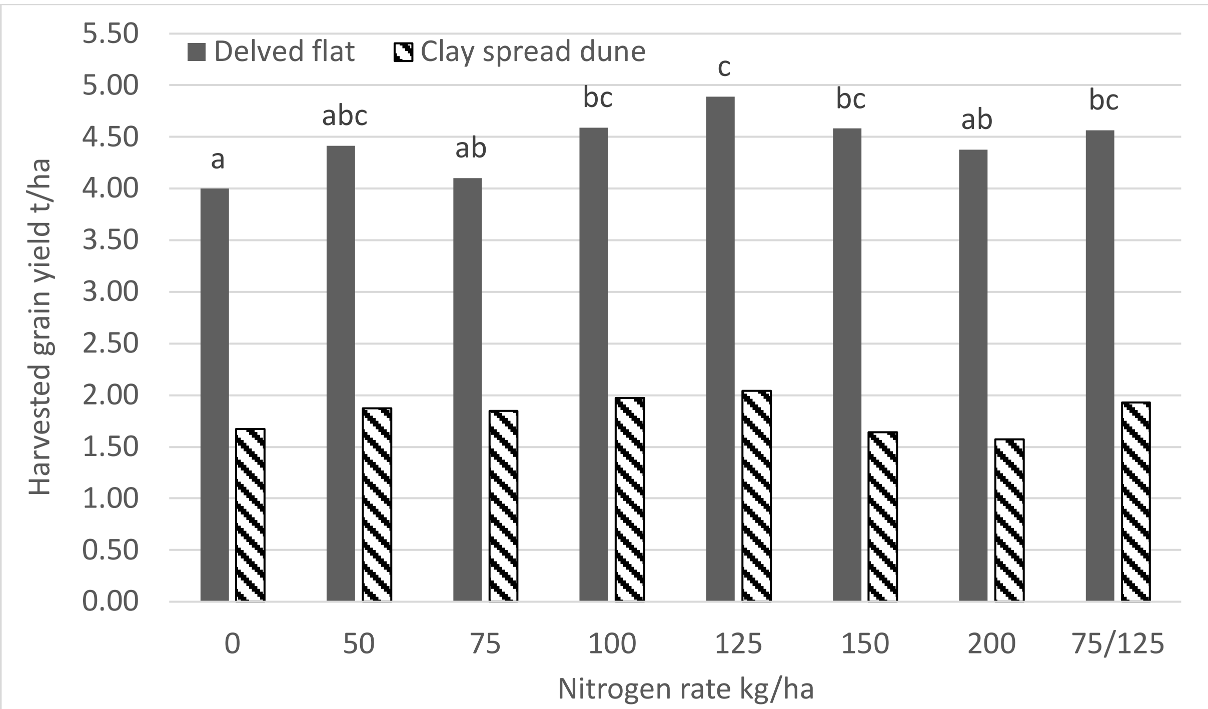

Figure 3. Wheat grain yield (t/ha) at Sherwood in 2023 in response to increasing rates of nitrogen fertiliser. Solid columns = delved flat; dashed columns = clay spread dune (not significant). Letters denote significance (p<0.05, Lsd=0.5).

Table 6: Grain quality at Sherwood in 2023 for different nitrogen (N) application rates.

Treatment kg N/ha	Test Weight kg/hl	Protein		Screenings		Receival grade
		%	Lsd group	%	Lsd group	
0	77.03	11.3	a	6.0	a	**AGP1**
50	77.48	12.7	b	8.6	bc	**AUH2**
75	77.52	13.0	bc	7.3	ab	**AUH2**
100	76.79	13.3	bcd	7.4	ab	**AUH2**
125	77.65	13.7	cd	7.9	abc	**AUH2**
150	76.64	13.7	cd	8.9	bc	**AUH2**
200	77.26	13.9	d	9.3	c	**AUH2**
75N + 20 K	77.79	13.1	bc	7.5	abc	**AUH2**
P Value	0.338	<.001	-	0.045	-	-
Lsd (0.05)	NS	0.8	-	1.9	-	-

Conclusion

Crop establishment can be improved following amelioration by adequately consolidating the seed-bed pre-sowing, which reduces seeder sinkage and excessive soil throw. Combining seed broadcasting with in-row seeding in vulnerable paddock zones can increase early ground cover and reduce in-crop wind erosion risks. Options to 'spade and sow' in one pass or broadcast seeds pre-spading also exist to minimise soil erosion risks and these techniques have been shown in other projects (CSP1606-008RMX) to achieve uniform crop establishment where there is moisture within the soil profile.

When amelioration of water repellence is successful, sowing rates can be reduced, with substantive seed cost savings and no penalty to grain yield, providing adequate nutrition is supplied to meet the new crop potential. Nitrogen has proven to be the major driver of yield responses after amelioration.

Despite successful amelioration of constraints (clay spreading, delving, spading), attainable yields are rarely consistent across different paddock zones, both spatially and temporally, hence zone-based approaches to soil sampling and in-crop nutrition are still needed to achieve potential yields in different soil types and topography.

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Notes

Strategic use of zinc phosphide is critical for successful mouse control

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Keywords

- background food, bait aversion, zinc phosphide.

Take home messages

- Reducing background food is critical to achieving effective bait uptake.
- 2mg of ZnP is required on each grain to deliver a lethal dose to a 15g mouse (Hinds et al. 2023).
- Grain bait mixed at 50g ZnP/kg wheat is significantly more effective.
- Strategic use of bait is more effective than frequent use of bait.

Background

Zinc phosphide mouse baits (25g ZnP/kg wheat; hereafter ZnP25) are the only registered product to control mice in Australian cropping systems, however, its application does not always lead to reduced populations or reduced damage. Growers have reported concerns regarding the effectiveness of commercially prepared ZnP25 wheat-based baits. CSIRO, with investment from the GRDC (CSP1804-012RTX: *Determining the effectiveness of zinc phosphide rodenticide bait in the presence of alternative food supply*), have conducted a suite of projects investigating the sensitivity of mice to ZnP baits and, subsequently, the efficacy of ZnP in paddocks. These projects have resulted in a clearer understanding of the delivery of an effective dose of ZnP for mice. Even though substantial gains were made, further questions remained about other factors that might have a negative impact on baiting outcomes. We investigated the effect that background food had on the efficacy of ZnP bait in an experiment conducted in mouse-proof enclosures at Walpeup in northwestern Victoria. Conservation tillage systems result in the retention of higher levels of crop residues (trash), minimal disturbance in the stubble phase and substantial amounts of residual or background food (specifically spilled grain) post-harvest. The results of this work not only showed that the amount of background food had a negative impact on the mortality rate of mice post-baiting, but the results were further negatively impacted by bait aversion that occurred after sub-lethal doses of the bait were encountered by mice. Note, this work has just been submitted for publication (Brown et al. 2024, available as a pre-print on bioRχiv).

Methods

Nine 15m x 15m (225m^2) mouse-proof enclosures were populated with at least ten mice, all marked with Passive Integrated Transponder (PIT) tags, enabling individual identification of each mouse. The vegetation in the enclosures was mown short to facilitate detection of dead or dying mice post-baiting. Rows of mown grass and small shelters were left in the enclosures to provide protection from the elements. Water was provided in three bird waterers in each enclosure.

Mice were captured from nearby wheat crops and placed in the enclosures for an acclimation period of ten days. Throughout the experiment, mice were provided with maintenance food (3g/day/mouse) broadcast evenly throughout each enclosure.

On day 11, a gradient design was used to impose the treatments to each enclosure. Different levels of background food (wheat) were added to each enclosure, two enclosures with maintenance food only (one being a control with no bait added); the next one with the equivalent of 10kg/ha, then doubling the amount in each subsequent enclosure until enclosure nine where 640kg/ha was added (Table 1).

Table 1: Amount of maintenance food and background food added to each enclosure while the toxic bait was available.

Treatment					
Added background food (kg/ha)	Added background food (grains per enclosure)	Maintenance food (g per enclosure per day)	Maintenance food (grains per enclosure per day) nm	Toxic grains (g per enclosure)	Toxic grains (grains per enclosure) np
0	0	30	750	22.5	562
10	5 625	30	750	22.5	562
20	11 250	30	750	22.5	562
40	22 500	30	750	22.5	562
80	45 000	30	750	22.5	562
160	90 000	30	750	22.5	562
320	180 000	30	750	22.5	562
640	360 000	30	750	22.5	562
Control	0	30	750	0	0

On day 16, ZnP25 bait was added to eight of the enclosures at the recommended label rate of 1kg/ha (approximately 2–3 grains of bait per square metre). No bait was added to the control enclosure where mice were provided with the maintenance ration each day. From day 17–26, enclosures were systematically checked for dead or dying mice. Any mice found were identified from their PIT tag and necropsied to look for signs of ZnP poisoning.

From day 20 onward, enclosures were trapped to calculate the number of mice that were not killed by the bait. All mice that were captured were humanely killed and necropsied to look for signs of sub-acute ZnP poisoning.

Results

Mouse mortality ranged from 0% (640kg/ha background food and Control enclosures) to 90% (0kg/ha background food) (Table 2). Mortality was high when there were low levels of background food present (mortality ≥70% for 0–40kg/ha background food), but mortality was low when there were abundant levels of background food present (mortality <40% for >160kg/ha background food). In order to achieve >70% mortality, background food needs to be less than 40–80kg/ha. As the amount of background food declines, the chance of a mouse encountering a grain coated with toxin increases. However, probability of encounter is not the only explanation for these results.

Table 2: Summary of mouse captures, fate and mortality for each treatment during the experiment. Twelve mice were initially introduced into each enclosure but were reduced to a target of 10 mice/enclosure at the pre-baiting trapping. Some mice were subsequently captured during the post-baiting trapping, so were included in the pre-baiting catch. Mortality (%) was calculated by post-baiting catch – pre-baiting catch.

Background food treatment (kg/ha)	Pre-baiting known to be alive	Found dead	Post-baiting trap-out	Mortality (%)
0	10	1	1	90
10	10	2	2	80
20	10	1	3	70
40	10		3	70
80	11 *1	3	5	55
160	11 *1		8	27
320	13 *2	1	8	38
640	11 *1		11	0
Control	10		10	0
Total	96	8	51	

** Includes mice (number indicated) that were captured post-baiting but were not captured pre-baiting (obviously alive at the time).*

Previous lab studies have shown that bait aversion is an issue when mice consume a sub-lethal dose of ZnP (Henry et al. 2022, Hinds et al. 2023). When the expected rate of mortality is modelled against background food with the laboratory-trial derived rate of aversion included (Figure 1), the model that includes aversion better fits the mortality rates measured in this study.

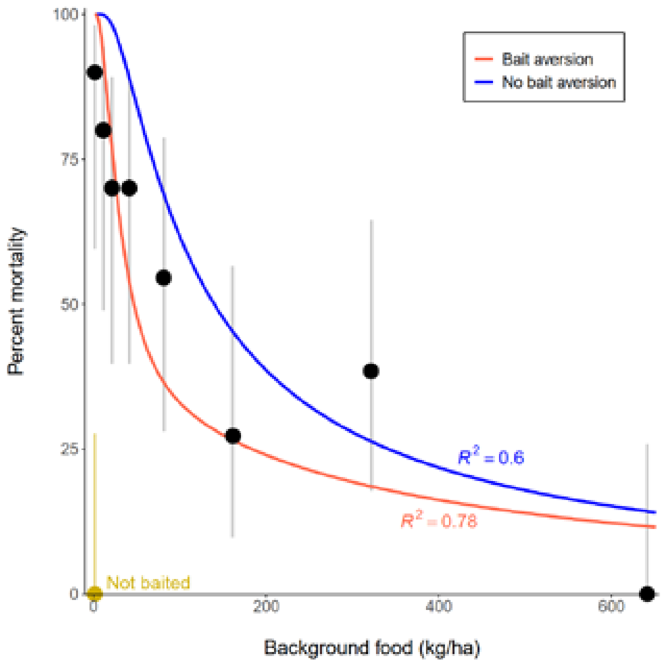

Figure 1. Observed mouse mortality as a function of background food availability for enclosures with added toxic grains (black-filled circles) and the control enclosure with no toxic grains (gold-filled circle) and associated 95% confidence intervals (grey and gold lines). Solid lines show the mortality rates predicted under the two modelled scenarios: random bait encounters without bait aversion, and random bait encounters with bait aversion.

In laboratory trials, using a higher dose of ZnP (50g ZnP/kg wheat; hereafter ZnP50), there was higher mortality than with ZnP25 baits (Hinds et al. 2023). Consequently, for a given level of background food availability, mortality rates are predicted to be higher for ZnP50 relative to ZnP25 baits for both scenarios (aversion and no aversion) (Figure 2). While mortality rates are also predicted to decline with increasing background food availability for ZnP50 baits, this decline is less marked than for ZnP25 baits. At the highest level of background food availability (640kg/ha), mouse mortality with ZnP50 grains and bait aversion is predicted to be >50%, compared to just over 10% for ZnP25 baits (Figure 2).

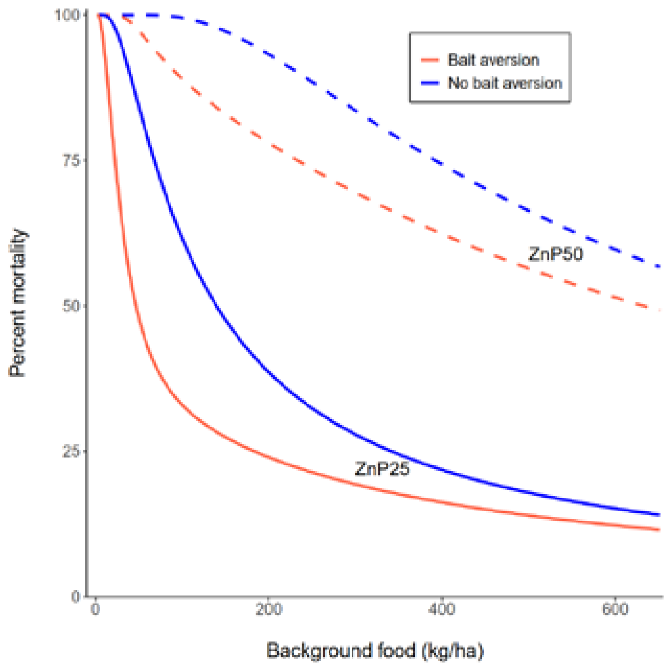

Figure 2. Mortality rates predicted under the two modelled scenarios – random bait encounter without bait aversion, and random bait encounter with bait aversion, with either the ZnP25 bait or with the ZnP50 bait.

Conclusion

- As background food increases, the probability that a mouse will discover a toxic grain decreases.
- If there is aversion as a result of sub-lethal dose ingestion, then the mortality rate declines further.
- 2mg of ZnP is required on each grain to deliver a lethal dose to a 15g mouse (Hinds et al. 2023).
- ZnP grain bait mixed at 50g ZnP/kg wheat (unregistered) is significantly more effective at reducing mouse populations than bait mixed at the registered rate of 25g ZnP/kg wheat, as demonstrated in large-scale replicated field trials (Ruscoe et al. 2023).

Applying bait when background food is at its lowest level and ensuring that every grain of ZnP contains a lethal dose are both critical factors for ensuring the best possible results from baiting effort.

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Novel weed control technologies from the USA – new possibilities for Australian growers

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Keywords

- allelopathy, electrical weeding, gametocides, WeedErase and Weed Seed Destroyer, weed recognition.

Take home messages

- New weed control technologies are under development for US cropping systems.
- Widespread occurrence of herbicide resistance in US cropping systems is driving the development of alternative weed control techniques.
- Opportunities to evaluate the potential of these systems in Australian grain production systems.

Background

Globally, the current rate of research and development on weed control technologies for large scale cropping systems is the greatest that we have ever seen. These efforts are being driven by necessity as well as innovation. Worldwide herbicide availability continues to decline, within creased regulatory restrictions and a lack of new molecules being released. To a lesser extent, there has also been progress on alternative, non-chemical weed control techniques. This has been aided by technological developments in machine learning that have created the potential for accurate in-crop weed detection and recognition. Although these innovative activities are occurring overseas, mostly in the US as well as Europe, some of the technologies under development could be highly suited for use by Australian grain growers. The more exciting of these developments are summarised here.

WeedErase and Weed Seed Destroyer

Global Neighbor, Inc. (https://g-neighbor.com/) is a startup based in Ohio who have developed a weed and weed seed control approach based on heat from the combination of 440 nm wavelength blue light and mid-wave infra-red (MWIR) wavelengths. The blue light at high intensity, 30 times sunlight, damages photosynthetic systems (chloroplasts), as evidenced by blackened leaves. MWIR which is not present in sunlight, penetrates the soil to damage weed roots. This technology is currently only commercially available as the handheld WeedErase® system for home garden use. Further research has found that the combination of high intensity blue light and MWIR can be effective at killing weed seeds. Global Neighbor, Inc. is now pursuing the use of this approach for targeting weed seeds during harvest. Preliminary studies have shown that complete control of weed seeds in chaff can be achieved within a few seconds exposure. Global Neighbor, Inc. are pursuing this opportunity with a development labelled the Weed Seed Destroyer (WSD). This technology is still very much under development, with prototype systems being produced for benchtop as well as field testing.

Preliminary testing with a benchtop system at the University of Western Australia has identified high efficacy (>90%) of the WSD on annual ryegrass seed present in wheat chaff. Although initial results are encouraginggaps remain in the efficacy of this approach in the field, across a range of weed species and crop chaff combinations in varying harvest conditions.

Electrical weeding

There are now commercially available electrical weeding systems suited to use in large scale crop production systems. Companies including Zasso (https://zasso.com/), a Swiss based company, RootWave (https://rootwave.com/) from the UK and Weed Zapper (https://theweedzapper.com/) from the US, have all developed high voltage electrical weeding systems. In the US, this type of system is being used to target weeds in organic crops where selectivity is based on height differences between crops and weeds. Weeds taller than the crop can be effectively targeted by the high voltage (>10,000V) electrical weeding systems (Schreier et al. 2022). The GRDC has a current investment with DPIRD investigating the potential use of the Zasso system in Australian agriculture systems (DAW2303-002OPX).

An Australian company, Azaneo (https://azaneo.au), is pursuing a more novel and precise approach to electrical weeding. Preliminary studies with their low powered, pulsed electrical weeding system have demonstrated high efficacy at very low power output (<3.0W) on broadleaf and grass weed seedlings in pot and field studies. This technology is being progressed towards achieving in-crop control through selective targeting of weed plants.

Weed recognition technologies

The opportunity to specifically target weeds with control treatments is driving considerable research activities and commercial developments. There is a substantial USDA-funded effort lead by Texas A&M University, on the development of an open-source database of annotated and classified images of major cropping weeds. They have focussed efforts on the major weeds of corn and soybeans, Palmer amaranth and waterhemp. Weed image data is being collected from both in-field and pot-grown scenarios, enabling the combined use of real world and synthetic data for training dataset development. The general goal for this research is to provide high quality image data for the entire weed control industry. This image data is being used for refined software development, such as weed growing point detection which enables accurate plant recognition despite high occlusion levels (for example, 50%). Hardware-based research includes the evaluation of 3D camera systems for the collection of whole of plant data.

Evaluation of gametocides to prevent weed seed production

Gametocides are frequently used to control crossing in the hybrid seed production industry wheregametocides act to prevent pollination from treated plants. A range of chemicals, including some herbicides, are routinely used as gametocides and several of these are now being considered for use in preventing the seed production in weed species. Targeting the pollen production of herbicide resistant plants could be important in preventing the seed production of these plants, as well as the spread of resistance genes to susceptible populations.

Allelopathic weed control and biological nitrification inhibition

The role of crop-produced chemical growth inhibitors (allelochemicals) on weeds has been documented for many crop:weed combinations (Dayan et al. 2010; Kong et al. 2011). There has been a considerable research effort aimed at developing an understanding of the weed control potential of crop root exudates (Duke, 2015). Recently, research has identified that allelochemicals produced by some crops also inhibit biological nitrification, leading to the more efficient use of soil available nitrogen. Root exudates of these crops have been shown to inhibit nitrification, the conversion of nitrite to nitrate, which contributes to nitrogen loses through NO3- leaching and N2O emissions. The production of secondary metabolites in crop root exudates have the potential to negatively impact weed growth, as well as reduce soil nitrogen losses.

Conclusion

There are several exciting new areas of weed research and weed control being developed in the US. These new approaches are in various stages of development and commercialization. These new technologies present the Australia grains industry opportunities to test and advance weed control in Australian cropping system.

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Management of disease complexes in the Southern Victorian Mallee cereals

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GRDC project code: BWD2303-002RTX

Keywords

- cereals, disease management, fungicide options, rainfall

Take home messages

- Variety choice is important for disease management.
- Economical and premium fungicide options performed similarly in many cases.
- Spot form and net blotch were common diseases in the southern Mallee barley site.
- Septoria tritici blotch, leaf and stripe rust were observed in the southern Mallee wheat site.
- Disease resistance of variety plays an important role in disease management in-season.

Background

The Mallee region experiences substantial fluctuations in seasonal conditions, with varying rainfall and patterns in recent years. This variability poses challenges in predicting the risk of disease and timing of application to produce economic returns for growers from fungicide use to manage disease. Given the nature of inconsistencies in economic returns for fungicide use in the Mallee environment, this project was established to support growers in making real-time decisions for disease control and maximise benefits from fungicide use. The objective of this project is to showcase diverse management strategies for disease complexes and identify optimal economic strategies that suit different crops grown in the Mallee region. This involves conducting plot trials at multiple locations, emphasising various fungicide management approaches in wheat, barley, and lentils. The trials are designed to encourage facilitated discussions and peer-to-peer learning regarding critical disease management decisions.

Method

Site establishment

In 2023, the Birchip Cropping Group (BCG) established five small-plot research trials across two locations in regional Victoria, the Mallee, located in Kinnabulla, 20km northwest of Birchip, and the North Central region, 13km south of Pyramid Hill. Data from the two Pyramid Hill trials (barley and wheat) have been omitted from this report, as the trials experienced heavy pressure from kangaroo grazing throughout the year. The three trials at the Kinnabulla site were sown to wheat, barley, and lentil, with different disease management strategies applied (Table 2). Data collected from the lentil trial showed that the disease load was lower than expected, and therefore this trial has been omitted from this report. All trials were established as randomised complete block design with four replications. The sites experienced timely early season rainfall with 57.4mm in June, resulting in good trial establishment as well as early season disease development. During the growing season, the trial received 187mm of rain. The rainfall received during the growing season was classified as decile 3, however, there was sufficient soil moisture due to higher-than-average rainfall (decile 10) in 2022.

Crop varieties and disease susceptibility

Three different varieties within each crop type were selected with varying disease susceptibility ratings (Table 1).

Table 1: Wheat and barley variety disease ratings[1] as follows, moderately resistant (MR), susceptible (S), moderately susceptible (MS), very susceptible (VS).			
Disease	**Variety**		
	Wheat		
	Scepter⍉	**Hammer CL Plus**⍉	**LRPB Matador**⍉
Septoria tritici blotch	S	MS to S	S to VS (P)[2]
Leaf rust	MS to S	S	MS (P)
Stripe rust	MS to S	MS	S (P)
	Barley		
	Leabrook⍉	**Maximus CL**⍉	**RGT Planet**⍉
Spot form net blotch	MR	MS	S to VS
Leaf scald	S to VS	S	S

[1] Disease ratings were sourced from 2023 Victorian and Tasmanian Crop Sowing Data Summary.

[2] Provisional rating.

Treatments

Table 2: Fungicide management spray treatments and application timings in wheat and barley. Treatments were chosen to illustrate a variety of different fungicide options to evaluate differences between economical and premium fungicide application strategies.

	Treatment	Pricing	Method/timing^	Rate
i)	Control		No fungicide	
ii)	Flutriafol			400mL/100kg
iii)	250 g/L Propiconazole and 40 g/L Benzovindifupyr		GS31	500mL/ha
iv)	Flutriafol and 125 g/L Epoxiconazole	Economical	GS31	400mL/100kg
v)	Flutriafol, 250 g/L Propiconazole and 40 g/L Benzovindifupyr	Premium	GS31	400mL/100kg 500mL/ha
vi)	250 g/L Propiconazole and 40 g/L Benzovindifupyr		GS39	500mL/ha
vii)	Flutriafol, 125 g/L Epoxiconazole 200 g/L Azoxystrobin and 80 g/L cyproconazole	Economical	GS31 GS39	400mL/100kg 500mL/ha 800mL/ha
viii)	Flutriafol, 250 g/L Propiconazole and 40 g/L Benzovindifupyr 150 g/L Prothioconazole and 75 g/L Bixafen	Premium	GS31 GS39	400mL/100kg 500mL/ha 500mL/ha

^Growth stage according to Zadoks scale, GS31 = stem elongation, GS39 = flag leaf emergence.

Results and discussion

Wheat

Variety was a primary driver in differentiating disease prevalence at growth stages GS31 and two weeks post-GS39, p <0.001 and p=0.036, respectively (Table 3). Septoria tritici blotch (STB) was detected on lower leaves early in the season (GS31). Although LRPB Matador⍉ is considered the most susceptible variety out of all three (based on provisional ratings), Scepter⍉ exhibited higher disease scores more consistently across all treatments throughout the season. At GS39, STB had migrated into the upper canopy in all varieties. The presence of rust was also noted at this growth stage in some untreated Hammer CL Plus⍉ plots. Two weeks following the GS39 treatment application, rust had formed hotspots in the trial, with rust appearing in most plots.

Table 3: General disease scores in wheat noted at four time points throughout the season.

Variety	Treatment	GS31	2 weeks post GS31 trt	GS39	2 weeks post GS39 trt
Hammer CL Plus	Control	3	3	5	5
	ii)	2	3	4	4
	iii)	3	3	3	4
	iv)	2	3	4	4
	v)	2	3	4	4
	vi)	2	4	5	4
	vii)	2	3	3	4
	viii)	2	3	3	3
LRPB Matador	Control	2	3	4	5
	ii)	2	3	3	3
	iii)	2	3	3	3
	iv)	2	3	3	3
	v)	2	3	3	3
	vi)	3	3	4	3
	vii)	2	3	4	2
	viii)	2	3	3	3
Scepter	Control	3	3	6	7
	ii)	3	3	3	3
	iii)	3	3	4	4
	iv)	3	3	3	3
	v)	3	3	4	3
	vi)	3	3	5	4
	vii)	3	3	3	4
	viii)	3	3	3	2
Sig. Diff.					
	Variety	<.001	NS	NS	0.036
	Treatment	NS	NS	0.001	<.001
	Variety x Treatment	NS	NS	NS	NS
Lsd (*p*=0.05)					
	Variety	0.1537	NS	NS	0.527
	Treatment	NS	NS	0.961	0.86
	Variety x Treatment	NS	NS	NS	NS
CV (%)					
	Variety	2.2	NS	NS	5.3
	Treatment	NS	NS	5.1	NS
	Variety x Treatment	NS	NS	NS	5.3

Plots were scored from 1–9 (9 = whole plot diseased). Replicate data for each group are summarised as the mean, based on four replicates unless otherwise stated. Scores denote observations of general signs of disease (lesions).

Both variety and treatment imposed statistically significant effects on grain yield (t/ha), p=0.008 and p=0.005, respectively (Table 4). Between the untreated controls, LRPB Matador$^{\oplus}$ was the highest yielding variety, and Scepter$^{\oplus}$ the lowest, illustrating the impact of disease, as shown in Table 3. Within varieties, Scepter was the most responsive to disease control, with all but one treatment (iii) showing a significantly higher yield compared with the control. Double spray applications (GS31 and GS39) resulted in the highest yield for Scepter$^{\oplus}$ (treatments vii and viii), with little difference between the economical and premium products. The partial gross margin (PGM) for treatment vii (GS31 and GS39 economical) showed a slightly higher return on investment (ROI), but the highest PGM for this variety was achieved by treatment vi, which was one application of propiconazole and benzovindifupyr at GS31.

Differences in yield between treatments were observed to a lesser degree for Hammer CL Plus$^{\oplus}$, and less again for LRPB Matador$^{\oplus}$. A common trend across both varieties was the high yields achieved for treatment iii (one application of propiconazole and benzovindifupyr at GS39) versus the premium version of this treatment (v) which included Flutriafol. Treatment iii across both varieties showed high yields, and the highest PGM.

Table 4: Average yield (t/ha) and partial gross margin (PGM) of wheat varieties and treatments.

Variety		Control	ii	iii	iv	v	vi	vii	viii
Hammer ᶲ CL Plus	**Yield (t/ha)**	4.50^{ef}	4.95^{b-e}	5.27^{a-d}	4.94^{b-e}	4.62^{d-f}	4.68^{d-f}	5.24^{a-e}	5.31^{a-d}
	PGM($/ha)^A	$1598	$1739	$1841	$1707	$1593	$1630	$1778	$1798
LRPB Matador ᶲ	**Yield (t/ha)**	4.89^{b-e}	4.94^{b-e}	5.80^{a}	5.17^{a-e}	5.46^{a-c}	5.47^{a-c}	5.61^{ab}	5.39^{a-d}
	PGM($/ha)^A	$1736	$1738	$2028	$1787	$1890	$1910	$1911	$1824
Scepter ᶲ	**Yield (t/ha)**	4.05^{f}	5.14^{a-e}	4.74^{c-f}	5.09^{a-e}	5.08^{a-e}	5.23^{a-e}	5.35^{a-d}	5.25^{a-e}
	PGM($/ha)^A	$1437	$1808	$1650	$1759	$1757	$1824	$1817	$1775
Sig. Diff.									
Treatment	**0.005**								
Variety	**0.008**								
Treatment x variety	**NS**								
Lsd (p=0.05)									
Treatment	**0.4425**								
Variety	**0.271**								
Treatment x variety	**NS**								
CV (%)	**2.2**								

Replicate data for each group are summarised as the mean. Letters in superscript denote significant differences between all treatments, and shading denotes significant differences for treatments compared to the control of respective variety.

[A]Partial gross margin of each treatment was calculated using the yields incorporated in the table, average price of APW $355 at three local receival sites (correct as of 3 January 2024) minus the flutriafol and fungicide prices and an application cost of $10 per spray.

An interesting finding was the lack of significant differences between economical and premium products, regardless of variety or spray application. However, PGM analysis showed in some instances that for plots with relatively similar yields, the return on investment was higher for the treatment using economic products, for example treatments iv (economic) and v (premium) in Hammer CL Plusᶲ, and treatments vii (economic) and viii (premium) in LRPB Matadorᶲ and Scepter ᶲ. This was not always the case, however, for example treatments iv (economic) and v (premium) in LRPB Matadorᶲ and Scepterᶲ where the opposite trend is observed.

Barley

As observed for the wheat, barley establishment was aided by timely rain and soil moisture, and this was also likely to increase disease load. Spot form net blotch (SFNB) was detected in every barley trial plot. RGT Planetᶲ suffered substantially higher damage from SFNB than other varieties (Table 5), which is unsurprising as this variety is considered more susceptible to this disease than Maximus CLᶲ and Leabrook ᶲ. At the time of the GS39 spray application net form net blotch (NFNB) was the main disease present in RGT Planetᶲ plots. Two weeks post-GS39 treatment application, NFNB had spread throughout the trial, however it was prevalent mainly in RGT Planetᶲ plots. At the same time point, leaf scald hotspots were beginning to appear within Maximus CLᶲ plots.

Table 5: General disease scores in barley noted at four time points throughout the seasons.

Variety	Treatment No.	GS31	2 weeks post GS31 trt	GS39	2 weeks post trt
Leabrook	Control	3	3	2	4^
	ii)	2	3	2	*
	iii)	2	3	2	3
	iv)	2	2	2	3
	v)	2	2	2	3
	vi)	2	3	2	3
	vii)	2	3	2	3
	viii)	2	3	2	*
Maximus CL	Control	3	3	3	2
	ii)	2	3	3	*
	iii)	3	2	2	2
	iv)	2	2	2	2
	v)	3	2	2	*
	vi)	3	3	3	*
	vii)	2	3	3	3
	viii)	3	3	3	3
RGT Planet	Control	4	5	5	6
	ii)	4	5	5	5
	iii)	4	4	5	*
	iv)	4	4	5	5
	v)	5	5	5	5
	vi)	4	5	5	*
	vii)	5	4	5	4
	viii)	4	5	5	4
	Sig. Diff.				
	Variety	NS	NS	NS	0.007
	Treatment	NS	NS	NS	<.001
	Variety x Treatment	NS	NS	NS	0.003
	Lsd (p=0.05)				
	Variety	NS	NS	NS	0.2749
	Treatment	NS	NS	NS	0.4489
	Variety x Treatment	NS	NS	NS	0.7775
	CV (%)	NS	NS	NS	31.6

Plots were scored from 1–9 (9 = whole plot diseased). Replicate data for each group are summarised, based on four replicates unless otherwise stated. Scores denote observations of general signs of disease present including evidence (lesions).

**Denotes missing values.*

^Denotes one replicate of data.

Both treatment and variety imposed significant effects on the yield (t/ha) (*p*=0.041) and variety (*p*<0.001) for yield (t/ha). In the control plots, the mean yield in Maximus CL$^{\phi}$ was significantly higher than the mean yields recorded for Leabrook$^{\phi}$ and RGT Planet$^{\phi}$ (Table 6). It is possible that the difference in yield between Maximus CL$^{\phi}$ and the other varieties is due to slightly lower disease loads for this variety later in the season, as shown in Table 5. Given that Leabrook$^{\phi}$ is the more resistant variety to SFNB, this may indicate that the environmental conditions in this trial favoured Maximus CL$^{\phi}$. Unlike the wheat trial, there were no varieties that responded strongly to treatments across the board, and for RGT Planet$^{\phi}$, no disease management treatment resulted in significantly different yields compared to the control.

Within the RGT Planet$^{\phi}$ variety data, no significant differences were detected between treatments, including the control. Nevertheless, the highest yield was obtained by treatment viii, the complete treatment strategy (two sprays with premium products) however, this did not translate to return on investment, as shown by the PGM; the highest PGM for RGT Planet$^{\phi}$ was for the control treatment. The opposite was true for Leabrook$^{\phi}$ and Maximus C $^{\phi}$; the highest return on investment occurred for plots that where the yields were significantly higher than the respective controls for each variety. These findings suggest a strong influence of variety choice and disease management strategies on each other.

Table 6: Average yield (t/ha) and partial gross margin (PGM) of barley varieties and treatments.

Variety		Control	ii	iii	iv	v	vi	vii	viii
Leabrook⁽ᴰ⁾	Yield (t/ha)	4.31^{f-j}	4.24^{f-j}	4.91^{b-d}	4.48^{d-h}	4.50^{d-h}	4.64^{c-g}	4.43^{e-i}	4.49^{d-h}
	PGM($/ha)[A]	$1,275	$1,238	$1,421	$1,279	$1,283	$1,342	$1,228	$1,239
Maximus CL⁽ᴰ⁾	Yield (t/ha)	4.84^{c-e}	4.87^{b-e}	5.10^{a-c}	5.34^{ab}	4.73^{c-f}	4.80^{c-e}	5.53^{a}	5.48^{a}
	PGM($/ha)[A]	$1,431	$1,426	$1,477	$1,532	$1,349	$1,390	$1,553	$1,534
RGT Planet⁽ᴰ⁾	Yield (t/ha)	3.98^{ij}	3.85^{j}	3.86^{j}	3.91^{j}	4.09^{h-j}	3.86^{j}	4.07^{h-j}	4.22^{g-j}
	PGM($/ha)[A]	$1,177	$1,124	$1,110	$1,111	$1,162	$1,110	$1,124	$1,160
Sig. Diff.									
Treatment	**0.041**								
Variety	**<.001**								
Treatment x Variety	**NS**								
LSD (p=0.05)									
Treatment	**0.2806**								
Variety	**0.1718**								
Treatment x Variety	**NS**								
CV (%)	**0.3**								

[A]Partial gross margin of each treatment was calculated using the yields incorporated in the table, average price of BAR1 $296 at three local receival sites (correct as of 3 January 2024) minus the flutriafol and fungicide prices and an application cost of $10 per spray. Letters in superscript denote significant differences between all treatments, and shading denotes significant differences for treatments compared to the control of respective variety.

Only one instance of significant difference between economic and premium products was detected; this was for treatments iv (economic) and v (premium) for Maximus CL⁽ᴰ⁾, where the economic treatment sprayed only at GS31 yielded higher than the premium treatment sprayed at GS31. As a result of the higher yield and lower input cost, the PGM showed a higher ROI for the economic option. Nevertheless, the yield for this treatment was lower than that for both the economical and premium double-spray option for this variety, indicating that for this variety, the double-spray choice was the ideal strategy, regardless of product choice, as the PGM showed a comparable ROI between the two double-spray strategies.

Conclusion

Interim findings of this project suggest that there are complex interactions between variety choice and disease management strategy. For wheat, Scepter⁽ᴰ⁾ was more receptive to fungicide treatment compared to LRPB Matador⁽ᴰ⁾ and Hammer CL Plus⁽ᴰ⁾. Despite this, no substantial difference in yield was detected between economic and premium products for this variety, and in this case the choice may be driven more by ROI, rather than yield alone. Similar observations were made for barley, however RGT Planet⁽ᴰ⁾ did not exhibit receptivity to any treatment when compared to the control. Like the wheat trial, only one product comparison showed a significant difference in yield between the single-spray economic and premium treatments at GS31. It is hypothesised these effects may vary season to season, and that variety susceptibility plays a significant role. BCG will continue this work in 2024 to build on the work presented here.

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Useful resources

2023 Victorian and Tasmanian Crop Sowing Guide (https://grdc.com.au/__data/assets/pdf_file/0026/580580/GRDC2023_SowingGuide_VIC-TAS_Final.pdf)

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Notes

Reducing risks to canola establishment under marginal conditions– defining the fundamentals

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GRDC project codes: CSP2212-005RTX,CSP1907-001RTX

Keywords

- Canola, germination, emergence, establishment.

Take home messages

- A new project is undertaking research to determine the critical environmental conditions for successful canola establishment.
- Canola has the same fundamental requirements in all growing regions; moisture, temperature, seed soil contact and soil strength. These factors can all be influenced by management and environment.
- Timing of establishment is generally more important than plant density for achieving grain yield potential.
- Wet soil is cool soil - at a depth of 2.5cm within the seedbed, wet soil could be greater than 8°C cooler than wet soil.
- Consider the temperature forecast when sowing early - soil surface temperatures can be up to 20°C hotter than air temperature.
- Different moisture thresholds are required for germination, cotyledon emergence and survival to be determined by this project.
- Soil texture will influence thresholds for sowing depth - canola is more likely to emerge from deeper sowing (3 – 5cm) on sandy soil than clay soil.
- Seeder setup is likely to play a larger role in establishment from depth.

Background

Canola suffers from unreliable establishment; however early establishment is crucial for aligning crop development with the environment and maximising yield potential. Typically, only 50% of germinated seeds will successfully establish, leading to issues including reduced yield, increased weed problems and potentially costly resowing. This results in an estimated annual cost of $100M–$200M from poor establishment. Climate change and farming adaptations are expected to exacerbate this issue. For example, the desire to sow and establish canola early to maximise yield potential coincides with less favourable seedbed conditions. Seedbed conditions are often hotter and drier, and more volatile than those for other crops that can be sown later and deeper in the soil. A new national GRDC project aims to use a combination of lab and field experiments with simulation modelling to focus on the underlying processes affecting canola establishment and provide management strategies to mitigate establishment risks. Successful establishment is driven by the same fundamental requirements across all regions; moisture, temperature and seed soil contact., However, the fundamental thresholds to derive rules of thumb for establishment have not been yet established or validated.

A review focusing on management and environmental factors influencing canola establishment identified key research areas:

1. Interaction of moisture and temperature on early sowing establishment.
2. Impact of sowing depth and moisture-seeking ability.
3. Effects of crop residue/stubble on early sowing establishment.
4. Influence of soil crusting and strength on seed growth.

Defining Canola Establishment:

Canola establishment, often vaguely defined, is considered successful when a crop develops a leaf canopy and root system large enough for the plants to grow on their own when they are no relying seed reserves for growth. Emergence is noted when cotyledons appear, but establishment is achieved at the 3-4 true leaf stage. This involves coordinated processes (Figure 1) of seed germination, hypocotyl extension, and growth of leaves and roots (Nelson et al 2022).

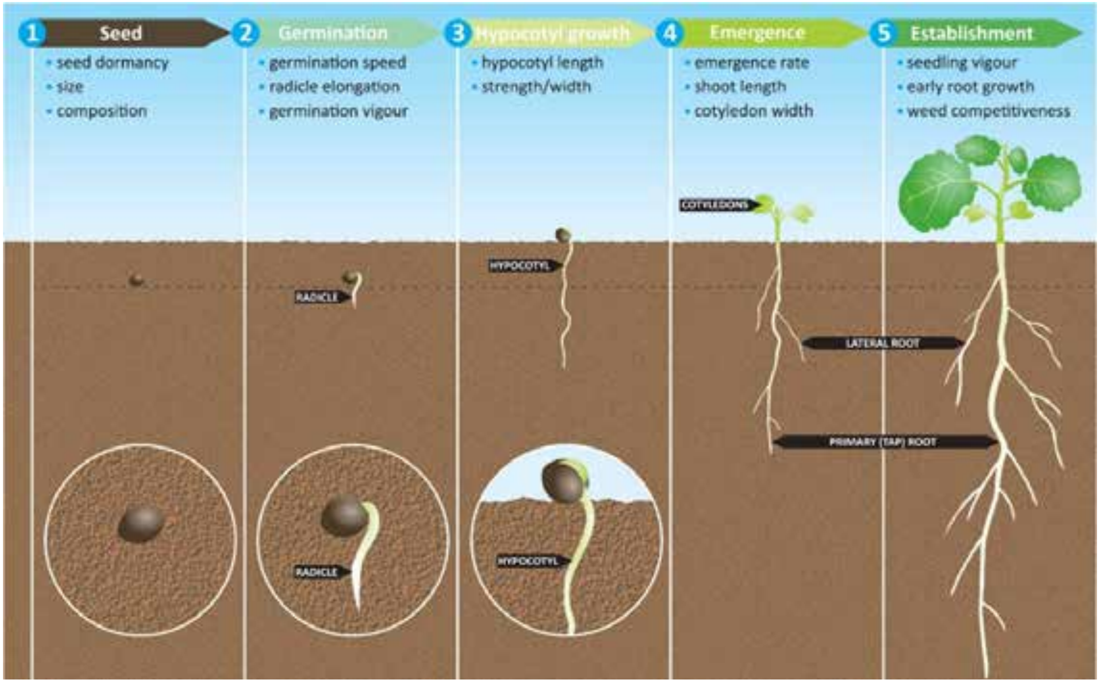

Figure 1 Growth stages between sown seed and establishment in Canola. Taken from Nelson et al. (2022).

Responses to temperature

Studies focusing on canola and related brassicas have primarily investigated germination responses to low temperatures. Optimal germination temperatures range between 25-35°C, with a base temperature of about 5°C, below which the process of germination halts. High temperatures above 35 to 40°C drastically reduce germination, often stopping it entirely. However, effects of supra-optimal temperatures remain less studied.

In 2023, field trials across Australia explored water, temperature, and soil texture gradients. These trials, including at Wynarka (sandy soil in the SA Mallee) and Ungarra (alkaline, dispersive clay on the Eyre Peninsula), involved manipulating and monitoring temperature and water at various depths in the seedbed. A significant observation was that, during April-May, surface soil temperatures in both clay and sandy soils were up to 20°C hotter than air temperatures, often exceeding accepted germination thresholds. In contrast, temperatures at 2.5cm depth in the seedbed were only up to 5°C higher than air temperatures, with the effect more pronounced in the sandy soil. This suggests that canola might have better germination prospects at cooler temperatures deeper in the soil and highlights the need to consider sowing depth in Early April when temperatures are warmer. A crucial observation from the studies is the significant cooling effect of wet soil on temperature. For instance, at Wynarka, when soil temperature was measured in the furrow late in the afternoon a day after sowing, a marked difference was noted. In sandy soil with less than 2% moisture, the temperature was 30.1°C, compared to 22.2°C in wet soil at 2.5 cm depth in the seedbed, indicating an 8°C difference. This temperature difference was less pronounced, deeper in the seed bed as both the extra layer of soil and increased moisture buffers temperature. This finding underscores the potential impact of soil moisture and depth on moderating heat stress and influencing germination timing (Figure 2).

The thermal time for canola emergence is reported to be between 90°C.d and 115°C.d. This metric can be used to estimate emergence time under optimal conditions. In southern Australian environments, this typically translates to 4-5 days under average late March to early April soil temperatures of 25°C, 7-8 days at 15°C in late April to early May, and over 12 days in May when temperatures drop below 10°C (McDonald, G., & Desbiolles, J. ,2023). This may help in understanding and predicting canola germination and emergence in varying soil moisture and temperature conditions.

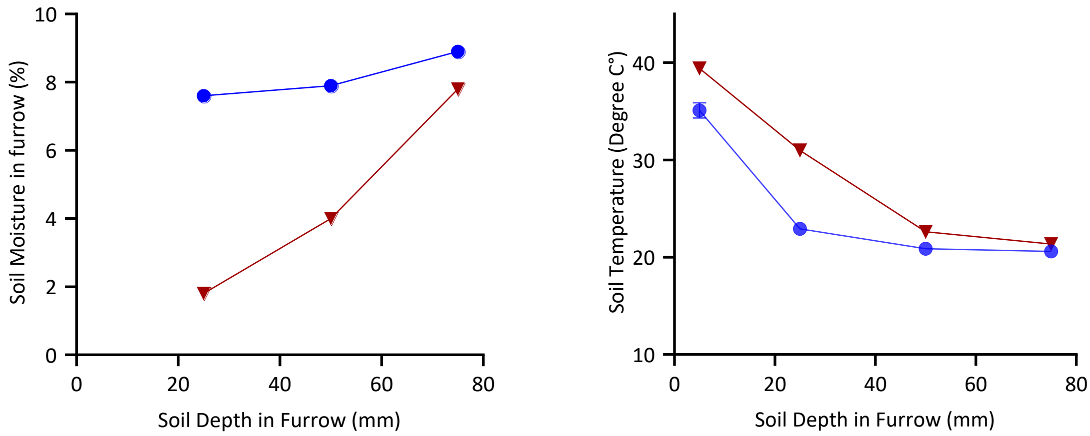

Figure 2. Soil moisture and temperature in the seed bed furrow at different depths (2.5cm, 5cm, and 7.5cm) at Wynarka in 2023 18 April under ▼ Dry conditions and ● Watered (25mm) conditions the day after sowing.

Moisture responses

The critical point in which germination is inhibited is crucial for comparisons across soil types, which exhibit different soil water release curves based on their texture. For canola, critical water potential is generally reported between -0.8 and -1.2 MPa for *germination*. However, this range might not be sufficient to guarantee *emergence* since it falls below the thresholds for any plant growth (the wilting point is at -1.5 MPa). Soil texture is a key factor, as it significantly influences soil moisture percentages and makes interpretation difficult until these numbers are converted to a known metric such as rainfall amount. For instance, the clay soil at Ungarra has a wilting point of 8%, while the sandy soil at Wynarka has a wilting point of 3.6% (as measured by suction pressure plates).

Field trials and lab experiments (with results still pending) were conducted to assess soil moisture levels both above and below the crop's lower limit. In 2023, plots were modified using tarps to exclude rainfall. A notable observation from the Wynarka sandy soil is that as little as 5mm of supplementary water applied at sowing (on 18 April) to a dry seedbed raised the soil moisture above the lower limit, leading to establishment comparable to that in soil at field capacity (figure 3). In contrast, in conditions of dry soil, emergence did not occur until 6.8mm of accumulated rainfall from 5 May to 11 May. This amount was just enough to reach the wilting point and trigger germination and emergence almost a month later than optimal, and outside the preferred sowing window for canola.

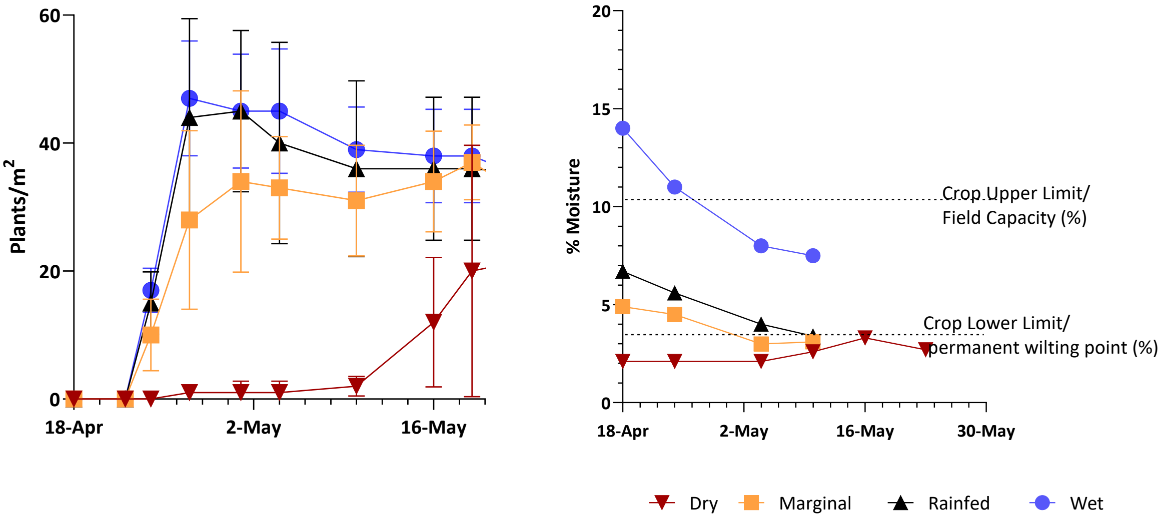

Figure 3. Plant establishment over time at 4 variable seedbed moisture profiles (2.5cm deep) at Wynarka in 2023, the cultivar was Hyola Regiment XC sown at 60 viable seeds/m^2 . Dry was tarped from the start of March until sowing to ensure dry seedbed, marginal was tarped for the same period with 5mm of water applied just prior to sowing, and wet had an additional 25mm of water at sowing.

Preliminary lab results highlight that canola's germination might occur below the wilting point, but achieving successful hypocotyl growth, cotyledon survival, and leaf emergence requires different moisture thresholds. Future research is directed towards understanding how germination inhibition relates to temperature under low moisture conditions. A key objective is to develop practical guidelines for predicting rainfall needs across various soil types, considering factors such as soil water repellence and the diversity in soil texture across different paddocks.

Implications for Yield Response

Yield responses in canola are often more closely linked to the date of emergence rather than plant density, owing to the crop's ability to compensate for reduced plant establishment. This was evident in the 2023 Wynarka trials, where early establishment correlated with higher yields. For instance, the marginal seedbed treatment that established on 23 April yielded 0.8t/ha more than crops established on 13 May under seemingly more ideal seedbed conditions (Table 1). This outcome underscores the importance of timely planting and the potential for increased yield by capitalizing on small rainfall events in April. These findings are significant for strategic farming practices, emphasizing the need for timely actions to optimize crop establishment and yield in canola farming.

Table 1. Establishment and yield response to selected treatments in the Canola cultivar Hyola Regiment XC at Wynarka on a sandy soil in 2023.

Sow Date	Treatment	Establishment Date*	Total Emergence (plants/m^2)	Grain Yield (t/ha)
17 Apr	Wet Seedbed (25mm water applied)	21 Apr	63 a	3.7 a
17 Apr	Marginal Seedbed (Dry seedbed + 5mm water)	23 Apr	30 b	3.6 a
17 Apr	Dry Seedbed	18 May	25 b	2.3 c
5 May	Wet Seedbed (25mm)	13 May	63 a	2.8 b

**Establishment date is expressed as days to achieve 20 plants/m2*

Sowing depth:

There has been renewed interest in deeper sowing as farmers sow canola increasingly early and seek moisture through deeper sowing. Research has generally shown that deeper sowing reduces canola establishment. In NSW, Brill et al. (2016) showed 30% reductions in canola emergence between 25mm and 50mm and a 70% reduction between 2.5cm and 7.5cm sowing depth on a heavier soil type. Results from the Wimmera in 2023 also found a 33% reduction in emergence from 2cm to 5cm deep on clay soil.

This was not the case on sandier soil types suggesting different thresholds with limited reduction in establishment from 2 – 5cm at Wynarka, and Kimba, however a 60, and 66% reduction in establishment respectively going from 2 – 7.5cm deep. This suggests the deep sowing threshold in sandy soils is higher than heavier textured soils with a rapid decline from 5cm rather than 2.5cm deep. Further analysis of all seedlings from the soil at Wynarka in 2023 showed establishment reduced by 10% for every 1cm deeper seed placement below 5cm at optimal moisture irrespective of soil temperature.

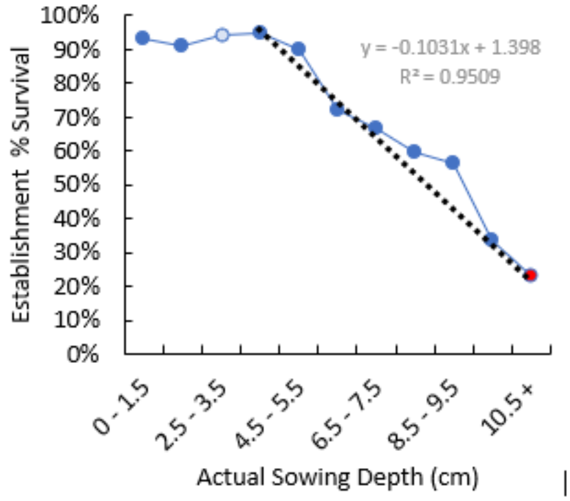

Figure 4. Relationship between seedling sowing depth and establishment survival from 5 April sowing at Wynarka sandy soil under optimal seedbed moisture conditions.

Although emergence was poor from > 5cm on these soils there were still some seeds that were able to emerge from this sowing depth and survive. This provides opportunity to exploit the interactions. Other management strategies such as cultivar type, seed size, and vigour also interact and are being explored. In a genetic study, Nelson et al. (2023) found that canola emergence at 50mm sowing depth was approximately 50% of the emergence rate at 20mm sowing depth for four common commercial cultivars across seven trials. They also tested a diverse range of genotypes from an international diversity panel and found that the best varieties from this diversity panel had emergence rates at 50mm sowing depth of up to 70% of their emergence rate when sown at 20 mm sowing depth. These cultivars originating from overseas sources, tended to be those identified as either having longer hypocotyls or high germination vigour. In contrast, Australian varieties uniformly have short-medium length hypocotyls. A new GRDC project (CSP2307-002RTX) has begun the process of introducing long hypocotyl genes from overseas varieties into Australian varieties with the aim of improving establishment potential. These are not yet commercially available. The other factor not discussed in this paper is the interaction between soil texture, compaction and soil strength which becomes more important when discussing soil depth and can be influenced by engineering and seeder setup.

Conclusion

This project will continue to work towards establishing the fundamental critical thresholds to update guidelines and reduce canola establishment failure. Key messages to date include:

- Establishment timing is more crucial for yield than plant density, with early sowing often leading to better outcomes.
- Consider the temperature forecast and soil moisture status at sowing as wet soil is cooler than dry soil, and surface soil temperatures can significantly exceed air temperatures, potential affecting seed development from shallow sowing.
- Sowing depth and soil type (ie.. sandy vs. clay) greatly influence germination and emergence thresholds and seeder setup and soil strength requires more investigation when scaling up.
- Deeper sowing typically reduces establishment, especially in heavier soils, however varietal differences, particularly in hypocotyl length and germination vigour, impact emergence, prompting efforts to incorporate beneficial traits from international varieties into Australian ones.

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 acknowledge and thank all cooperating farmers technical staff and project collaborators from other regions of the national project.

Useful resources

https://grdc.com.au/resources-and-publications/all-publications/publications/2023/crop-establishment-and-precision-planting

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Notes

New acid tolerant rhizobium strains for inoculant groups E and F

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GRDC project code: UOA2312-008RTX

(Improving the understanding and the effectiveness of N fixation in pulses in Australia)

DPI1901-002RTX

(Increasing the effectiveness of nitrogen fixation in pulses through improved rhizobial strains in the GRDC Northern region)

UOA1805-017RTX

(Increasing the effectiveness of nitrogen fixation in pulse crops through development of improved rhizobial strains, inoculation and crop management practices)

UMU1901-002RTX

(Increasing the effectiveness of nitrogen fixation in pulses through improved rhizobial strains in the GRDC Western Region)

Keywords

- Soil acidity, rhizobia, inoculation, nodulation, faba bean, lentil, field pea, N_2-fixation.

Take home messages

- Inoculation of pulses including lentil, field pea, vetch and faba bean is widely recommended, particularly where the pulse is sown into paddocks with acidic soils or, where the pulse or another in the same inoculation group has not been sown for a number of years.
- Two new high-performing rhizobia strains for inoculant Group E (lentil, field pea, vetch) and Group F (faba and broad bean) with improved nitrogen fixation and acid soil tolerance will be available for the 2024 season.
- The new strains (Group E - WSM4643, Group F- SRDI-969) will replace strain (WSM-1455).
- The new strains can provide optimal nodulation down to pH_{Ca} 5.0 and improved nodulation to pH_{Ca} 4.5.

Summary

Two new high-performing rhizobia strains for inoculant Group E (lentil, field pea, vetch) and Group F (faba and broad bean) with improved acid soil tolerance will be available for the 2024 season. The rhizobia for group of legumes are especially sensitive to soil acidity below pH_{Ca} 5.5. As a result, expansion of pulse sowings into areas containing acid soils has been restricted because of poor nodulation, plant establishment and growth. With GRDC investment, two improved inoculant strains have been selected to facilitate successful establishment and improve production of field pea, lentil and vetch, and faba and broad beans on acidic soils. The new strains (Group E - WSM4643, Group F- SRDI-969) will replace strain (WSM-1455) and can provide optimal nodulation down to pH_{Ca} 5.0 and improved nodulation to pH_{Ca} 4.5. For faba bean, the new strain (SRDI-969) has shown an average improvement of 65% in nodulation and 24% in N

fixation in field trials on acidic soils. For field pea, lentil and vetch, the new rhizobia strain (WSM-4643) has shown an average improvement in nodulation of 30% and yield of 15%, with yield responses observed at one-third of sites.

The new rhizobia strains should be used in conjunction with an effective liming strategy.

Two GRDC fact sheets (QR code links below) have been produced which how and where strains can be used and the benefits associated with the improved rhizobia strains.

Group E Inoculant Fact Sheet

Group F Inoculant Fact Sheet

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Notes

Oaten hay yield and quality response to agronomic levers

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Keywords

- agronomy, hay, oats, pathology, yield

Take home messages

- Oaten hay varieties respond similarly to different agronomic levers – choose high yielding varieties with best genetic quality traits to optimise production of export quality hay.
- Sowing early maximises hay yield but not always quality – let the variety maturity rating guide the ideal sowing time. Sow with higher plant densities than grain crops, and supply 60–90kg/ha of nitrogen depending on starting soil N levels to drive biomass without penalising quality.
- Cut oaten hay crops at watery ripe (Z71) not later to avoid the risk of hay quality declining.
- Strobilurin fungicides applied to manage crop disease four weeks before cutting reduced discolouration by saprophytes on the outside of the windrow compared to the control.

Background

The Australian export fodder industry has increased year on year over the last decade, now exporting about 1.2 million tonnes of hay, valued at more than $500 million. Over the past 10 years, the main export production states were Western Australia, South Australia and Victoria, averaging 40%, 31% and 21% of production volume respectively (AgriFutures Export Fodder Program Strategic RD&E Plan 2021–2026).

The AgriFutures Australia Export Fodder program invests in oaten hay quality research to influence grower practices and strengthen Australia's position as a supplier of choice within our export markets.

The National Hay Agronomy (NHA) project (2019–2022) was an investment with the objectives to:

- improve agronomic guidelines to maximise oaten hay production and quality (variety selection, nutrition, optimum seeding date to increase quality and decrease risk)
- clarify the potential for growth regulators in oaten hay production
- update disease management guidelines for oaten hay crops.

Method

To improve agronomic guidelines, a core trial series evaluated the performance of eight different varieties sown with three or six different nitrogen (N) rates and two sowing dates across three seasons (12 trials located in Western Australia (WA); Muresk (2019 to 2021), South Australia (SA); Hart (2019 to 2021), Victoria (Vic); Kalkee (2019), Rupanyup (2020), Wallup (2021) and New South Wales (NSW); Yanco (2019), Yenda (2020), Wagga Wagga (2021). Additional regionally specific trials were sown to 1) Evaluate five new oat varieties in WA; Muresk (2021) and SA; Jabuk, Tarlee (2021)), 2) Compare Kingbale⁽ᴰ⁾ versus its parent Wintaroo⁽ᴰ⁾ (four trials: WA; Wongan Hills, Muresk (2020), SA Tarlee, Lameroo (2020)) 3) Measure the effects of growth stage at cutting on hay performance (two trials: WA; Muresk (2020), Vic; Rupanyup (2020)), 4) Investigate the role of grazing in mixed farming systems and its impact on oaten hay (four trials: NSW; Dirnaseer, Gerogery (2020), Yenda (2020, 2021), Wagga Wagga (2021)), and 5) Identifying the target plant density for export oaten hay in NSW; Gerogery (2019 to 2021), Yanco, Marrar (2019), Dirnaseer, Yenda (2020), Wagga Wagga (2021)).

Glasshouse screening and field trials evaluated Moddus® Evo for lodging management (four trials: WA; Nunile, Highbury (2019), SA; Tarlee (2020), Vic; Kalkee (2019)) and ProGibb® SG for assisting panicle emergence (four trials: WA; Wongan Hills (2020), SA; Booleroo, Lameroo, Tarlee (2020)). Note, ProGibb® SG is not registered for use in oaten hay.

The project conducted a review of plant diseases impacting oaten hay and produced disease management factsheets with updated management guidelines for red leather leaf, Septoria, oat stem and leaf (crown) rust. Disease surveillance occurred on 20 crops annually (Vic, WA), and disease management trials were conducted for red leather leaf (RLL) (six trials: Vic), Septoria (five trials: WA), oat leaf (crown) rust (two trials: WA) and saprophyte suppression (management of weather damage) (five trials: WA, Vic).

Results and discussion

The following summarises key oaten hay agronomy results from the National Hay Agronomy trials 2019 to 2021.

Time of sowing

- Earlier sowing (late April/early May) increased the opportunity to maximise hay yield but did not always maximise hay quality compared to a conventional sowing time.
- Earlier sown hay tended to have thicker stems, higher fibre levels and lower crude protein, but had higher water-soluble carbohydrates (WSC) (except Koorabup) compared to sowing in late May/early June. This trend was not always consistent across sites and years but was the general trend when the data was averaged.
- The variety response to sowing date was variable, and not easily predicted at the start of the season; often the pattern of in-season rainfall had the most influence.

Nitrogen rate

N applications drove more biomass, taller and greener plants, and increased the risk of lodging, especially in susceptible varieties.

- Peak hay yield was achieved with 90kg N/ha, although 60kg N/ha was adequate when sites received below-average rain during critical growth periods.
- Nitrogen was not a major driver of hay quality defects (thick stem diameter, or high acid detergent fibre (ADF), neutral detergent fibre (NDF) or lignin), but was linked to increased crude protein and decreased WSC. Applying >90kg N/ha increased the risk of not meeting industry WSC guidelines for premium hay of more than 22%.
- Varieties responded the same to increasing N rates for hay quality traits, across a range of seasons. More N could be applied to varieties with higher genetic WSC, for example, Yallara$^{\phi}$, before they drop a grade, potentially growing more hay of export quality.
- The response to N was generally consistent between the planting dates, albeit with varying degrees of impact.
- Across trials, both season and variety were the larger drivers of hay quality rather than the rate of N applied.

Variety choice

Hay yield and quality was assessed for four dual-purpose varieties (Carrolup, Durack$^{\phi}$, Williams$^{\phi}$ and Yallara$^{\phi}$) and four hay-only varieties (Brusher$^{\phi}$, Koorabup$^{\phi}$, Mulgara$^{\phi}$ and Wintaroo$^{\phi}$).

- Brusher$^{\phi}$ and Wintaroo$^{\phi}$ were the leading varieties for hay yield, when yields were averaged across years, sites, N treatments and sowing dates, at the first sowing date (late April/early May), while Wintaroo$^{\phi}$ had the highest yield of the second sowing date (late May/early June). The varietal hay yield differences at the early sowing date were 1.0t/ha and 0.6t/ha when sowing was delayed. Brusher$^{\phi}$ lost the most hay yield with delayed sowing (1.8t/ha), while Carrolup and Durack$^{\phi}$ were the least affected, with only a 1.0t/ha reduction in yield.
- Brusher$^{\phi}$ and Wintaroo$^{\phi}$ were most likely to experience lodging, followed by Mulgara$^{\phi}$. Varieties differed in stem diameter, with Carrolup, Durack$^{\phi}$ and Koorabup$^{\phi}$ averaging 0.5mm narrower stems than Mulgara$^{\phi}$, Williams$^{\phi}$ and Wintaroo$^{\phi}$. Wintaroo was most likely to produce hay with a stem diameter wider than 6mm, the upper limit for premium hay.
- Brusher$^{\phi}$ was more variable across years, sites, N treatments and sowing dates in its hay greenness, as measured by a Soil Plant Analysis Development (SPAD) chlorophyll meter, than the other seven varieties. Durack$^{\phi}$ hay was the greenest, averaging five SPAD units darker than Carrolup, Mulgara$^{\phi}$ and Wintaroo$^{\phi}$, which were the lightest green. Williams$^{\phi}$ varied the least in the greenness of all the varieties. Their greenness was related to their performance and suitability for the different sowing dates.

- Hay variety quality traits were measured in the NHA trials.
  - o Digestibility – Brusher^⊕^, Mulgara^⊕^ and Yallara^⊕^ were more digestible than Durack^⊕^.
  - o Crude Protein (CP) – Williams^⊕^ had the highest CP and Wintaroo^⊕^ the lowest.
  - o WSC – Yallara^⊕^ had the highest WSC, and Koorabup^⊕^ and Williams^⊕^ had the lowest.
  - o ADF – Koorabup^A^ and Wintaroo^⊕^ had the highest average ADF, and Brusher^⊕^ and Yallara^⊕^ the lowest.
  - o NDF – Koorabup^⊕^ and Wintaroo^⊕^ had the highest average NDF, and Yallara^⊕^ had the
  - o lowest.
  - o NDF digestibility after 30 hours (NDFDom30) – Brusher^⊕^, Mulgara^⊕^ and Yallara^⊕^ hay had higher levels of rumen digestibility after 30 hours than Carrolup and Durack^⊕^ hay.
- Yallara^⊕^, a quick dual-purpose variety, was best performing for quality, with the highest WSC and lowest fibre levels, and thin stems. Yallara^⊕^ had comparable hay yield to Brusher^⊕^ and Wintaroo^⊕^, with lower lodging risk and similar hay colour. Its flag leaf is erect, making it more vulnerable to impact by adverse weather in a dry finish. Yallara^⊕^ can be a bit quick for better seasons in higher rainfall areas.
- New specialist hay variety Koorabup^⊕^ (released for superior Septoria resistance) did not perform well when benchmarked against Brusher^⊕^, yielding 0.5t/ha lower, with a higher ADF and NDF risk, lower WSC, but had similar hay greenness and stem diameter.

New hay varieties

Intergrain are working hard to breed new oat varieties with improved hay and grain profitability (*Allan Rattey, pers. comms. January 2023*).

- Wallaby^⊕^ is a mid-late maturity line with market leading quality, suitable for sowing in the last week of April until the third week of May, like Kingbale^⊕^ and Wintaroo ^⊕^, and 7–10 days earlier than Mulgara^⊕^.
- Kultarr^⊕^ is a tall, mid-maturity line with market leading biomass and export suitable quality for May sowing.
- Archer^⊕^ and Kingbale^⊕^ produce high biomass and export suitable quality. Archer^⊕^ and Kingbale^⊕^ are suitable for IMI residue (IBS) systems.
- 13008-18 is a promising new line, with improved grain yield and grain quality, being slightly taller and earlier to flower than Bannister^⊕^. Early dual-purpose data for 13008-18 is encouraging.

Cutting growth stage

Watery ripe (Z71) (when grain is formed but only contains clear, greenish liquid and is not drawing heavily on carbohydrate from photosynthesis or storage) is considered the ideal cutting time for optimising hay yield and achieving quality targets. As the industry looks to optimise hay quality, one option available to growers is to cut the crop before it reaches the watery-ripe stage. Choosing the best cutting time is a careful balance between quality, yield, panicle emergence, current and forecast weather.

NHA trials demonstrated the effect of spring growing conditions on delayed cutting and the subsequent effect on hay quality. In 2020, WA trials at Muresk experienced a drier than average spring. Hay quality and quantity was optimised between panicle emergence (Z59) and Z71. During this growth window, traits such as WSC, ADF, NDF and leaf chlorophyll content plateaued, but then deteriorated as the crop growth progressed beyond Z71. Crude protein progressively reduced following Z59. Further yield increase beyond Z71 was outweighed by lower quality, and profitability fell. Victorian trials at Rupanyup experienced a wetter than average spring, and most oat varieties held hay quality from Z59 through to 14 days after Z71. Yield increased significantly as the crop matured.

Cutting in the Z59 to Z71 window helps minimise curing time before quality starts to rapidly decline. Slight delays in cutting can be tolerated when there is adequate spring moisture and mild conditions.

Spikelets ripen down the panicle, so inspect the top florets to make growth stage cutting decisions. Note however, that panicle emergence and watery ripe growth stage aren't always sequential, i.e. genetics and environmental conditions influence the degree of panicle emergence prior to the onset of watery ripe.

Effects of grazing

Southern NSW hay crop production typically achieves high yields which may not meet export quality standards, therefore the focus is on supplying domestic dairy markets. Grazing dual purpose oats is common. In NSW crop defoliation trials sown in 2020 and 2021, both very wet, high yielding years, simulated grazing significantly reduced hay yield compared to the control (from 13.5–15.5t/ha ungrazed to 10–11t/ha grazed), however, produced more manageable crop canopies with quality better aligned to the requirements of export hay customers for hay production.

An SA trial at Tarlee in 2020 measured similar responses to grazing on oaten hay crops, reducing hay yield by 2t/ha, with a reduction in plant height and lodging, and finer stems compared to the ungrazed crop.

Gains achieved from grazing crops and potential hay quality improvements will depend on livestock returns and the export price premium over the domestic market at that time.

Target plant density

Southern NSW growers typically sow fodder crops at grain-crop densities, which can be more than 50% lower than what is beneficial in other states (targeting 320 plants/m^2). Research evaluated the effect of plant densities ranging from 160–360 plants/m^2.

Hay yield responded to the different seasonal conditions.

- In the dry 2019 season, hay yield was maintained across increasing plant density.
- Hay yield increased in the wetter seasons of 2020 and 2021, but only by 1.2t/ha.
- As plant densities increased, stem diameter decreased, improving physical hay quality in all seasons.
- In a more average season, the cost of higher plant densities positive impact on hay yield should offset the cost of sowing extra seed.

To target higher quality oaten hay, set the crop up at the beginning of the season with higher target plant densities than grain-only crops to reduce stem diameter, and other hay quality traits, while also providing a stronger plant base structure to support cut hay off the ground, reducing potential quality losses from slower drying hay windrows or wet soil.

Lodging management using Moddus Evo

Moddus Evo inhibits the formation of gibberellic acid (GA), which promotes cell elongation. It is sometimes used to reduce height of wheat or barley crops grown in higher rainfall or high fertility situations that are prone to lodging.

Trials on oaten hay varieties showed the label rate of 400mL/ha of Moddus Evo applied at Z31–Z32, compared to the control:

- improved straw strength and reduced the lodging risk
- reduced yield and height
- did not change stem diameter when cut at 15cm
- affected panicle emergence for some varieties which could cause curing time issues.

Careful consideration should be given before applying Moddus Evo at the label rate to oats for export hay, as it is hard to predict the likelihood of lodging at Z31 and could cause panicle emergence issues.

A lower (unregistered) trial rate of 200mL/ha of Moddus Evo at Z31–Z32, compared to the control and higher rate of Moddus Evo:

- maintained the benefit of better straw strength and lowered lodging risk
- reduced the risk of yield loss.

Managing panicle emergence using gibberellic acid

In dry seasons, and in low rainfall environments, the panicles of oats can be slow to emerge from the leaf sheath, often only partially emerging prior to the watery ripe growth stage. This results in growers either delaying cutting until they have fully emerged or cutting at the right growth stage with extended curing time due to the biomass contained within the leaf sheath. Both of these scenarios can result in reduced hay quality due to the decline in water soluble carbohydrates and increase in fibre when cutting occurs at the later growth stages, or the increased environmental exposure and potential for weather damage as the hay cures over a longer period of time.

Trials showed application of GA as ProGibb SG at 40g/ha at Z31–Z32, Z37–Z39, or both times, did not improve panicle emergence. Note, ProGibb SG is not registered for use in oaten hay (but is recommended on oats for forage).

- GA elongated the nodes, but it elongated them all, producing taller plants, not just the peduncle.
- There was no adverse effect on hay yield or quality of applying ProGibb SG.
- Later applications (post-flag leaf emergence) of GA may be required, or other growth regulator products, so that effect is only seen on the peduncle.

Plant pathology

Disease surveillance

Disease surveillance conducted across Western Australia and Victoria from 2018 to 2021 showed:

- *Septoria avenae* blotch was the most common disease in WA (>90% paddocks surveyed)
- RLL is the most common and severe foliar disease in Southeastern Australia

- RLL was detected and confirmed in WA oat crops.

Saprophyte suppression/weather damage trials

Post-cutting hay discoloration due to saprophytes reduces visual quality, suitability for export markets and economic returns. Saprophytes feed on dead and decaying plant tissue, so curing hay provides an ideal environment for colonisation, especially when it coincides with rainfall events.

- Late season strobilurin application reduced the visual quantity of saprophytic fungal growth on the exposed/bleached portion of the windrow (the green portion of the windrow was unaffected), without impacting yield and nutritional quality.
- Strobilurin fungicides were more effective at decreasing saprophytic growth than triazole based chemistries. Strobilurin chemistries all had the same level of impact as each other.
- Applying strobilurins 4 weeks prior to cutting at Z71, was just as effective as applying 3 weeks prior to cutting and provided a wider cutting window while reducing hay residue risk compared to no application.
- Fungicides should be applied to manage the diseases present in-crop, with any additional saprophyte suppression an off-target bonus rather than being for the sole purpose of the application.

Conclusion

Growing oaten hay that meets export quality standards is achieved by choosing high yielding varieties with favourable quality traits, and by managing the crop for with optimal nutrition and disease protection, coupled with timely cutting and curing that maintains this high quality.

Varieties respond similarly to agronomic levers, but by choosing varieties with genetically higher quality traits, their hay quality response to sowing time, higher nitrogen rates that drive biomass and seasonal rainfall patterns, growers will be more likely to meet export quality hay standards.

Understand your hay tests for quality and understand your buyer needs to plan agronomic strategies that help improve or continue to produce a consistent quality product.

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Plant diseases impacting oaten hay production in Australia – a review (https://agrifutures.com.au/product/plant-diseases-impacting-oaten-hay-production-in-australia-a-review/)

Red leather leaf of hay oats disease management guide (https://agrifutures.com.au/product/red-leather-leaf-of-hay-oats-disease-management-guide/)

Septoria avenae blotch disease management guide (https://agrifutures.com.au/product/septoria-avenae-blotch-disease-management-guide/)

Oat stem and leaf (crown) rust disease management guide (https://agrifutures.com.au/product/oat-stem-and-leaf-crown-rust-disease-management-guide/)

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Notes

Emerging strategies for managing pulse foliar disease

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Keywords

- ascochyta pathotype, botrytis, disease management, sclerotinia.

Take home messages

- Foliar disease in pulses was infrequently reported in 2023, likely due to the dry spring. Foliar fungicides were likely unnecessary unless disease was observed, as most pulse foliar diseases require high humidity or recurring rain events.
- The first step to good disease management is choosing a resistant variety.
- Integrated disease management (IDM) practices also serve to minimise the risk of fungicide resistance developing.
- Sclerotinia disease in pulses was rare in 2023. However, severe Sclerotinia was reported in canola crops, reflecting a legacy effect of soil inoculum in paddocks sown to pulses in 2022.
- There were early reports of Botrytis disease in lentil and faba bean in July 2023. This is due to high inoculum load from 2022, coupled with above average June rainfall. Disease did not progress in the dry spring.
- Manage lentil varieties for Ascochyta blight based on pathotype 2 (Hurricane-virulent) ratings, as this pathotype is dominant in South Australia. A shift away from pathotype 1 (Nipper-virulent) towards dual pathotype 1 and 2 virulence has occurred.

Integrated disease management

To reduce the risk of foliar pulse disease and the risk of fungicide resistance developing, implement as many of the following practices each season.

- Maintain a 3–4-year gap between crops of the same type in the same paddock to reduce disease carryover from stubble and soil.
- Sow disease-resistant varieties to help reduce disease and the number of fungicide applications required.
- Sow clean seed or apply seed treatments to protect emerging seedlings. Seed and soil testing before sowing helps informs growers of disease risk.
- Avoid sowing near the previous year's pulse crop, including neighbour's stubble, to avoid infection by stubble-borne diseases.
- Monitor early for disease, especially near neighbouring stubble, in over-sown areas of the paddock and under trees or powerlines.
- Plan your foliar fungicide strategy early. Always mix and rotate fungicide groups, avoid consecutive use of the same group, and adhere to label restrictions. Spray ahead of rain, if disease is present.
- A pre-canopy closure spray will protect the base of the plant before the canopy closes over. Podding sprays may be required to protect the developing grain.
- Consider economics of continued disease management and crop end use (withholding periods, minimum residue levels).

For information on minimising the risk of fungicide resistance, including workshops, podcasts and the fungicide resistance management guide, visit the Australian Fungicide Resistance Extension Network (AFREN) at afren.com.au.

Disease ratings for pulse varieties are reviewed annually in the National Variety Trial (NVT) disease ratings review. This is usually finalised by early March and updated ratings are available from nvt.grdc.com.au/nvt-disease-ratings.

Sclerotinia white mould in pulses

Sclerotinia white mould (SWM) poses an increasing threat in southern Australian grain growing regions. SWM is caused by the soilborne fungus, *Sclerotinia* spp., and produces durable survival structures (sclerotia) that survive in the soil for many years, creating a legacy effect for future pulse or canola crops. High sclerotia populations can lead to basal stem infection and seedling death. Symptoms include bleaching or cottony white fungal growth on and in foliage, stems, pods and grain, and flowers are susceptible. Sclerotia on/in plant foliage can contaminate harvested grain, acting as a future inoculum source if the grain is not screened.

Prevalence of SWM in 2022 vs 2023

The 2022 season was highly conducive for SWM and several lentil paddocks were severely affected in SA (Blake et al. 2023) and Vic (Fanning 2023), whereas SWM was sporadically reported in 2023 likely due to the drier conditions and decile 1/2 rainfall (BOM). Surveys of lentil crops conducted in SA in spring revealed disease incidence in four of six paddocks of 88–95% in 2022 (Blake et al. 2023), compared to disease incidence in four of five paddocks of 2–9% in 2023. In Victoria during 2022, 60% of paddocks had Sclerotinia with a greater proportion in the Mallee compared to the Wimmera. Despite a high risk moving into 2023, no Sclerotinia was observed in the paddock surveys due to environmental conditions. The legacy effect of SWM in lentil in SA was also shown through reports of severe Sclerotinia stem rot in canola in 2023 that occurred in paddocks sown to lentil in 2022.

Lentil trials examining yield loss, agronomic factors and varietal response to SWM

In 2023 at Long Plains in SA, trials were conducted to examine the yield loss from SWM in different lentil varieties (Table 1) and under different crop canopies manipulated by two times of sowing (Table 2). This site was selected as it had a high level of soil inoculum and high disease severity in 2022 (Blake et al. 2023). A low level of SWM symptoms were rated in the trials on 26 September 2023. Grain yield of lentil varieties was poorly correlated with their disease severity (R^2=0.203); however, higher grain yield was achieved at the earlier time of sowing despite the higher level of disease symptoms. These trials will be repeated in 2024 in anticipation of more conducive environmental conditions for SWM disease at the site.

Table 1: Grain yield (t/ha) and SWM disease severity (% of wilted plants per plot) of lentil varieties at Long Plains SA in 2023. Least significant difference of means (5% level) shown for each variable.

Variety	Grain yield (t/ha)	% wilted plants/plot
PBA HighlandXT⍉	2.46 a	24.17 b
PBA Hallmark XT⍉	2.40 a	15.00 c
GIA Lightning⍉	2.35 a	25.00 b
PBA Hurricane XT⍉	2.20 b	34.17 a
GIA Leader⍉	2.08 bc	27.50 ab
PBA KelpieXT⍉	1.96 c	24.17 b
p	<.001	0.008
Lsd (5%)	0.1462	9.0

Table 2: Grain yield (t/ha) and SWM disease severity (% of wilted plants per plot) of PBA Hurricane XT⍉ at two times of sowing at Long Plains SA in 2023. Least significant difference of means (5% level) shown for each variable.

Time of Sowing	Grain Yield (t/ha)	% wilted plants/plot
TOS1 - 2 May	2.27 a	32.22 a
TOS2 - 5 June	1.93 b	0.33 b
p	0.042	0.003
Lsd (5%)	0.305	13.24

In 2022 at Wagga Wagga, NSW, a lentil variety trial was conducted to assess yield loss from SWM and a high level of SWM developed. Unfortunately, continued wet weather through spring compromised results. Yields were highest in the Complete Control (fortnightly fungicide) treatments, but this was not always significant and yield response to a single foliar fungicide application at canopy closure did not always increase yields over the Nil treatment (Table 3). Plant infection was lowest in the Complete Control treatment, but there were no significant differences between the Nil and Canopy Closure treatments (Table 4). A single application of foliar fungicide at canopy closure did not provide adequate periods of protection under conditions of prolonged disease pressure. Interestingly, total sclerotia weight was highest in the Complete Control treatment, likely due to the retention of green leaf within the canopy (Table 5).

Table 3: Effect of foliar fungicide treatment to manage Sclerotinia disease (SWM) on grain yield averaged across five lentil varieties sown at Wagga Wagga, NSW 2022.

Treatment	Grain weight (t/ha)	SE	Test 5% Lsd
CANOPY_CLOSURE	1.44	0.196	A
COMPLETE_CONTROL	2.07	0.196	B
NIL	1.36	0.196	A
SED	0.166		
5% Lsd	0.3294		

Table 4: Effect of foliar fungicide treatment on the incidence of Sclerotinia disease (SWM) (% plants infected along 2m row) averaged across five lentil varieties sown at Wagga Wagga, NSW 2022.

Treatment	% infected per 2m row	SE	Test 5% Lsd
CANOPY_CLOSURE	58.2	3.65	B
COMPLETE_CONTROL	26.3	3.64	A
NIL	57.2	3.64	B
SED	4.024		
5% Lsd	8.127		

Table 5: Effect of fungicide treatment to manage Sclerotinia disease (SWM) on production of sclerotia averaged across five lentil varieties sown at Wagga Wagga, NSW 2022.

Treatment	Sclerotia weight (kg/ha)	SE	Test 5% Lsd
CANOPY_CLOSURE	4.11	0.067	A
COMPLETE_CONTROL	5.44	0.067	B
NIL	3.13	0.067	A
SED	0.566		
5% Lsd	1.12E-01		

Management of SWM in pulses

Crop rotation and careful paddock selection to avoid SWM infection are the most effective control measures. High risk paddocks are those with canola or pulses in the rotation, a history of previous outbreaks of Sclerotinia, and where high growing-season rainfall is forecast. Note that pasture and broadleaf weed species are also hosts. PREDICTA B testing of *Sclerotinia* spp. soil inoculum levels after harvest will inform growers of disease risk. The new GRDC investment (DPI2206-023RTX) is showing that behaviour of Sclerotinia disease in each crop species is unique. The behaviour of SWM in pulses is very different to that in canola and should be managed as such, as the plant to plant spread of the disease, for example, is unique to lentil.

Foliar fungicides will go part way to managing the disease, but basal infections cannot be managed. There are a limited number of fungicides registered for control of Sclerotinia disease in pulse and canola crops. For more information: extensionaus.com.au/FieldCropDiseasesVic/sclerotinia-in-victorian-pulses/

For information on Sclerotinia in canola: grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/07/managing-sclerotinia-stem-rot-of-canola-in-2022

Botrytis disease of lentil and faba bean

Botrytis grey mould (BGM) of lentil and chocolate spot (CS) of faba bean were infrequently reported during 2023 in SA. Early reports of BGM on lentil in SA and Vic in mid-July 2023 following the decile 9/10 rainfall in June (BOM) did not progress in spring, likely due to the dry seasonal conditions.

Botrytis disease is favoured by mild temperatures (15–25°C) and high humidity (>70%). It can also develop slowly in cool conditions, particularly with a high inoculum load, humidity, or a full soil moisture profile. Early sowing or high seeding rates can create a warm humid microclimate under dense canopies, ideal for rapid disease development in spring. In lentils, symptoms start as pale grey to light tan leaf lesions without black spots in the centre. Severe infections may result in easily liberated fluffy grey fungal material when the canopy is parted and eventual crop collapse. Faba beans show initial symptoms as red-brown discrete scattered spots over leaves and flower petals. With severe infection, lesions merge causing rapid defoliation and flower abortion within a few days.

The development of cost-effective IDM strategies for control of Botrytis disease (and Ascochyta blight, AB) of lentil and faba bean is the focus of a new national three-year GRDC investment led by Agriculture Victoria (DJP2304-004RTX; 2023-2026). This will complement validation research being conducted in the SARDI/UoA-led state-wide Grain Legume Validation project (GRDC investment UOA2105-013RTX, 2021-2025). However, due to the dry spring in 2023, Botrytis disease did not develop in these trials at Maitland, Riverton or Tarlee in SA.

Growers are encouraged to implement IDM best practice (see above). Sowing disease resistant varieties helps reduce disease severity and preserve or increase grain yield (Blake et al. 2023;). Ensure that varietal selections are compatible with the disease risk profile, paddock history, local climate, soil type, and agronomic management. Disease risk will be higher in regions where canopy closure is achieved, as often climatic conditions in these regions are more disease conducive.

Managing BGM in lentil with foliar fungicides

Several fungicides are registered for control of BGM in lentil. Newer fungicides with dual modes of action, as well as Filan® and Sumisclex®, show superior disease control and grain yield preservation in a high disease situation (Blake et al. 2023). However, judicious use of fungicides along with cultural practices and crop rotation, is critical to protect the current chemistries.

Two new coformulations (DMI+SDHI and DMI+QoI) of three new active ingredients not currently registered on pulses are anticipated for registration in the next 12–24 months by BASF (I. Francis, *pers. comm*.).

For medium to high rainfall regions, apply a pre-canopy closure spray regardless of the BGM resistance rating. Varieties rated MRMS and less may require additional sprays before rain in high-risk situations every 2–3 weeks. Follow-up sprays may be necessary in MR varieties or during highly conducive disease seasons. A podding spray may also be required to protect the developing grain from both BGM and AB. Always follow label directions. In low rainfall zones, the economic justification for fungicide sprays should consider the likelihood of achieving canopy closure and of ongoing humid conditions that favour the disease. This is particularly important with early sown crops.

In 2023, Agricultural Innovation & Research Eyre Peninsula (AIR EP) and South Australian Grain Industry Trust (SAGIT) co-funded research to examine the effectiveness and economic benefit of different fungicide strategies on lentil in a warm, low rainfall climate with short, mild winters. Trials were conducted at Mount Cooper and Mount Damper on the Eyre Peninsula, however no disease developed as conditions were not conducive. Fungicide spray(s) were uneconomical in a decile 1 rainfall spring in this region.

Managing CS in faba bean with foliar fungicides

PBA AmberleyΦ, rated MRMS, is the most resistant faba bean variety to CS but still benefits from foliar fungicide application. Several fungicides are registered or permitted for control of CS in faba bean, however application timing is critical. During 2022, reports of a mistimed spray(s), often due to persistent rain restricting paddock access, were associated with moderate to severe CS, crop lodging, and occasional crop failure. Proactively control CS with early-mid flowering sprays before symptoms appear. Follow-up sprays are needed in high rainfall situations and high biomass crops. Crop areas around trees and under power lines can be CS hot spots if not reached by spray equipment.

Monitoring the lentil Ascochyta blight pathogen population

Annual controlled environment testing of 29 *Ascochyta lentis* isolates collected from SA in 2022 was conducted in 2023 on an expanded lentil differential host set that included alternative sources of resistance to AB (Table 6). This is the second year in a row that no isolates were characterised as pathotype 1 (Nipper-virulent). A shift towards pathotype 2 (Hurricane-virulent), and dual virulent isolates that combine both pathotypes 1 and 2, has occurred (Figure 1). Of the isolates tested, 90% were capable of infecting PBA Hurricane XTΦ which is currently rated MRMS to AB pathotype 2. Twelve of 29 isolates (41%) were capable of infecting PBA HighlandXTΦ and five of 29 (17%) were capable of infecting PBA Jumbo2Φ.

Monitor and proactively manage lentil varieties for AB based on the current NVT rating for pathotype 2. If disease occurs, plan to spray before rain, mixing and rotating modes of action. Where AB is present with persistent wet weather before harvest, pod infection may cause seed staining and quality downgrades. Podding sprays may be necessary in a wet spring; always adhere to withholding periods and follow label directions for use.

Table 6: Twenty-nine *Ascochyta lentis* isolates collected in 2022 from SA were inoculated onto a lentil host differential set in controlled environment conditions in 2023. Entries in the table are the number of isolates per category.

Test reaction	**Cumra** (susceptible check)	**Nipper**$^{\phi}$	**PBA Hurricane XT**$^{\phi}$	**PBA HighlandXT**$^{\phi}$	**PBA Jumbo2**$^{\phi}$	**AK Mercimek** (landrace from Turkey)	**ILL2024** (elite breeding line with boron tolerance)	**ILL7537** (elite breeding line)
R	3	14	3	17	24	21	6	29
MR	4	9	7	8	4	8	7	0
MRMS	5	5	8	4	1	0	12	0
MS	15	1	10	0	0	0	4	0
S	2	0	1	0	0	0	0	0
Total	29	29	29	29	29	29	29	29

Key: R = resistant, MR = moderately resistant, MRMS - moderately resistant moderately susceptible, MS = moderately susceptible, S = susceptible

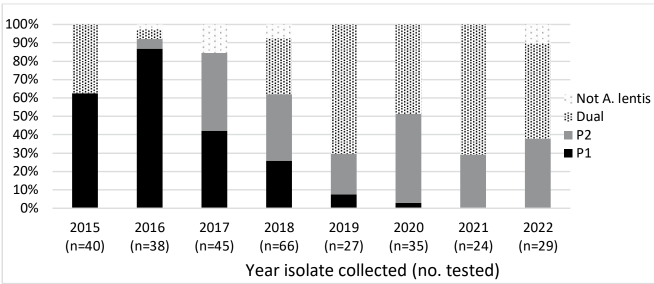

Figure 1. Annual testing of *Ascochyta lentis* isolates (n) collected from 2015 to 2022 from SA and VIC and their pathotype characterisation. Legend: P1 = pathotype 1, Nipper-virulent; P2 = pathotype 2, Hurricane-virulent; dual = combined pathotype 1 and 2; Not *A. lentis* = did not infect susceptible lentil check line.

Diseased samples of Ascochyta blight and Sclerotinia sought

Diseased samples of pulses with AB, and pulses and canola with Sclerotinia, are sought by SARDI for GRDC investments monitoring pathogen populations and changes in varietal resistance. If you can help, please contact Sara Blake (sara.blake@sa.gov.au) or Mohsen Khani (mohsen.khani@sa.gov.au) for a collection kit that includes sample envelopes and a return Express Post envelope.

Diagnostic plant samples

Send 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. Please email PIRSA.SARDIPulsepathology@sa.gov.au to notify the team that the plants are coming.

Crop protection products for pulses

For current registrations including minor use permits, visit Grain Producers Australia (www.grainproducers.com.au/industry-pesticide-permits) or APVMA (www.apvma.gov.au).

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Resources

Seasonal disease reports – subscribe to SA Crop Watch e-newsletter (bit.ly/CropWatchSA)

2024 South Australian Crop Sowing Guide (bit.ly/2024SASowingGuide)

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Notes

Regenerative opportunities for building soil biological resilience – a case study in the low-rainfall zone in Southern Australia

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GRDC project codes: CSP2401-015RTX

Keywords

- biota, microorganisms, regenerative agriculture, resilience.

Take home messages

- Soil improvement is at the core of regenerative agriculture, with a strong focus on ecosystem and environmental sustainability.
- Management is the key to maintaining and enhancing soil biological functional capacity in lower organic matter soils in southern Australia, which is integral for productivity, C sequestration, soil and ecosystem health and sustainability of agriculture.
- Management practices that reduce the amount of plant C inputs, such as grazing crops/stubble and hay removal, generally resulted in lower soil biological capacity and overall multi-functional biological index.
- Practices relevant to regenerative agriculture have direct consequences on soil multi-functionalities and resilience in the lower fertility agricultural fields of southern Australia, suggesting potential for some customisation of regenerative agriculture application in this region.

Background

To meet the ever-increasing global food demand, new approaches for sustainable agriculture with reduced environmental impact have been proposed. These include sustainable intensification, climate-smart agriculture, organic and regenerative agriculture, all of which rely on soil's health or capacity to support production and other ecosystem functions. While there are many definitions of regenerative agriculture (RA), it is usually seen to have a central emphasis on the state and trajectory of the natural capital base (soil, water and biodiversity), including soil resilience (Robertson et al. 2022). Although there are many versions of what RA is, enhancing and improving soil health, optimising resource use and management, tackling climate change and improving water availability are agreed as core themes (Schreefel et al. 2020, Dempster et al. 2021).

Maintaining and enhancing a resilient soil biological functional capacity is integral for productivity, soil and ecosystem health and sustainability of Australian agriculture, especially on lower fertility/organic matter soils in the low rainfall regions in southern Australia. In these soils, management is the key to maintaining and improving soil biological functions and C sequestration (Gupta et al. 2019), including their ability to withstand and recover from environmental, physical or chemical stresses (resilience). In the low rainfall, winter-dominant rainfall environments, establishing perennial pastures is typically not a feasible option.

Soil microbial communities mainly determine the soil functional capacity relevant to nutrient supply and availability, microbial C turnover and C sequestration. The status of soil biological functional capacity in agricultural systems is influenced by soil, environment (rainfall and temperature), plant type and management practices through changes in the diversity, composition, population level and activity of soil (micro)biota. Hence, understanding the effect of crop and management factors on soil biological capacity and functional resilience is essential to maintain and improve the soil resource base in the low rainfall regions where microbial C turnover plays a key role in providing functions essential to sustainable production and overall system health.

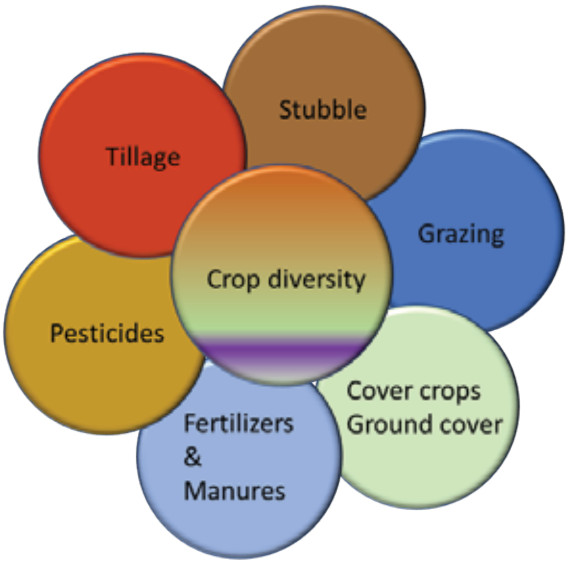
Adoption of conservation agriculture (CA) practices during the last two decades has helped to improve production, as well as water and resource use efficiency in low rainfall regions of South Australia and Victoria. However, recent attention to the regenerative agriculture approach has raised interest in understanding the relevance and importance of various management practices that are part of CA systems, in terms of their influence on soil biological functional capacity and resilience across different low rainfall agroecological regions. Understanding how to improve both resistance and resilience of soil systems to stress and stress thresholds is important for land managers and policy makers to optimise management decisions.

Regenerative agriculture practices have been developed for particular environments in different climates around the world, so the applicability and feasibility of the different farming practices need to be adapted for other agricultural regions. Currently, there is a need for greater context-specific evidence of the profitability of regenerative farming systems (Francis 2020) and agri-environmental impacts. In this study, we use a grower field-based assessment approach for science-based evidence, focussing on the potential soil impacts of management practices considered relevant to the practice of regenerative agriculture, specifically in the light textured soils of the low rainfall zone in south-eastern Australia.

The aim of this work was to determine the status of soil biological capacity and resilience as influenced by practices relevant to regenerative agriculture in the low rainfall region in southern Australia.

Methods

Surface 10cm soils were collected from 35 grower fields from across the low rainfall cropping regions in South Australia and Victoria during the in-crop season in 2021 and summer period in 2022. Fields were selected to provide sufficient contrast with crop/soil management practice categories generally considered relevant to the RA philosophy (Dempster et al. 2021). These included tillage, stubble management, crop diversity, ground cover/cover crops, grazing during pasture phase, use of pesticides and fertilisers and manures (Figure 1).



Tillage
0 = zero till (no workings other than sowing with points or disc)
1 = 1 working and sow with points or disc, or just sow with shares
2 = old school (2 or more workings)

Biomass/stubble management
0 = All the residues retained on surface and not grazed
1 = residue retained but grazed
2 = residue retained but worked in
3 = residue removed (burnt, baled), windrow burning

Plant/Crop diversity
0 = Rotational crops including mixed pastures/cover crops
1 = Continuous cropping with rotational crops
2 = Single species - self sown pasture
3 = single species cropping

Cover crops / extensive green ground cover
0 = Permanent pasture >5 months of green cover, cover crops (not cut for hay)
1 = Managed pasture or self sown but with good coverage for 3 - 5 months of green cover
2 = self sown, no management; poor cover or sparse plant density
3 = long bare fallow (>8 months)

Fertiliser & manures (name and rate, kg/ha)
0 = no synthetic chemical fertilizers but organic manures or gypsum or lime added
1 = low levels of chemical fertilizers (<20 kg MAP/ha/y
2 = high inputs (starter fertilizer and in-crop applicatio

Grazing - green winter pasture phase
0 = strategic grazing (cell grazing)
1 = rotational grazing
2 = set stocking
3 = no grazing

Pesticides
0 = no herbicides or other pesticides including fungicides and insecticides
1 = occasional use of herbicides, strategic use of <2 sprays or chemicals per annum
2 = multiple chemistry and applications

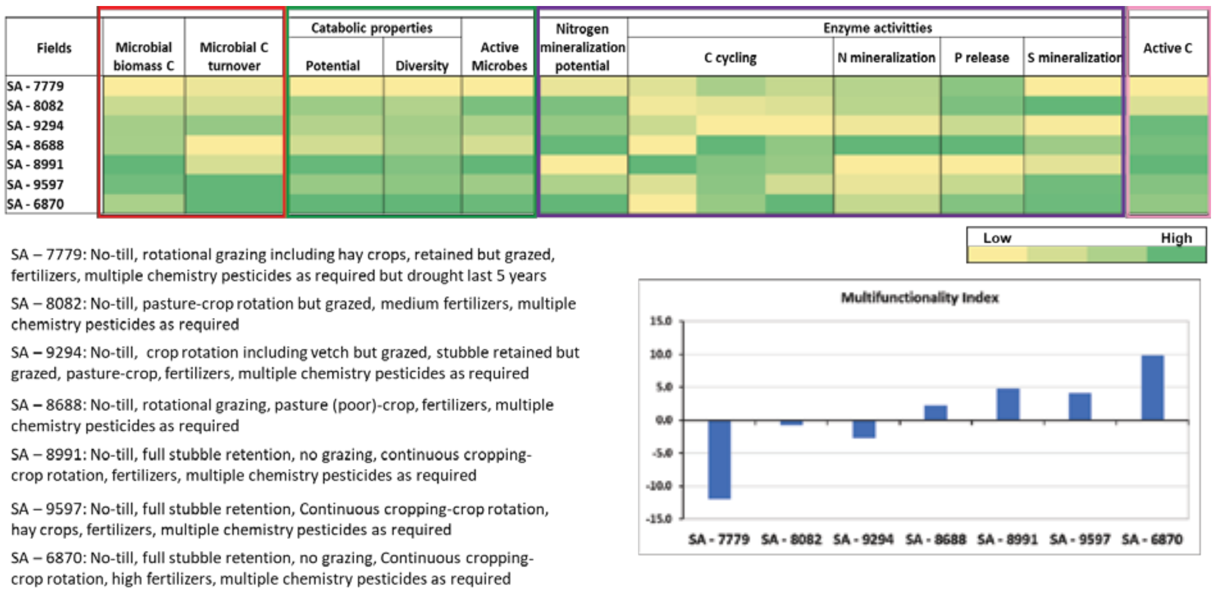
Figure 1. *Key categories of management practices commonly followed in broadacre agricultural systems and their relevance to accepted regenerative agricultural (RA) practices (Dempster et al. 2021). Practices are ranked on a 0–2 scale where '0' represents one of the accepted RA principles.*

Using a functional microbial ecology approach that integrates responses and changes in microbial biomass (MB), C turnover, N mineralisation, catabolic diversity and enzyme activities, representing functional microbial groups involved in C, N, P and S cycling, were measured. Additionally, resilience in biological properties when exposed to wet-dry cycles simulating changing rainfall patterns was also determined (Gupta et al. 2008). In view of the complexity of soil functionality and microbial properties, a multi-functionality (MF) index was calculated to compare across fields. The MF index determines the average level of a suite of functions by standardising each function to a common scale by taking their mean across all the soils tested in this study using a z-score transformation (Bradford et al. 2014).

Results and discussion

Results indicated that surface 10cm soils in the study area had a wide range of soil organic C (SOC, 0.33–1.73%) and total N (0.04–0.16%) and significant differences between fields reflected the influence of variations in cropping history within the sandy and sandy loam texture soils in the region. Since changes in SOC from crop management practices generally take long periods (decades), differences in SOC levels observed are likely the result of long-term management. Average microbial biomass C and N levels were 338±39µg C/g soil and 49±5µg N/g soil, with significant variation between fields within the sub-regions of SA and Victoria, indicating the influence of different crop management practices. Differences in MB levels showed a significant relationship with active soil C levels confirming previous reports that in the lower organic matter soils in this region, MB levels are regulated by the availability of C (Gupta et al. 2019). Also, the generally lower microbial quotient (MB per unit SOC), for example, ~50% of fields showed microbial quotient (MQ) values <3.5%, suggests the necessity to implement management practices that would increase MB levels and associated benefits. Similarly, data for microbial catabolic diversity and C turnover related processes (for example, average metabolic response and C mineralisation potential) showed significant variation between fields but the differences between in-crop and summer collected soils were seen only in some soils. For the in-crop soils, enzyme activities related to C, N, P and S cycling were significantly different between fields. The variation in C-cycling enzymes showed a correlation with MB and/or total SOC, stoichiometric ratio of C to N and S cycling enzymes indicated N and S limitation for C cycling and nutrient availability. Nitrogen mineralisation potential (PMN) was generally higher in the in-crop samples (0.54kg N/ha/day) compared to the summer samples (0.46kg N/ha/day) for the majority of fields and PMN showed a significant positive relationship with MB, catabolic properties and total N (R^2=0.43, 0.41 and 0.42, respectively; $P<0.05$).

Figure 2. *Effect of different management practices on soil biological properties and multi-functionality index for soil samples from*



selected SA soils collected during in-crop 2021. Measurements are categorised in groups relevant for (i) microbial biomass and turnover (red box), (ii) catabolic diversity and activity (green box), (iii) N mineralisation and C, N, P, S cycling (purple box) and (iv) active carbon levels (pink box).

Overall, the use of MF index that aggregated responses in various microbial and functional properties provided an integrated metric or index reflecting the soil biological functional capacity as influenced by management practices (Figure 2). This was also made possible by the selection of measures using a functional microbiology approach. In general, the differences in the MF index for different fields were explained mainly by the differences in a range of biotic properties, for example, MB, C turnover, catabolic diversity and PMN. In general, differences in MF index could be explained based on differences in the amount of C inputs returned to the soil under various practices. Higher amounts of MB were mostly seen in fields under management practices that added larger amounts of plant C inputs (Figures 2 and 3). Management practices such as stubble retention, no-till and crop rotation are generally common across these fields but some of them with low MF index have some forms of crops/pasture grazing and/or stubble or hay removal practice, all of which would have reduced the amount of C inputs returned to the soil. Additionally, fields SA 7779 and VIC-5961 were also exposed to lower C inputs, either due to recent repeated droughts or fallow as part of rotation. Conversely, fields showing a higher MF index (for example, SA-6870, SA-9557, VIC-101103, VIC-5658, VIC-4143) didn't practice grazing as part of the management practice (Figures 2 and 3). For example, fields with grazing as a management practice had a lower MF index (-4.06±1.67) compared to those with no grazing practice (2.01±1.84).

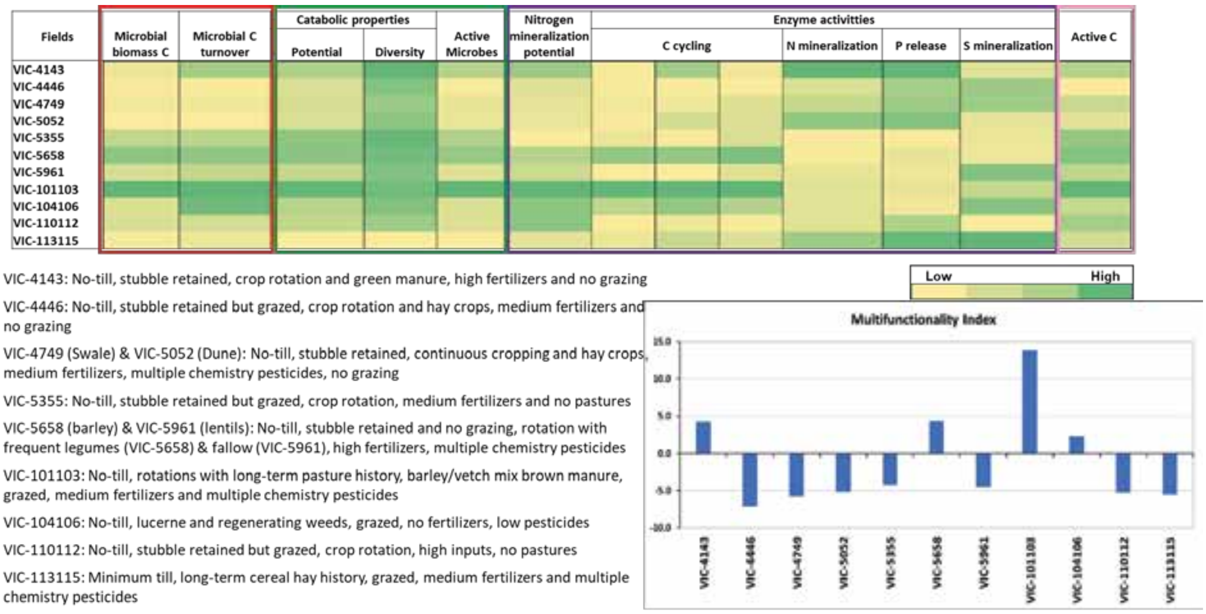


Figure 3. Effect of different management practices on soil biological properties and multi-functionality index for soil samples from fields in Victorian low rainfall Mallee during in-crop 2021. Measurements are categorised in groups relevant for (i) microbial biomass, (ii) catabolic diversity and activity, (iii) N mineralisation and C, N, P, S cycling and (iv) active carbon levels. Grazed = -4.008+1.684 MF index; No grazing = 1.121+3.40 MF index.

Variations in the use of fertilisers and herbicides did not show any measurable relationship with differences in the MF index. Since the majority of fields tested were exposed to no-till practices, effects of tillage/disturbance could not be evaluated. Results from the resistance and resilience of biological properties and functions when exposed to repeated wet-dry events indicated that sandy and sandy loam soils have limited stable soil structural components (that is, micro- and macro-aggregation due to very low clay content) and habitat conditions for highly stable biological functions are limited. These results also confirm that long term practice of grazed volunteer pastures, stubble grazing and fallow-crop rotations can cause a decline in the biological functional capacity resilience of microbial populations and processes.

Table 1: Summary of previous knowledge and potential effects of management practices on soil biota and their processes in agricultural soils in Australia.

Tillage	• Tillage causes substantial changes in microbial community composition. • Alters N mineralisation-immobilisation processes.
Stubble management	• Stubble is a critical source of C for soil microbes, microbial biomass and biological processes. • Causes substantial changes in composition of microbial community, both beneficial and deleterious.
Grazing	• Removal of C inputs can affect microbial biomass and biological processes. • Effects on microbial community composition are not known.
Extensive groundcover (for example, cover crops, fallows)	• Source of C for soil microbes, microbial biomass and biological processes. • Can cause substantial changes in composition of microbial community, both beneficial and deleterious.
Crop diversity	• Plant type-based differences exist in microbial community composition (beneficial and deleterious). • Differences in quantity and quality of C inputs between crops, affecting biological processes.
Pesticides	• Effects depend upon the chemistry, frequency and repeated applications, and mixtures.
Fertilisers	• Essential for crop growth and C inputs above and below ground. • Effects on microbial community composition only at very high rates.

Conclusions

- A framework categorising the various crop and soil management practices for their relevance to regenerative agricultural (RA) philosophy is proposed for a systematic interrogation of practices currently adopted as part of conservation agriculture-based farming systems.
- Management practices that reduce the amount of plant C inputs, such as grazing crops/ stubble and hay removal were associated with generally lower soil biological capacity and overall multi-functional biological index.
- Resistance and resilience of soil biological functional capacity in the sandy and sandy loam soils is generally low, hence management practices that include pastures, stubble retention and reduced till systems are required to maintain and improve soil biological health and build soil C in the long-term.
- The functional microbial ecology approach used in this study clearly demonstrated potential effects of some of the regenerative agriculture practices on soil biological health and resilience.
- With the adoption of locally appropriate management practices that promote biological activity, it is possible in low rainfall environments to achieve soil improvement relevant to the objectives of regenerative agriculture.
- The MF index should also be linked to productivity, and whether RA management practices can be adopted to maintain improve resilience without compromising farm sustainability.

Acknowledgements

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Notes

Taking the lab to the field

Peter Johnston.

Hone Corporation.

Keywords

- Cereal grain moisture, cereal grain protein, grain quality, spectral models.

Take home messages

- Agricultural producers need accurate, reliable real time data to support better management decisions.
- Rapid on-farm sampling can enable production decisions to be optimised, ensuring farm enterprises reap the economic benefit of the quality that they produce.
- Advances in Machine learning provides in spectroscopy, create the opportunity for hardware developments and design that allow infield applications
- Further creation of models for pasture quality, tissue testing (macro- and micronutrients) will further enhance the economic value of in-field application of Near Infra-Red spectroscopy

Background

Australia's on-farm grain storage has exceeded 18m tonnes, with 90% of growers storing an average of 41% of normalised grain production (GRDC 2021 – 'boosting the efficiency of on farm storage'). The catalyst for this has been a combination of increased domestic demand (local market), increased mechanisation (header throughput), tax incentives to support grower's drought resilience and accelerated asset depreciation.

This seismic shift has required grain producers to act as the first mile of the supply chain, where quality attributes of grain need to be tested, validated, and monitored to ensure the resilience of Australia's access to international and domestic markets.

Concurrently, wheat producers are harnessing the value of their production through segregating grain to optimise its quality, both at point of initial storage and then subsequent out loading. Industry figures indicate that the average farmgate value through the correct segregation of wheat can nett between 1–2%.

These structural changes have required grain producers to adopt technology akin to what a bulk handler has for the testing and subsequent management of grain quality. Recognising this, Hone Corporation has developed a field-based spectrometer for the testing of cereal grain protein and moisture called Hone Lab Red. This initial use case has led to Hone developing a range of spectral models for soil, leaf, and feeds to provide the core data that agricultural producers need in real time.

The challenge

Agricultural producers require timely and accurate data to make decisions. Laboratory facilities are typically located a long way from where the samples are taken. This has limited producers' ability to make timely decisions at harvest for grain segregation. This created a dependency of producers to rely on access to bulk handlers' desktop-based testing equipment.

Testing grain quality through the application of NIR (Near Infrared) spectroscopy has been widely practiced and forms the mainstay of grain testing in Australia (Walker et al. 2023). These desktop instruments require extremely specific environmental conditions to operate within tolerances required by industry. Models and calibrations are stored locally on each instrument and require regular and ongoing servicing and calibrations. These instruments typically cost between $35K to $45K.

The science

In the last decade, the development of portable spectrometers has enabled the technology to move on-farm (Yan et al. 2023). With the rise of on-farm storage and increased climatic variability, portable instruments are increasingly in demand (Walker et al. 2023). The portable instrumentation offers farm managers a high degree of throughput, versatility, and simplicity to quantify a range of analytes in their crop (Du et al. 2022).

Concurrently, there has been an increase in computing power and efficient learning algorithms (Chadalavada et al. 2022). This has enabled the development of user-friendly software applications that move the technology out of the hands of researchers and into the hands of growers (Yan et al. 2023). As a result, growers can now rapidly classify the market value of grain to optimise economic return and minimise production risk at the farmgate (Walker et al. 2023).

Understanding the limitations of adoption

Spectroscopy is well established as a methodology for testing grain analytes. In Australia, most grain producers will be familiar with NIR spectrometers utilised for testing cereal grain protein and moisture. But the application is not limited to just cereal grain, nor protein and moisture. Spectroscopy is used in over dozens of industries.

The opportunity presented across three areas:

- All samples start in the field; why not take the laboratory to the field?
- Many analytes can be measured by NIR; why not design and develop technology that can span across multiple applications?
- Traditional methodologies for building models and calibrations required chemometricians with specific skills, limiting the development of new applications; why not use machine learning (ML) and artificial intelligence (AI) to bridge this constraint?

Guiding principles

Hone developed a view that anyone should be able to test anything, anywhere. It was identified that agricultural producers have one of the highest needs by frequency and volume of analyte testing from pre-production (soil), in crop (plant tissue) to post-production (grain and fodder). However, testing remained at low levels due to cost and accessibility.

The solution needed to satisfy the constraints that producers faced.

- The technology needed to be mobile first, designed for field use in agriculture.
- Test results needed to be available as close to near real time as possible.
- Analytes to be tested should be narrowed to those for which decisions can be made that provide tangible economic and agronomic benefits.

Challenges to be overcome

To build models to measure specific analytes, there was a requirement for vast amounts of spectral data to be assessed against wet chemistry results. This data was difficult to acquire and typically required skilled chemometricians to assess and validate the data to build the models. This led to the realisation that we needed a methodology of capturing and analysing spectral data at a resolution and speed that would circumvent the technical knowledge of a chemometrician. To do this, we developed Hone Create, a cloud-based ML engine that has been specifically designed and engineered to create extraordinarily complex models and calibrations.

This enabled Hone to:

- Design, engineer and produce a handheld spectrometer specifically for infield agricultural applications
- create models and calibrations extremely quickly from less samples utilising the processing depth of the cloud
- develop a self-learning validation process to ensure model performance
- deploy enhanced models to the cloud for all devices to utilise
- focus the instrument spectral capture range to that of the target analyte, resulting in higher resolution and model performance.

Applications and outcomes

Cereal grain

Displayed in below are Hone's resulting models for wheat grain. For wheat, the total number of samples scanned was 476 for protein and 1576 for moisture (Figure 1) across multiple varieties in a composite sample resulting in an R squared value of 0.99 for moisture and in Figure 2 we can demonstrate a R squared value of 0.99 for protein. The 'predicted' axis represents samples that were scanned on Hone's HLR1A device (hone's handheld spectrometer), whereas the 'actual' axis represents samples that were from a NATA accredited analytical reference lab.

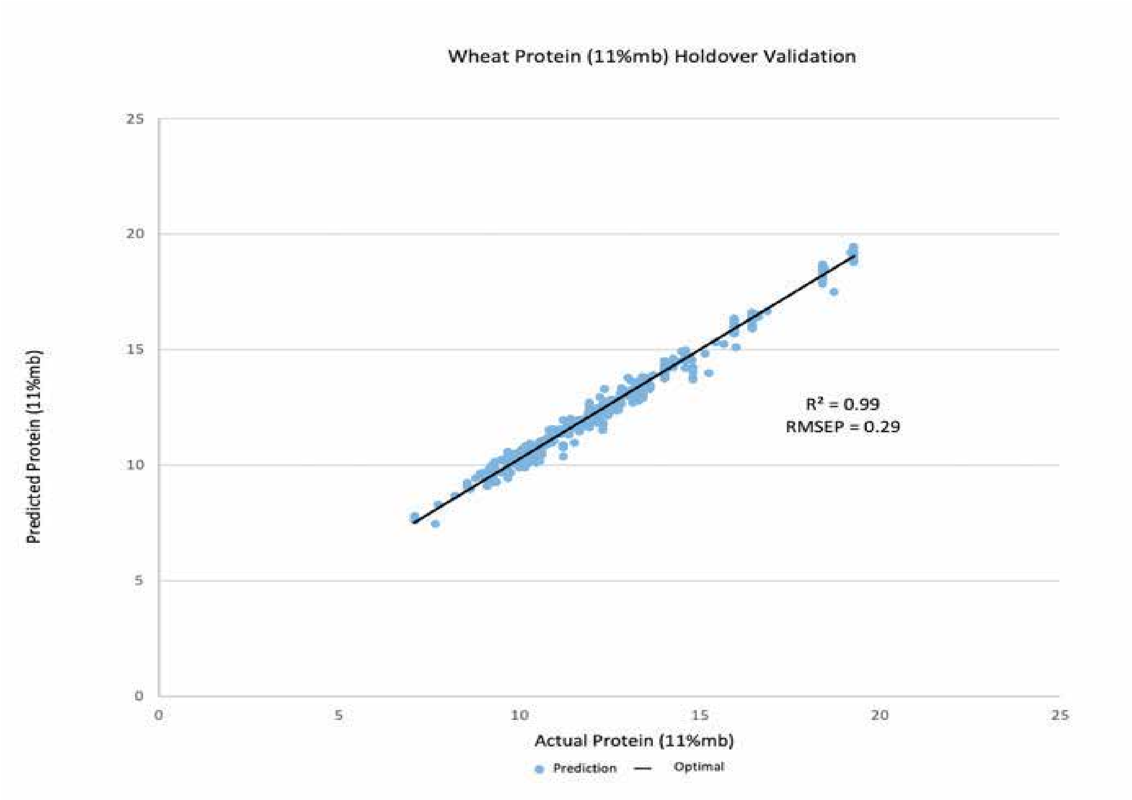

Figure 1. *Wheat moisture predictive model.*

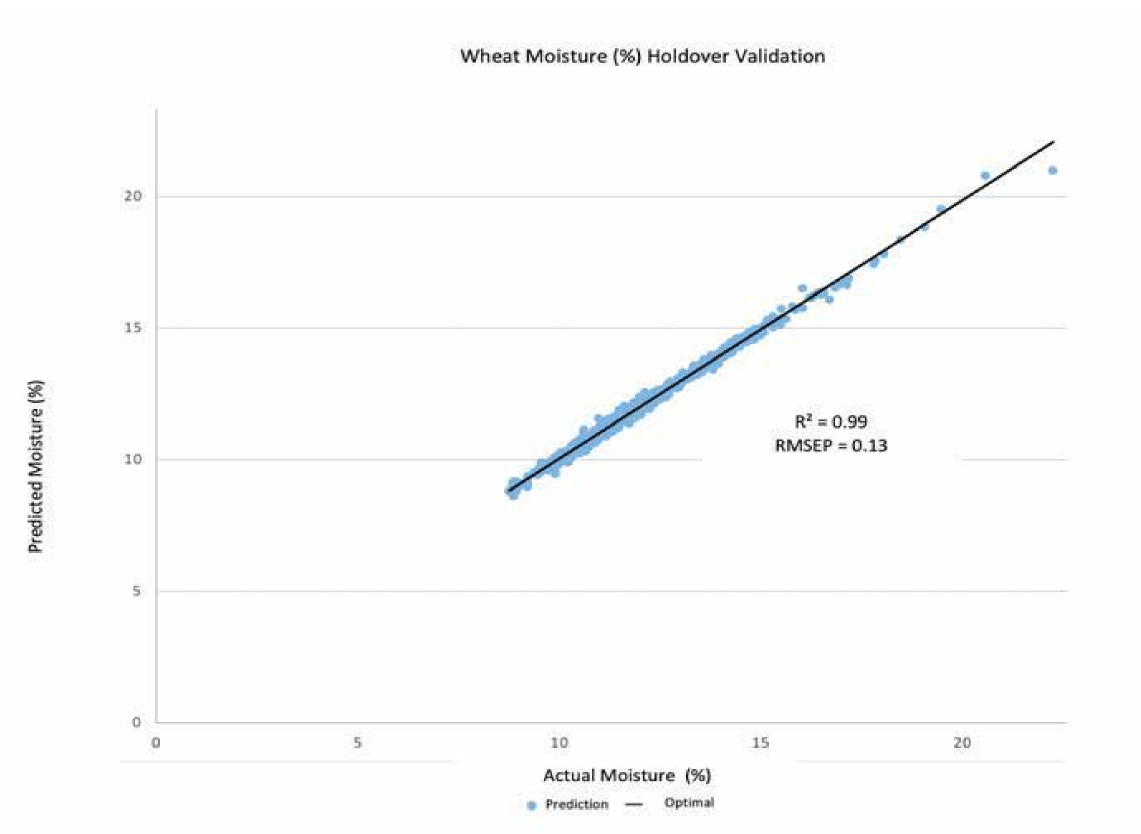

Figure 2. *Wheat protein predictive model.*

Feed grain

Displayed in Figure 3 are Hone's models for 'feed grade grain'. Within the holdover validation set, there were 356 samples for the faecal digestible energy model and 314 samples for the illeal digestible energy model (Figure 3). The 'predicted' axis represents the samples scanned on the HLR1A device, produced by Hone, whereas the 'actual' axis represents samples that were from a NATA accredited analytical reference lab from in-vivo experiments.

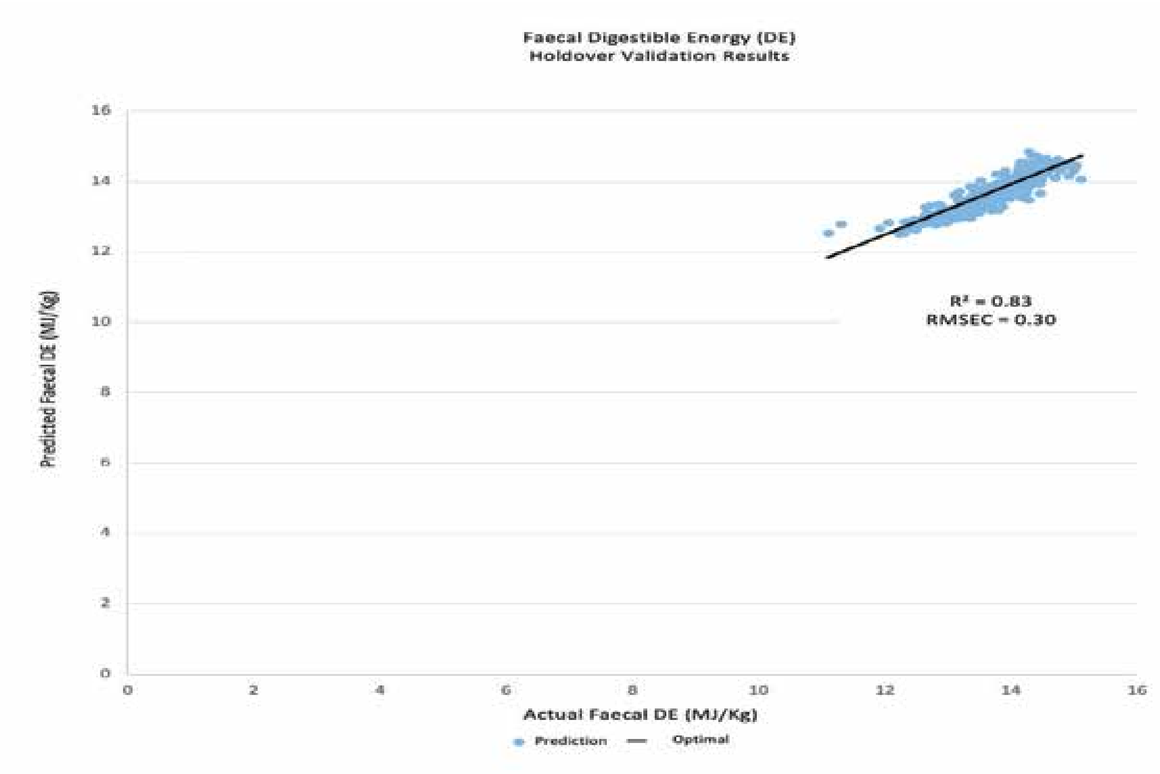

Figure 3. *LHS; Faecal digestible energy (MJ/kg) cross validation results*

Economics

Decisions on what silo / location to store wheat enables wheat producers to extract value from the quality (Protein) of the grain that they produce. As wheat in Australia is priced through Grain Trade Australia (GTA) standards, there is the opportunity to blend grain on farm to maximise its value within this grade structure. Decisions on segregating wheat quality load by load on farm prior to storage typically results in an overall increase in the value of their production by greater than 0.5%.

The table below highlights how a 1500 tonne wheat producer, making informed segregation decisions can achieve a 0.5% increase in farmgate values based on 1:10 upgrade ratio (conservative).

On-Farm Wheat Segregation

Grade	Price (Murtoa)	Quantity (t)	Value	% Upgrade	Quantity (t)	Value	Delta Value
ASW	$ 320	500	$ 160,000	10%	475	$ 152,000	$ 16,000
APW	$ 337	500	$ 168,500	10%	500	$ 168,500	$ -
H2	$ 375	500	$ 187,500	10%	500	$ 187,500	$ -
HI	$ 405		$ -		50	$ 20,250	$ 20,250
Total	$ 344	1500	$ 516,000		1500	$ 518,125	$ 4,250

The annualised cost of the Hone Lab Red is $2450 (+GST) per annum, resulting in a nett ROI of over 70% per annum. The additional value of being able to assess cereal grain for feed quality will open further opportunities for producers and consumers of feed grain.

Acknowledgements

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The regional disease surveillance network – a BioScout endeavour

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GRDC project code: BIS2305-001RTX

Keywords

- automated disease surveillance, BioScout, disease management, SporeScout.

Take home messages

- BioScout technology empowers proactive disease management by combining automated microscopy with machine learning to provide growers with near real-time airborne fungal data.
- Launching in 2024, Australia's first regional airborne disease surveillance network, supported by GRDC investment, will deploy BioScout units across three regions, offering valuable data on key threats across large distances.
- Free access for GRDC-approved users until early 2026 provides an early opportunity to leverage this novel resource and optimise disease management strategies.
- Register your interest to stay informed about network availability and contribute to shaping a future of informed and sustainable crop protection.

The disease problem

Australia's grain crops face substantial yearly losses due to diseases. The FAO (2019) estimates that plant diseases are responsible for 20 – 40% of crop losses on average, costing the global economy US$220 billion annually. In Australia, Murray and Brennan severity and yield loss caused by 41 pathogens were assessed from a survey of 18 wheat pathologists covering the wheat-growing areas of Australia. The survey provided data on the frequency of years that each pathogen developed to its maximum extent, the proportion of the crop then affected in each growing area, and the yield loss that resulted in the affected crops with and without current control measures. These data were combined with crop production and quality data to estimate the value of the losses aggregated to the Northern, Southern and Western production regions. Pathogens were estimated to cause a current average loss of $913 × 106/year or 19.5% of the average annual value of the wheat crop in the decade from 1998–99 to 2007–08. Nationally, the three most important pathogens were Pyrenophora tritici-repentis, Puccinia striiformis and Phaeosphaeria nodorum with current average annual losses of $212 × 106, $127 × 106 and $108 × 106, respectively. If current controls were not used, losses would be far higher with potential average annual losses from the three most important pathogens, P. striiformis, P. triticirepentis and Heterodera avenae, being $994 × 106, $676 × 106 and $572 × 106, respectively. The average value of control practices exceeded $100 × 106/year for 12 pathogens. Cultural methods (rotation, paddock preparationestimated back in 2009 that foliar fungal infections cost the grains industry over AUD 470 million annually despite spending around AUD 84.3 million on fungicides; these numbers are now likely much higher. Addressing these losses can boost crop production profitability by protecting yield while promoting sustainable practices without additional land clearing or inputs.

A key issue with disease management is knowing which diseases are present in a given area before plants are symptomatic. Spores of disease-causing fungi are largely invisible. Since plants are asymptomatic during early infection stages, growers must make fungicide application decisions based on weather conditions and plant growth stages or wait until after plants show symptoms, which is generally too late to prevent yield and economic losses from disease damage to the crop. These decisions are often made without knowing for certain whether plants are at risk of infection.

BioScout technology

BioScout's advanced automated SporeScout system (Figure 1) aims to address these issues by monitoring airborne disease-causing fungi in near real-time, providing data-based insights for sustainable and profitable production. SporeScout units photograph microscopic airborne particulates, analyse that imagery to identify and quantify fungal spores of interest and scales this process through machine learning. Data from the SporeScout units are displayed on BioScout's online dashboard, with graphs containing the airborne spore concentrations of several pathogens of interest, which are updated daily (Figure 2).

Automated disease surveillance is currently available for the following broadacre pathogens:

- general rust (*Puccinia* spp.)
- blackleg (*Leptosphaeria maculans*)
- general Alternaria (*Alternaria* spp.)
- powdery mildew (*Blumeria graminis*)
- Botrytis (*Botrytis cinerea*).

Figure 1. A SporeScout unit in wheat. The unit is powered by a solar panel on the left side, and a black wind vane keeps the intake nozzle consistently pointed into the wind for optimal air sampling.

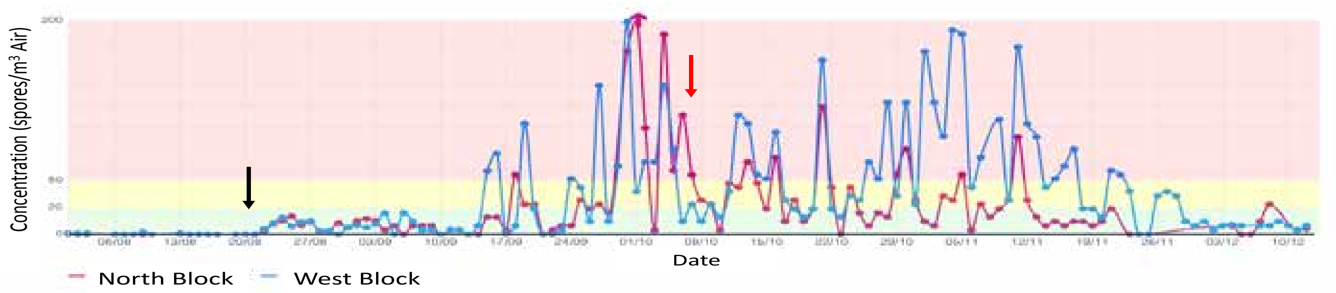

Figure 2. A graph from the BioScout dashboard displaying airborne concentrations of general rust detected through the SporeScouts during an outbreak. Two SporeScouts were placed at a site in Victoria from June to November 2023. North Block (pink line) and West Block (blue line) were located 776m and 600m away from a wheat rust nursery, respectively. The black arrow indicates the day that symptoms (flecking) were first observed at the nursery, and the red arrow highlights the approximate day that plants had peak infection and were ready for resistance scoring. The traffic light system in the background provides an approximate indication of the quantity of spores in the air, with green (< 25 spores/m^3 air) indicating low levels, yellow (25 - 50 spores/m^3 air) indicating moderate levels and red (> 50 spores/m^3 air) indicating high levels. Arrows at the top of the graph indicate spore concentrations have exceeded 200 spores/m^3 air, and the exact number can be obtained by hovering over the data point.

The data generated from this system can offer substantial advantages to the agriculture industry and stakeholders. Early pathogen detection can enable more informed management decisions and swift, timely responses by growers, preventing rapid disease spread and minimising economic losses. Growers can also see the impacts of any management decisions through responses in airborne spore loads. Moreover, SporeScouts also contain weather stations, offering localised weather data including temperature, humidity, pressure, rainfall, windspeed, wind direction, and air quality. This integration enhances the value of the spore monitoring network by enabling data-driven decisions for fungicide applications based on weather conditions and spore presence, reducing unnecessary chemical use, reducing the risk of fungicide resistance developing, and improving sustainability.

The regional disease surveillance network project

The Australian agricultural landscape is poised for improvements in disease management with the launch of the nation's first dedicated airborne fungal pathogen surveillance network. This groundbreaking initiative, commencing in April 2024, will deploy 60 SporeScout units across all three GRDC regions. The network collaborates with researchers, state pathologists in each growing region, and the GRDC. This strategic deployment of SporeScout units, augmented by four iMapPESTS Sentinels for DNA validation, will provide near real-time data on the presence and concentration of airborne fungal spores across vast regions. This unprecedented access to granular, geographically specific data empowers growers and researchers alike. An example of the website for the surveillance network can be seen in Figure 3 and Figure 4.

The network's design also incorporates a robust research component. Several SporeScout units in the network will be placed within existing disease field research trials. The data generated from these trials will serve to provide recommendations regarding how best to incorporate BioScout data into existing integrated disease management practices, maximising the return on investment for growers and the industry as a whole.

Figure 3. Example landing page for the regional disease surveillance network. Upon entering the site, users will see a map with icons displaying the locations of SporeScout units in that region. Users can zoom in on the map and select individual units to view spore concentrations and weather data. Note: this is a mock-up and may vary from the real landing page.

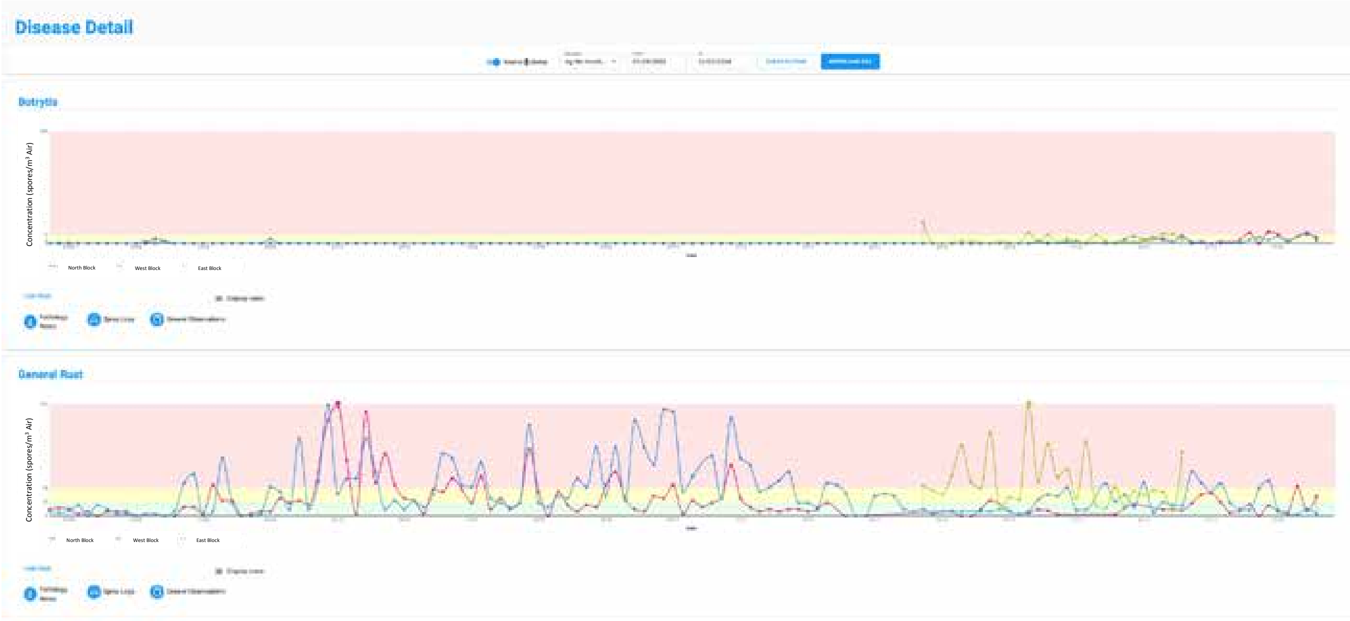

Figure 4. Example landing page for the regional disease surveillance network. Users can select multiple SporeScout units and view the spore concentrations of the pathogens we track. Users can filter the data by selecting specific SporeScout units and date ranges and can download the filtered data in a CSV file. Note: this is a mock-up and may vary from the real landing page.

Participation in this initiative is available to GRDC-approved users free of charge until April 2026. We invite researchers, industry stakeholders, and growers to join us in shaping the future of Australian agriculture by contributing to this transformative project. If you would like to have access to the disease surveillance network, we encourage you to provide your email address using the QR link below.

Conclusions

- BioScout technology provides fully automated disease surveillance for airborne pathogens
- A regional airborne disease surveillance network will come online in early 2024, providing data on airborne pathogens as well as weather variables available to view online or download as a file
- Research involving BioScout units in disease management will be undertaken, with recommendations with how best to use BioScout data provided to growers later this year

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Acknowledgements

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Notes

Building rapport and effective communication with clients

Clint Vawser

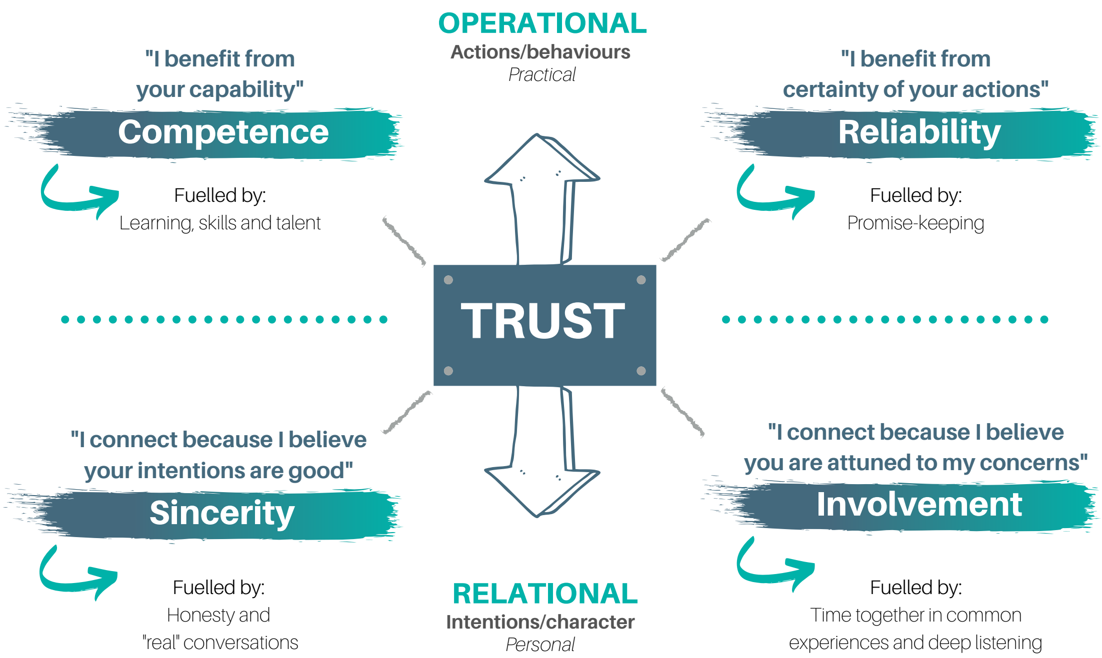
NAVIGATING PERCEPTIONS OF TRUST

On Trust

Building, maintaining, and enhancing relationships requires trust. The deterioration of trust produces deterioration in the quality of relationships, and indicates negative assessments about how concerns are being addressed, or are likely to be addressed, by the relationship. The absence of trust, or low trust, can be one of the most inhibiting factors in the development of cooperation and the coordination of action. Without sufficient trust we are crippled in how we can build better futures together - in our families, our social relationships and our organisations. Trust and the effective coordination of action develops *collective capital* - the capability of people to work together to deal constructively with current problems (including conflict) and to design a more constructive and productive future.

Coaching to the Human Soul Vol 1, Alan Sieler

4 Elements of Trust

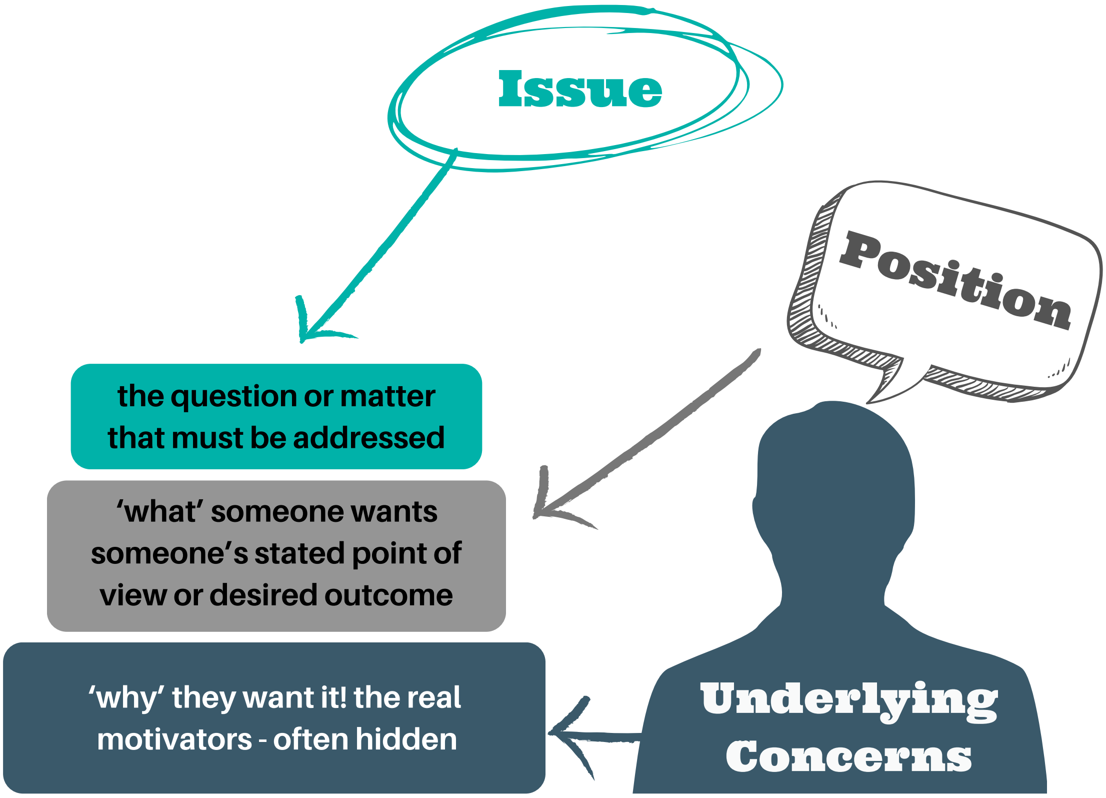


Source: 4 Elements of Trust - Alan Sieler (Newfield Institute)

Trust Activity

TRUST COMPONENT	Your rating (1-10) **of them** plus brief comments	Your guess of their rating **of you** (1-10) plus brief comments
SINCERITY		
COMPETENCE		
RELIABILITY		
INVOLVEMENT		

"Issue ~ Positions ~ Concerns" Model



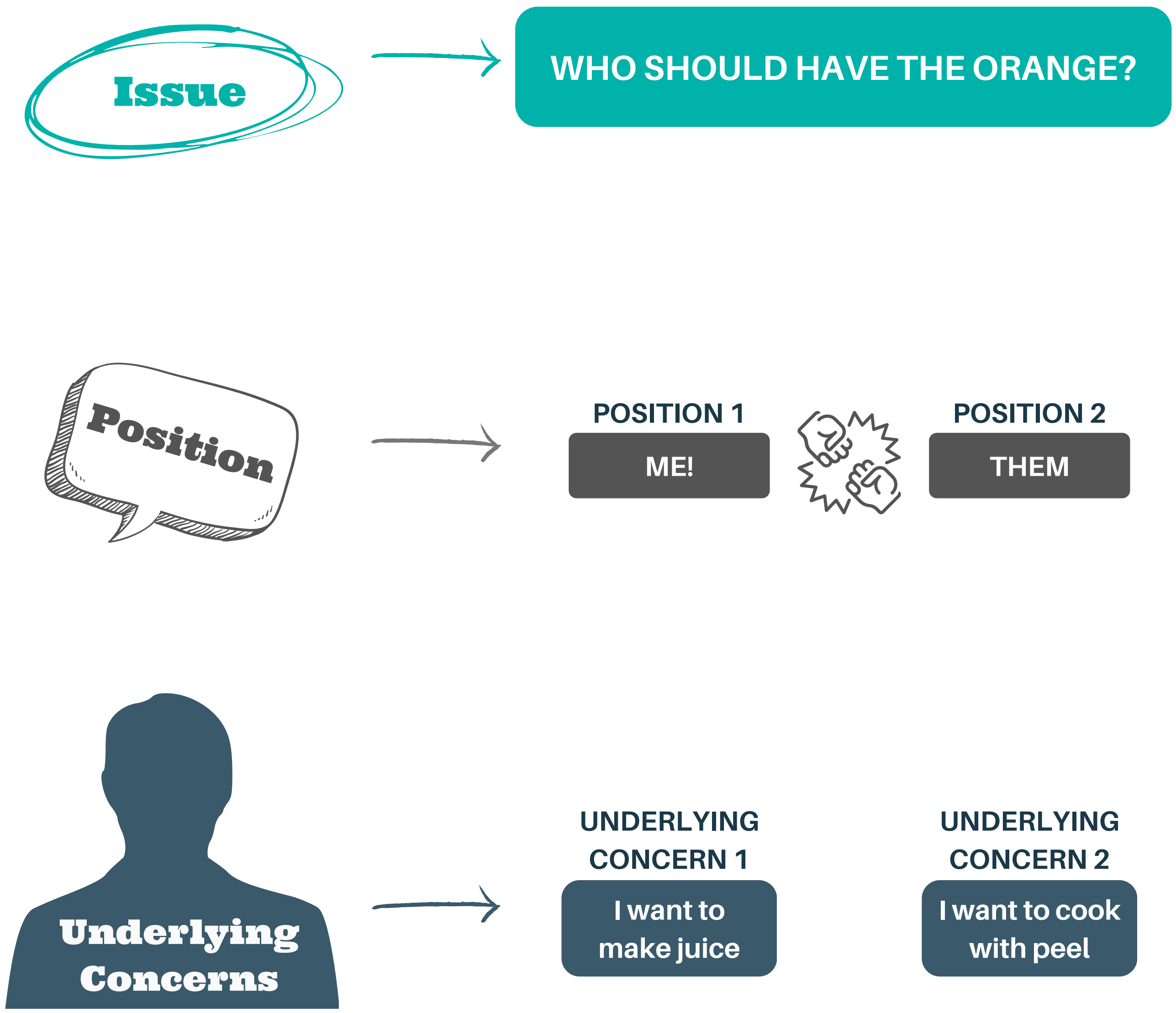
Conversation should focus in on the **concerns**, not merely the **positions** people are taking on the **issues**.

Those **concerns** may be interests, desires, needs, limitations, or fears.

Source: Adapted from Peacewise Australia

OUR CONCERNS EXPLAIN OUR POSITION ON ISSUES

"Issue ~ Positions ~ Concerns" Model



Some Hallmarks of Genuine, Open and Honest Questions

- You cannot anticipate the answer
- Questions that don't just focus on the problem or issue but relate to the person as well (e.g. What would a really good day look like for you?)
- Questions that come from your heart, not just your head
- Questions that help expand thinking on the issue or problem. Yes/No or Right/Wrong questions tend to close down inquiry.
- Questions that are simple

What's Happening Beneath the Surface?

Sample Questions to Support Listening for Concerns

- What is the key issue for you? / What do you think is the main issue you are grappling with?
- What makes this a key issue for you?
- What is missing for you?
- What is at stake for you in this issue?
- What key concerns are not being addressed?
- What is important for you that is not being taken care of?

Clint Vawser

PRINCIPAL CONSULTANT

Clint specialises in:

- Development and Performance
- People Systems and Processes
- Human Resource Practices
- Leadership Development
- Team Dynamics
- The Enneagram

About Clint

Like running long distances, leadership and personal transformation requires passion, persistence, the pursuit of wisdom and an openness to new possibilities. These are hallmarks of Clint's life.

Clint is one of the two founders and directors of Oasis People and Culture, having joined forces with **Stuart Wesley** in 2016. He is a seasoned Learning and Development professional and has a pedigree in Human Resource Management and Leadership Development spanning three decades in employment then consulting roles across commercial, government, not for profit, resources, and industrial sectors. Prior to Oasis, he developed his own consulting business working with a nationally recognised training provider delivering Cert III, Cert IV and Diploma level leadership and personal development programs (**Leadership Management Australia and Leadership Management International**), where he was internationally awarded for his efforts. Clint is also a founding member of the **Perth HR Alliance**.

Clint is passionate about seeing people unleashed in their personal and leadership potential and seeing organisational cultures come alive in ways that lead to high performance and connect deeply at a human level. For Clint, seeing individuals understand their own (and each other's) core motivational drives, brings an enormous amount of satisfaction and makes an incredible difference in people's lives.

Clint has worked with over 100 mid-level leaders at **Western Power** strengthening their frontline leadership capabilities, many of whom have gone on to significant functional roles in the business and beyond. Likewise, as the primary leadership learning partner for a **Civil Construction** business in shaping and equipping their leadership teams with tools and practices that lead to high levels of team member retention and positive culture.

Clint is a self-proclaimed running junky, loves running and hiking trails and pushing his limits over ultra-distances. Clint is fascinated and motivated to understand what makes people (including himself!) tick. These days, he and his wife Sue are edging towards a quieter family life as his two young adult children navigate their own significant milestones like university graduations and weddings.

Oasis work with a wide variety of businesses which includes a strong representation in the Ag sector including family farm businesses around the topic of succession, Ag advisory service businesses and Ag software businesses in both Australia and the US. Clint is also a facilitator for Rural Edge in Western Australia.

Clint's accreditations include:

- Bachelor of Business (Human Resources and Organisational Development)
- Post Graduate Certificate (Christian and Vocational Studies: Vancouver, Canada)
- Diploma of Management
- Cert IV Workplace Training and Assessment
- Accredited Practitioner of Enneagram (Integrative9), Barrett Values System and Genos Emotional Intelligence Assessment System.

Notes

Optimising efficacy of pre-emergent chemistry

Christopher Preston.

School of Agriculture, Food & Wine, University of Adelaide.

Keywords

- annual ryegrass, herbicide resistance, pre-emergent herbicide, solubility.

Take home messages

- There are four main causes for pre-emergent herbicides to fail to control weeds: herbicide resistance, too little persistence, too little rainfall and too much rainfall.
- Understanding the properties of pre-emergent herbicides can ensure the best product or mixture of products are employed in each situation.
- Early post-emergent use of pre-emergent herbicides is a good way of increasing annual ryegrass control, but each herbicide needs to be used in a particular manner to get the best out of it.

Background

Pre-emergent herbicides are now widely used to control annual ryegrass and some other weeds in cropping in Southern Australia. Pre-emergent herbicides are more complex to use than post-emergent herbicides, as they need to be in the right location as the weed seeds germinate. This requires an understanding of how herbicides move in soil, where the herbicides are taken up by the germinating seedling and where weed seeds are most likely to be located.

Most pre-emergent herbicides are taken up by weed seeds by the roots or the mesocotyl (the part of the shoot immediately adjacent to the seed). The main exception to this is triallate and the Group 14 herbicides. Triallate is taken up by the coleoptile and Group 14 herbicides are taken up by the shoot as it moves through the herbicide layer in the soil. For all other herbicides, it is essential for the herbicide to reach the weed seeds to be effective.

In no-till farming systems, most weed seeds fall on to the soil surface and will still be close to the soil surface at sowing time. Any disturbance of the soil surface over summer will tend to bury weed seeds. However, weed seeds will only be buried to the depth of the disturbance. Weed seeds that were set in previous years that have not germinated will have been buried by the previous sowing operations. The deeper weed seeds get buried, the further the herbicides need to move through the soil to reach them. Tillage operations to control summer weeds, for example, will tend to bury weed seeds and make it harder for the less soluble herbicides to reach them.

Weed seeds are moved with the seeding operation. Where they end up depends on the type of equipment used. Seeds that are in the soil thrown from the furrow with a knife-point seeder will get separated from the herbicide. Some seeds will remain in the furrow or end up on the shoulder and will avoid the herbicide, particularly with use of the less soluble herbicides.

Understanding herbicide behaviour in soils

There are several factors that influence how far herbicides will move through soil. These include soil type, soil organic matter, rainfall and herbicide chemistry. There are two key factors of herbicide chemistry that are important: solubility of the herbicide; and its ability to be bound in soil (Table 1). Solubility determines how likely the herbicide will be dissolved in soil water and hence, be moved by rainfall. Binding to soil components tends to slow the herbicide movement through the soil.

Table 1: Behaviour of some pre-emergent herbicides used for grass weed control.

Pre-emergent herbicide	Trade name	Solubility (mg/L)		K_{oc} (mL/g)	
Carbetamide	Ultro®	3270	Very high	88.6	Medium
S-Metolachlor	Dual Gold®, Boxer Gold®*	480	High	226	Medium
Metazachlor	Tenet®	450	High	45	Low
Cinmethylin	Luximax®	63	Medium	300	Medium
Bixlozone	Overwatch®	42	Medium	400	Medium
Prosulfocarb	Arcade®, Boxer Gold®*	13	Low	2000	High
Propyzamide	Edge	9	Low	840	High
Triallate	Avadex® Xtra	4.1	Low	3000	High
Pyroxasulfone	Sakura®, Mateno® Complete*	3.5	Low	223	Medium
Aclonifen	Mateno® Complete*	1.4	Low	7126	High
Trifluralin	TriflurX®	0.2	Very low	15,800	Very high

**Boxer Gold contains both prosulfocarb and S-metolachlor,*
Mateno Complete contains aclonifen, pyroxasulfone and diflufenican

Herbicides with high water solubility and low binding to organic matter, such as metazachlor, will tend to move further through the soil profile and can be lost below the root zone of weeds. Herbicides with low water solubility and high binding to soil components, such as trifluralin or aclonifen, will not move very far. The distance that herbicides with other properties will move depends a lot on the amount of rainfall and the properties of the soil.

Sandy soils tend to have larger particle sizes and hence, larger pores between the particles. This allows water to move more quickly through the soil and hence, take more herbicide with it. Sandy soils also tend to have lower organic matter contents. Organic matter tends to slow the movement of herbicides through soil, particularly for herbicides that have high binding to organic matter.

The main causes of pre-emergent herbicide failure

There are essentially four main causes for pre-emergent herbicides to fail to control weeds. Firstly, there is herbicide resistance. The latest resistance survey indicates resistance to trifluralin is present in 38% of crop fields in South Australia and 21% of crop fields in Victoria. Resistance to Boxer Gold is present in 1% of crop fields in South Australia and in 9% of crop fields in Victoria. If herbicide resistance is confirmed or suspected, alternative pre-emergent herbicides should be used.

Secondly, insufficient persistence of herbicides. This is particularly a problem for products, such as Boxer Gold, prosulfocarb and Tenet, where the efficacy of the herbicide declines rapidly after application. Later emerging weeds are able to avoid the herbicide. This is more of a problem in higher rainfall zones or in longer seasons. However, over recent years, some annual ryegrass populations have evolved increased seed dormancy in response to continuous cropping, making short persistence herbicides, such as Boxer Gold, less effective. The solution is to use longer persistence products and mixtures to obtain more control of the weeds.

Thirdly, too little rainfall after application of the herbicide. This is normally a problem for the less soluble products, such as Sakura, propyzamide and Mateno Complete. It typically occurs where there has been good rainfall prior to application of the herbicide, that causes annual ryegrass to germinate. Without sufficient follow-up rainfall after herbicide application, the herbicides are not activated in time to control the weeds. Trifluralin, despite its low water solubility, is not usually affected by this issue, as it becomes a gas on contact with water allowing it to be absorbed by the germinating weeds. Mixtures with herbicides that have different properties can overcome this problem. Useful mixtures have been Sakura plus Avadex Xtra and Sakura plus trifluralin. An alternative is to use Boxer Gold or prosulfocarb as an early post-emergent salvage option to control the annual ryegrass that has got through.

Finally, there is too much rainfall after application of the herbicide. This can move the herbicide out of the root zone of the germinating weeds. This mostly occurs with the more soluble herbicides, such as Tenet and Luximax, and mostly on lighter soil types. However, it can be a problem for many herbicides if there is sufficient rainfall. Herbicide leaching can also occur on heavier soil types that have low organic matter. There are additional factors to consider. There have been more problems with Luximax moving out of the weed root zone than Overwatch, despite their similar behaviour. Some of this is because Luximax is less likely to be bound by organic matter and some is due to the longer persistence of Overwatch. The roots of the weeds will eventually grow into the herbicide, but if there is insufficient herbicide remaining, or the weeds are too large, they will not be controlled. Herbicides will move further with the first rainfall event in dry soil, so the more soluble herbicides should be avoided in dry sowing situations. Using herbicides with lower water solubility in higher rainfall regions, will manage this problem. However, in situations where unexpected high rainfall occurs after sowing, there is only the early post-emergent salvage option available.

Using pre-emergent herbicides in the early post-emergent timing

There are several pre-emergent herbicides that are also registered for early post-emergent use. When using pre-emergent herbicides in this way, it is important to understand that they will not control established weeds and so, a pre-emergent application should always be used first. Early post-emergent herbicide applications can increase the amount of annual ryegrass controlled, control annual ryegrass in the furrow and on the shoulder, and extend the length of control.

It is essential to have rainfall after application to get herbicides to control annual ryegrass at the early post-emergent timing. How much rainfall depends on the herbicide product. Of the cereal herbicides, Boxer Gold requires the least amount of rainfall, followed by Arcade with Mateno Complete requiring more rainfall. This means that Boxer Gold and Arcade can be used for salvage weed control where pre-emergent herbicides failed to adequately control annual ryegrass, whereas Mateno Complete will be less effective at this. Boxer Gold and Arcade are best applied when annual ryegrass is at the 1-leaf stage but can be used up to the 3-leaf stage.

The higher rainfall requirement to activate Mateno Complete means it is best applied before the next flush of annual ryegrass has germinated. Mateno Complete is best used as a strategic approach to maximise annual ryegrass control through the season. This means using a pre-emergent herbicide prior to sowing and then applying Mateno Complete at the appropriate crop stage, regardless of whether annual ryegrass is present or not. The herbicide will then be available once sufficient rainfall occurs to germinate the annual ryegrass.

Tenet has more water solubility than the other herbicides and needs less rainfall after application to activate. However, the rate of Tenet that can be used early post-emergent in canola is insufficient to give reliable control of annual ryegrass. Therefore, another herbicide active on annual ryegrass, such as clethodim, needs to be applied with it.

A note about herbicide persistence

Having longer persistence is good for annual ryegrass control but can cause problems for future crops. Be aware that sensitive crop plant backs have both a time and a rainfall component for Sakura, Mateno Complete and Overwatch. My thinking about early post-emergent Mateno Complete use was that it would provide a solution for growers in higher rainfall zones. When using this herbicide early post-emergent in lower rainfall zones, you need to be aware that you have reduced the opportunity of the herbicide to be degraded before the next crop is sown. This is particularly true in years with a dry spring, such as 2023. There is a requirement of 250 mm of rainfall prior to sowing barley, canola and pulse crops. November and December rains in 2023 mean that many growers will not now have a problem with residues of this herbicide. However, fields that did not receive sufficient rainfall in this period could still have a problem with residues in the soil. If in doubt, plant a tolerant crop.

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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.

Useful resources

Soil behaviour of pre-emergent herbicides in Australian farming systems: a reference manual for agronomic advisers (https://grdc.com.au/resources-and-publications/all-publications/publications/2018/soil-behaviour-of-pre-emergent-herbicides)

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Notes

2023–2025 GRDC SOUTHERN REGIONAL PANEL

December 2023

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ANDREW RUSSELL, PANEL CHAIR

Rutherglen, Victoria

Andrew is the 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 has served on GRDC's medium rainfall zone Regional Cropping Solutions Network and has held leadership roles with Riverine Plains Inc, Victorian Farmers Federation and the Rutherglen Group of fire brigades.

PRU COOK, DEPUTY CHAIR

Dimboola, Victoria

Raised on a mixed farm in Victoria's Wimmera region, Pru has spent her professional career working in extension for the grains industry. Starting her career at the DPI, she has worked at GRDC and the Birchip Cropping Group, managing a number of extension projects. She has recently started her own business specialising in extension, project development and project management.

TIM MCCLELLAND

Birchip, Victoria

Tim farms with his wife, father and aunt on a 6500-hectare mixed property in the southern Mallee. After completing his Bachelor of Agriculture and Commerce at the University of Melbourne in 2006, he took on work at Advisor Edge, Birchip Cropping Group (BCG) and RMCG. In 2011, he moved back to Birchip to become formally involved in the family farm and continue his role with BCG.

RUTH SOMMERVILLE

Burra, South Australia

Ruth is an agroecologist who runs a consulting business. She has a Bachelor of Science in Ecology and Master of Applied Science in Wildlife Management from the University of Sydney, and has worked in sustainable agriculture research, development and extension and property management since 2002. Ruth has been the Upper North Farming Systems Group executive officer and project manager since 2013.

ANDREW WARE

Port Lincoln, South Australia

Andrew is a research agronomist who started his career with the South Australian Research and Development Institute (SARDI) and then spent time at CSIRO in Adelaide. This was followed by 10 years away from research, managing the family farm on the Lower Eyre Peninsula, before returning to SARDI. In 2019, he started his own research company, EPAG Research, delivering applied research across the Eyre Peninsula.

MICHAEL TRELOAR

Cummins, South Australia

Michael is a third-generation grain grower who produces wheat, barley, canola, beans, lupins and lentils on a range of soil types. He has been involved in a number of research organisations, including the South Australian Grain Industry Trust (of which he was chair for four years), the Lower Eyre Agricultural Development Association and the South Australian No-Till Farmers Association (both of which he has been a board member).

NEIL FISHER

Adelaide, South Australia

Neil's family grain farming legacy dates back to 1889, giving him an extensive understanding of the challenges faced by grain growers in SA and Victoria across the Mallee, Wimmera and Riverina regions. With his wife Jenny, he retains a cropping/grazing property at Bordertown, producing wheat, canola, barley, beans and hay. He has held chief executive and board roles in organisations including Sugar Research Australia, Grains Council of Australia, Grape and Wine Research and Development Corporation and Plant Health Australia. Neil has previously worked for GRDC managing a large portfolio of research projects.

PETER DAMEN

Kindred, Tasmania

Peter is a grower from north-western Tasmania with more than 10 years' experience growing and processing commercial grain crops. He holds a degree in agricultural science from the University of Tasmania. Peter has production, research and development experience in quinoa, oats, buckwheat, spelt, hemp, adzuki beans, wheat, barley, ryegrass and more. He is working at Tas Stockfeed, focusing on technical support, sales and grain procurement and processing. In 2017, he was recognised as the Young Farmer of the Year.

DR KATHY OPHEL-KELLER

Adelaide, South Australia

Kathy is a strategic science leader with a strong track record in developing and leading national research programs with industry co-investment, including GRDC. Her own research background is in plant biosecurity and molecular detection of plant pathogens and she has a strong interest in capacity building and succession planning. Kathy is a former acting executive director of SARDI and a research director at Crop Sciences, covering applied research on plant biosecurity, crop improvement, climate risk management, water use efficiency and crop agronomy.

DR PATRICIA FLYNN

Douglas, Victoria

Patricia is a grower in the southern Wimmera, Vic. She holds a Bachelor of Science (Honours) from the University of Western Australia and a PhD from the Australian National University. Her expertise lies in farming systems research with a specific interest in soils management and farm business profitability. Patricia is the financial manager of a family mixed cropping and Merino sheep enterprise – Kwangaloo Pastoral. She held research and development positions at the WA Department of Agriculture, CSIRO, and what was the Department of Primary Industries in Victoria.

CRAIG BAILLIE

GRDC Executive Manager

Craig Baillie is GRDC's general manager of applied research, development and extension. He has oversight of research areas including sustainable cropping systems (agronomy and soils) and crop protection (pests, weeds and diseases). He also has responsibility for GRDC's grower and stakeholder engagement at a national level.

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FMC
Pioneer Seeds

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

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INTERGRAIN

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Australian Grain Technologies

Australian Grain Technologies (AGT) is Australia's largest plant breeding company, developing new wheat, barley, durum, canola and lupin varieties for Australian farmers.

AGT considers it a privilege to be able to serve Australian farmers and the world's population by developing new field crop varieties that are more productive, better quality, and cost less to grow. This is what drives the AGT team. Our goal is to see Australian farmers more prosperous, and the global population well nourished.

Barista coffee supported by

ADAMA Australia Company Profile

ADAMA is a leading global crop protection company, providing solutions to combat weeds, insect pests and disease, so farmers can do what they do best: feed and clothe the world.

Trade display supported by

BASF Company Profile

BASF works with Australian growers to help them get the most out of every season so they can confidently overcome some of the toughest challenges faced in agriculture today. From high-performing seed varieties through to the latest game-changing pest and disease solutions that are backed with trusted advice from our expert team, we strive to deliver value to every customer. With ongoing investment in global and local R&D, BASF offers the market-leading solutions growers need today, and tomorrow so they can succeed at the biggest job on Earth. Learn more about how our products and people can help you get the best out of every season at crop-solutions.basf.com.au or by following us on social media.

OUR LINKS:
Website: crop-solutions.basf.com.au
Facebook: @BASF.AgriculturalSolutions.AU
Twitter: @BASF_Agro_AU

Syngenta

Syngenta is a global science-based agtech company with over 30,000 employees, in more than 90 countries, working to protect the productivity of broadacre enterprises and more. Collaboratively we're investing in a more sustainable agriculture which is good for nature, farmers and society. Locally, we are accelerating innovation in a field of potential, through our global research and development network, agricultural innovations, and unmatched product support. Our work with like-minded industry partners, agronomists, advisors and growers, is helping to enhance the quality and sustainability of Australian grown produce through the management of pests, weeds and disease. This approach is exemplified through the development of VICTRATO® seed treatment, to support integrated management of crown rot and root lesion nematodes.

ABOUT US

Trade display supported by

InterGrain

InterGrain is a cereal breeding industry leader, delivering market leading wheat, barley and oat varieties with significant agronomic advantages and high-quality end-user benefits. Our highly successful breeding programs target the major cereal growing regions of Australia. It is our vision to support the competitive advantage and sustainability of the Australian agriculture sector. InterGrain's shareholders are the WA State Government (58%) and GRDC (42%). InterGrain employs 65+ staff and has offices in Perth, Horsham and Narrabri and a marketing team based across Australia.

Bayer

Bayer is a global life sciences company of thousands of people who use science and innovation to promote Health for All and Hunger for None. Our Crop Science division is shaping Australian agriculture to benefit farmers and consumers, for the good of Australia's environment, society and economy. For almost 100 years we have used innovation and partnerships across agriculture to tackle our most pressing issues. We are a leader in seeds and traits and we have the most innovative crop protection portfolio, together with the most advanced digital farming platform. We provide tailored solutions for farmers to plant, grow and protect their harvests using less land, water and energy.

FMC – Our Story

FMC is an agricultural sciences company that advances farming through innovative and sustainable crop protection technologies. We have been embedded in agriculture and innovation for 130 years, earning the trust of growers and industry partners to maximise their productivity, profitability, and sustainability.

We are passionate about bringing new solutions from our industry leading pipeline to growers and look after our people and the communities we service by creating opportunity and supporting diversity.

Our team of over 100 people across Australia and

New Zealand are guided by our values: Integrity, Safety, Sustainability, Respect for People, Agility, and Customer Centricity. It is what sets FMC apart and is key to our long-term growth.

FMC has manufacturing operations worldwide, including here in Australia. Our Wyong NSW facility has been manufacturing quality crop protection products, working to strict safety, environmental and quality standards, for more than 30 years.

Pioneer® Seeds

Pioneer® Seeds has been researching high quality seed genomics, to provide high quality hybrid seed and inoculant products to Australian farmers for almost 50 years. A Yates family-owned business in Australia, the Pioneer Seeds team supports the industry with integrity, unmatched agronomic knowledge and solutions to help it succeed.

2024 Adelaide GRDC Grains Research Update Feedback

1. How would you describe your <u>main</u> 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

2. Current and likely impacts of international grain markets: *Nick Carracher*

Content relevance ☐ /10 Presentation quality ☐ /10

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

3. Adopting innovative agronomic practices and research - a Canadian experience: *Dr Sheri Strydhorst*

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. 11:00 am	**The market and agronomic challenges of carbendazim usage.** *Panel:* ***Leigh Nelson,*** *GRDC* ***Gerrard McMullen,*** *National Working Party for Grain Protection,* ***Jake Rademacher,*** *Grower Supplies*	**An update on powdery mildew.** ***Sam Trengove,*** *Trengove Consulting*	**Cereal disease management 2024 and key strategies for detection.** ***Grant Hollaway,*** *Astute Ag*	**Key learnings from long term lime response trials.** ***Brian Hughes,*** *SARDI*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

5. 11:40 am	**Leveraging seed treatments and management strategies to effectively control crown rot.** ***Steven Simpfendorfer,*** *NSW DPI*	**New development scales for wheat and barley.** ***Corinne Celestina,*** *University of Melbourne*	**Back Chat' discussion with Dr Sheri Strydhorst. Facilitated Q & A in follow up to Plenary with Sheri.** ***Sheri Strydhorst,*** *Alberta, Canada*	**Digging Deeper: Back to nitrogen basics - Soil testing and nitrogen budgeting fundamentals.** ***James Hunt,*** *University of Melbourne.* ***Jeff Braun,*** *The Agronomist*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

6. 12:20 pm	**BOM developments in long term forcasting accuracy - The implications for Autumn sowing.** ***Jonathan How,*** *BOM*	**The impacts of canopy closure and N on frost mitigation.** ***Ben Smith,*** *Agrilink Consultants*	**Integrated pest management strategies and the impact of beneficials.** ***Luis Mata,*** *CESAR Australia*	**Digging Deeper: Broad leaf weed management - Identifying critical growth stages, timings and treatments.** ***Chris Davey,*** *Next Level Agronomy.* ***Darren Pech,*** *Elders*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

LUNCH

7. 1:55 pm	**The N Bank - Why and How?** ***James Hunt,*** *University of Melbourne*	**An update on powdery mildew.** ***Sam Trengove,*** *Trengove Consulting*	**Cereal disease management 2024 and key strategies for detection.** ***Grant Hollaway,*** *Astute Ag*	**BOM developments in long term forcasting accuracy - The implications for Autumn sowing.** ***Jonathan How,*** *BOM*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

8. 2:35 pm	**Key learnings from long term lime response trials.** ***Brian Hughes,*** *SARDI*	**The impacts of canopy closure and N on frost mitigation.** ***Ben Smith,*** *Agrilink Consultants*	**Strategies for optimising glufosinate and tackling efficacy challenges.** ***Chris Preston,*** *University of Adelaide*	**Leveraging seed treaments and management strategies to effectively control crown rot.** ***Steven Simpfendorfer,*** *NSW DPI*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

9. 3:15 pm	**Agronomic strategies when growing lentils in marginal areas.** *Agronomist Panel*	**Integrated pest management strategies and the impact of beneficials.** ***Luis Mata,*** *Cesar Australia*	**The N Bank - Why and How?** ***James Hunt,*** *University of Melbourne*	**Strategies for optimising glufosinate and tackling efficacy challenges.** ***Chris Preston,*** *University of Adelaide*	**None**

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

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

AFTERNOON TEA

10. Molecular and phenotypic characterisation of synthetic auxin herbicide tolerant pulse germplasm. *PHD Simon Michelmore*

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

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

11. Physiology of yield determination in faba bean genotypes with differing phenological and morphological traits. *PHD James Manson*

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

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

12. Profitable nitrogen decision making & risk management: Peter Hayman & Barry Mudge

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

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

DAY 2

13. 9:00 am	**Strategies for post amelioration sowing and crop establishment on sandy soils.** ***Mel Fraser,*** *Soil Function Consulting*	**Novel weed control technologies from the USA - New possibilities for Australian growers.** ***Michael Walsh,*** *Charles Sturt University Wagga Wagga*	**The efficacy of mice baits and impact of background food availability.** ***Steve Henry,*** *CSIRO*	**Establishing A decision matrix for disease management strategies.** ***Thomas Jones,*** *BCG*	**None**

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

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

14. 9:40 am	**Does timing trump precision? - Optimising canola establishment.** ***Kenton Porker,*** *CSIRO*	**Showcasing new rhizobium strains for group E and F inoculent groups.** ***Liz Farquharson,*** *SARDI*	**Building soil biological capacity on low performing soils.** ***Gupta Vadakattu,*** *CSIRO*	**Evaluating varietal response in oaten hay.** ***Alison Frischke,*** *BCG*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

MORNING TEA

15. 10:50 am	**Emerging strategies for managing pulse foliar diseases.** ***Sara Blake,*** *SARDI*	**GRDC Ag Tech Startups Forum** ***Michelle Demers,*** *BioScout,* ***Peter Johnston,*** *Honeag,* ***Les Finemore,*** *Yarta*	**Does timing trump precision? - Optimising canola establishment.** ***Kenton Porker,*** *CSIRO*	**Establishing A decision matrix for disease management strategies.** ***Thomas Jones,*** *BCG*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

16. 11:30 pm	**Building soil biological capacity on low performing soils.** ***Gupta Vadakattu,*** *CSIRO*	**GRDC Ag Tech Startups Forum** ***Michelle Demers,*** *BioScout,* ***Peter Johnston,*** *Honeag,* ***Les Finemore,*** *Yarta*	**Novel weed control technologies - New possibilities for Australian growers.** ***Michael Walsh,*** *Charles Sturt University Wagga Wagga*	**Evaluating varietal response in oaten hay.** ***Alison Frischke,*** *BCG*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

17. 12:10 pm	**The efficacy of mice baits and impact of background food availability.** ***Steve Henry,*** *CSIRO*	**Showcasing new rhizobium strains for group E and F innoculent groups.** ***Liz Farquharson,*** *SARDI*	**Strategies for post amelioration sowing and crop establishment on sandy soils.** ***Mel Fraser,*** *Soil Function Consulting*	**Emerging strategies for managing pulse foliar diseases.** ***Sara Blake,*** *SARDI*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

LUNCH

18. Building rapport and effective communication with clients.
Clint Vawser

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

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

[ ]

19. Optimising efficacy of pre-emergent chemistry.
Chris Preston

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

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

[ ]

Your next steps

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

[ ]

21. 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

22. This Update has increased my awareness and knowledge of the latest in grains research

Strongly agree	Agree	Neither agree nor Disagree	Disagree	Strongly disagree
❑	❑	❑	❑	❑

23. Do you have any comments or suggestions to improve the GRDC Update events?

[ ]

Thank you for your feedback.

WE LOVE TO GET YOUR FEEDBACK

Choose your preferred way to give feedback:

– access the digital form via your event app, or scan the QR code below

– leave feedback as you go - click 'Next' to save responses before exiting the survey.

– fill out the hardcopy survey overleaf. Tear out the pages and leave at the rego desk at the end of the event.

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