BENDIGO
VICTORIA
TUESDAY 21
WEDNESDAY 22
FEBRUARY 2023

GRAINS RESEARCH UPDATE

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grdc.com.au

GRAINS RESEARCH UPDATE

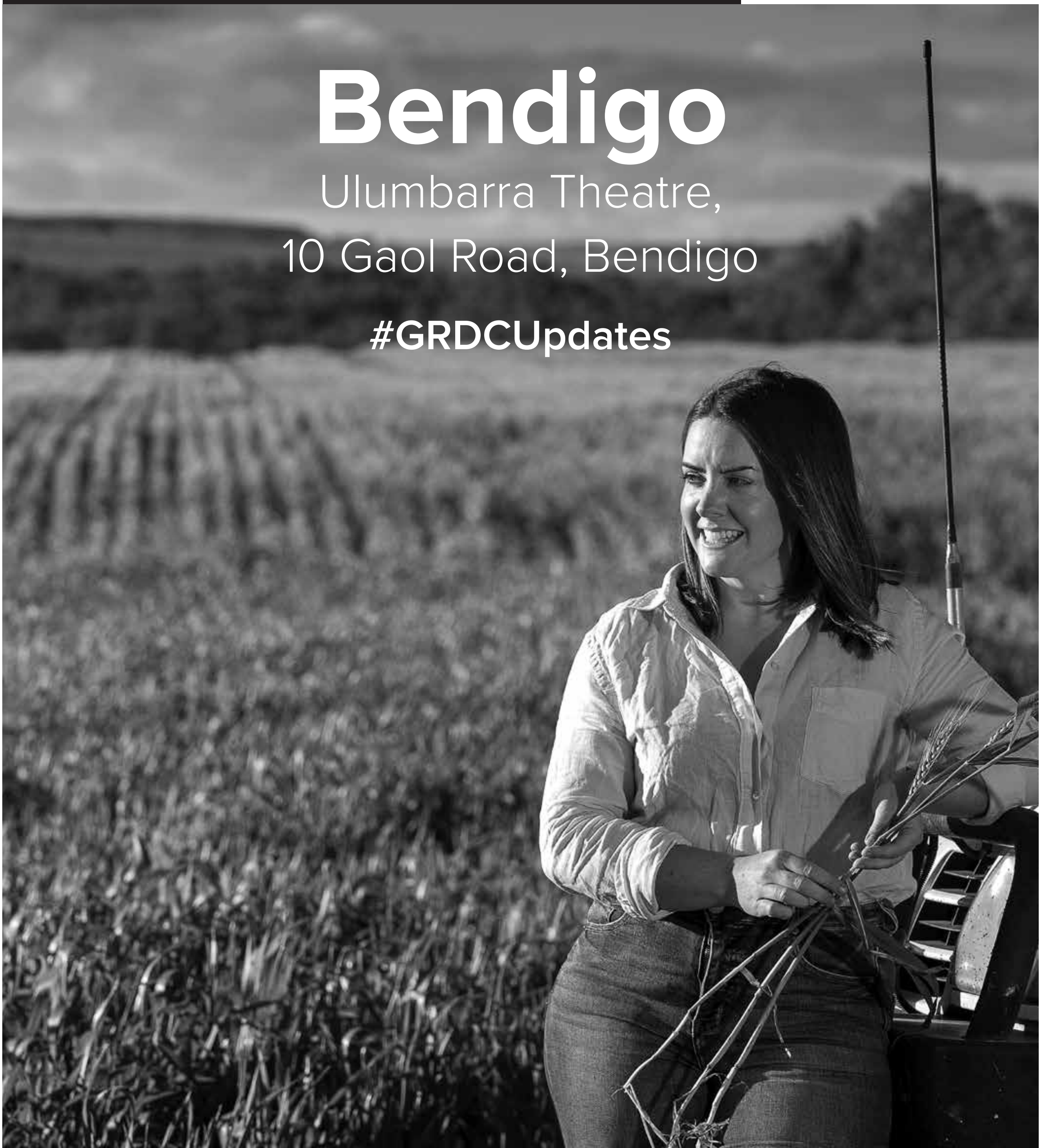
GRDC™ GRAINS RESEARCH & DEVELOPMENT CORPORATION

Bendigo

Ulumbarra Theatre,

10 Gaol Road, Bendigo

#GRDCUpdates



2023 Bendigo GRDC Grains Research Update planning committee

Andrew McMahen	*Nutrien*
Ashley Wallace	*Agriculture Victoria*
Bruce Larcombe	*Larcombe Ag*
Craig Farlow	*Elders*
Dale Grey	*Agriculture Victoria*
Greg Toomey	*Nutrien*
James Murray	*Birchip Cropping Group*
Kate Stuch	*S & D Consulting*
Trudy McCann	*Aginvestman*
Jamie Thornberry	*ORM*
Matt McCarthy	*ORM*
Tom Blake	*GRDC*

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Bendigo GRDC Grains Research Update convened by ORM Pty Ltd.

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

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GRDC Welcome

Proceedings for the GRDC Grains Research Update – Bendigo, 21-22 Feb 2023

Welcome

On behalf of GRDC, I'd like to welcome you to the 2023 GRDC Grains Research Update – Bendigo

GRDC Grains Research Updates aim to ensure growers, whose levies support GRDC research, development and extension (RD&E) investments, can benefit from the emerging technologies, innovations in best practice and new knowledge that those investments generate.

Following a wetter than usual season for most of the southern region in 2022, growers are now presented with both opportunities and challenges as we embark on the 2023 season, with many tasks like paddock repair from bogged machinery and management of volunteer weeds from unharvestable crops required in many areas. So, it will be a frantic autumn for most, and prioritisation will be important.

The 2023 Grains Research Update – Bendigo 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 valuable information for growers and advisers to successfully manage farming enterprises in 2023 and beyond.

This year's update marks a return to a face-to-face event and we're looking forward to meeting everyone in person again. Following the success of the livestreamed updates during the COVID-19 pandemic, all presentations in the Auditorium will be livestreamed – ensuring all GRDC stakeholders can be involved. We look forward to your engagement in 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.

We also hope that by participating in the Update we will inspire you to provide input to the draft GRDC RD&E Plan (2023-2028). Over the past year we have consulted extensively with growers and industry to prepare the draft Plan. Once finalised, the Plan will guide our RD&E investments over the next five years.

GRDC's National Grower Network had its first full year of delivery in 2022 under the newly evolved model that saw GRDC on the road engaging directly with growers and industry stakeholders Australia-wide to identify local priorities for RD&E. In 2022, we ran 13 NGN forums in the southern region resulting in more than 20 investments and initiatives in direct response to short-term opportunities. In 2023, more NGN events will run across the state and we invite your ongoing participation.

Also reflecting your input are two initiatives focusing on sustainability and risk that we will launch in 2023. The Corporate Sustainability Initiative will ensure GRDC investments help growers achieve sustainable economic, environmental and social outcomes – it will provide an overarching framework for all our investments. The National Risk Management Initiative is large-scale multi-partner investment that will run over five years to understand and improve risk-reward outcomes for Australian grain growers through participatory action research - this will 'hit the ground' early in 2023.

These initiatives will keep improving the impact of GRDC's RD&E investment portfolio to support enduring profitability for Australian grain growers. For individual growers, we will retain our popular sponsorship to participate in study tours and if you feel inspired to travel to other regions after the Update then consider this option (grdc.com.au/grdcstudytours).

For now, enjoy the Update and these proceedings. We hope they contribute to the success of your grain production businesses, and we look forward to seeing how you implement and adapt what you learn.

Stephen Loss

Senior Regional Manager South

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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

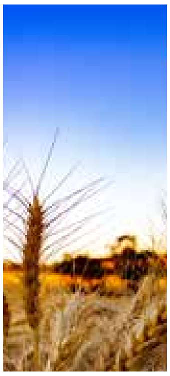
Rotating buys you time, mixing buys you shots.

- 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

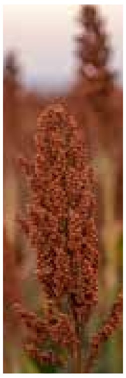
Preserve glyphosate and paraquat

- 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

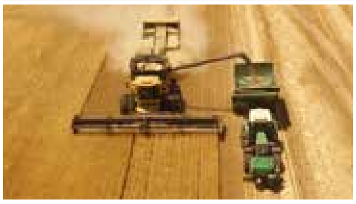
- Aim for 100% control of weeds and diligently monitor for survivors in all post weed control inspections,
- Crop top or pre-harvest spray in crops to manage weedy paddocks,
- Consider hay or silage production, brown manure or long fallow in high-pressure situations,
- Spray top/spray fallow pasture 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

Ulumbarra Theatre

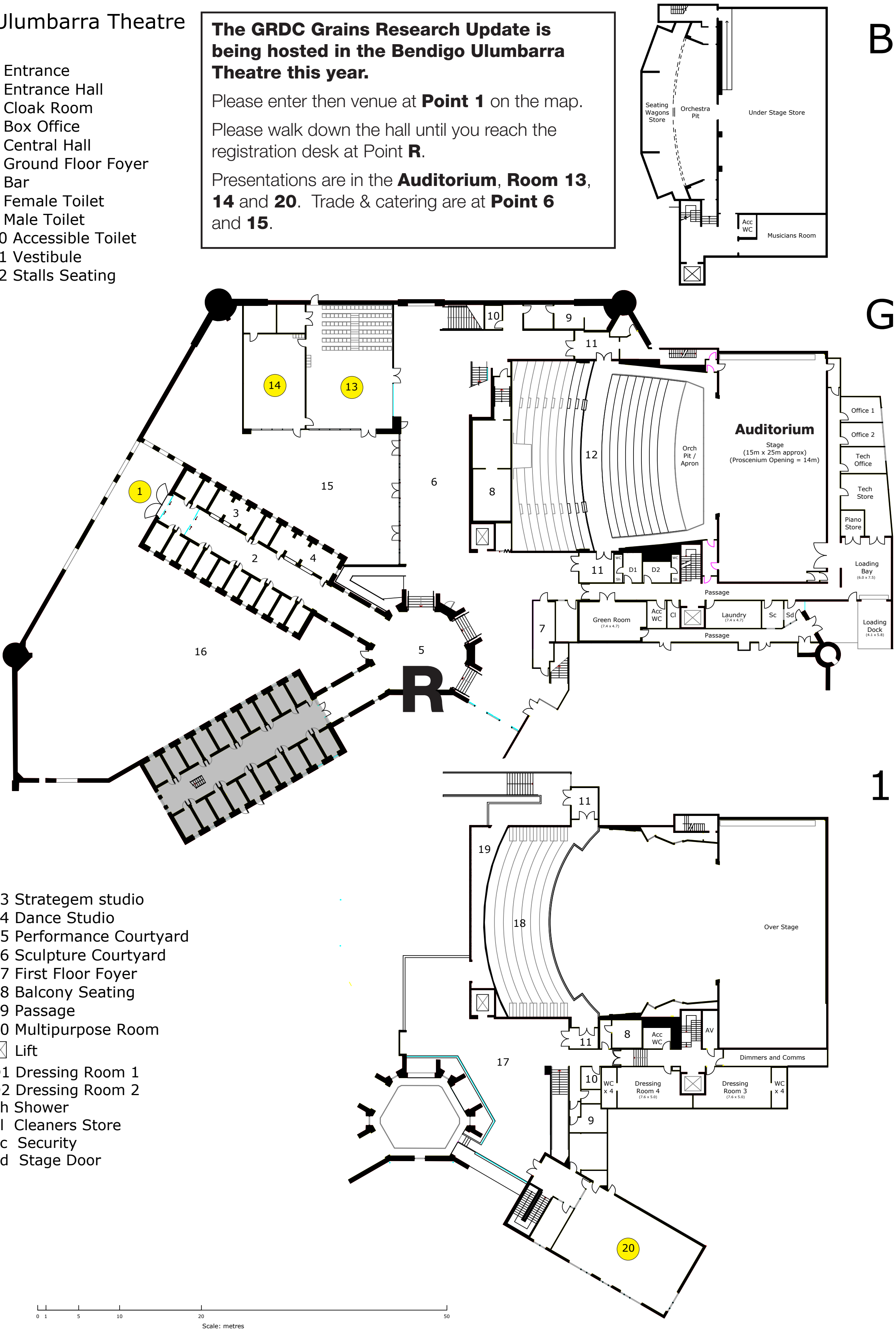
1 Entrance
2 Entrance Hall
3 Cloak Room
4 Box Office
5 Central Hall
6 Ground Floor Foyer
7 Bar
8 Female Toilet
9 Male Toilet
10 Accessible Toilet
11 Vestibule
12 Stalls Seating

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

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

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

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



13 Strategem studio
14 Dance Studio
15 Performance Courtyard
16 Sculpture Courtyard
17 First Floor Foyer
18 Balcony Seating
19 Passage
20 Multipurpose Room
☒ Lift
D1 Dressing Room 1
D2 Dressing Room 2
Sh Shower
Cl Cleaners Store
Sc Security
Sd Stage Door

Contents – DAY 1

GRDC Grains Research Update BENDIGO

Contents – DAY 2

CONCURRENT SESSION

PLENARY SESSION :

FURTHER INFORMATION

GRDC Grains Research Update BENDIGO

PROGRAM DAY 1 – FEBRUARY 21st

8:15 am	**Registrations**	
9:00 am	**Welcome to country**	
9:10 am	**GRDC opening address**	
9:25 am	**Classification – a pathway to market access**	***Megan Sheehy,*** *Grains Australia*
9:50 am	**Revisiting the levers to maximise wheat yield – an international perspective**	***Allan Mayfield,*** *Allan Mayfield Consulting*
10:20 am	**GRDC Awards Presentation**	
10:30 am	**Morning tea**	

	Auditorium	Dance studio	Strategem studio	Multi purpose room
10:50 am	**Integrating new herbicides into the rotation** ***Chris Davey,*** *WeedSmart, YPAG Agriservices*	**Combatting septoria, rust and other battles** ***Grant Hollaway & Hari Dadu,*** *Agriculture Victoria*	**Emerging research on PGRs in high yielding environments and the photo thermal quotient.** ***Kenton Porker,*** *CSIRO*	**Canola disease management** ***Steve Marcroft,*** *Grains Pathology &* ***Kurt Lindbeck,*** *DPI NSW*
11:30 pm	**A seasonal update on the hyper yielding crops project** ***Darcy Warren,*** *FAR Australia*	**Integrating new herbicides into the rotation** ***Chris Davey,*** *WeedSmart, YPAG Agriservices*	**Emerging powdery mildew challenges** ***Sam Trengove,*** *Trengove Consulting*	**Digging Deeper – agronomic fundamentals forum - Nitrogen budgeting** ***James Hunt,*** *University of Melbourne*
12:10 pm	**Combatting septoria, rust and other battles** ***Grant Hollaway & Hari Dadu,*** *Agriculture Victoria*	**Guidelines for batching and mixing new chemistry** ***Andrew Hewitt,*** *University of Queensland*	**The agronomics of pulses, implications of new varieties and herbicide tolerance traits.** ***Jason Brand,*** *Agriculture Victoria*	**Digging Deeper – agronomic fundamentals forum - Agronomic implications of crop growth stages** ***Dale Grey,*** *Agriculture Victoria*

12:50 pm **LUNCH**

CONCURRENT SESSIONS (40 minutes including time for room change)

	Hall C	Dance studio	Strategem studio	Multi purpose room
1:50 pm	**Canola disease management** *Steve Marcroft, Grains Pathology & Kurt Lindbeck, DPI NSW*	**The development of a more effective zinc phosphide mouse bait** *Steve Henry, CSIRO*	**Emerging research on PGRs in high yielding environments and the photo thermal quotient.** *Kenton Porker, CSIRO*	**Testing the N Bank Theory across varying soil types** *James Hunt, University of Melbourne*
2:30 pm	**Emerging powdery mildew challenges** *Sam Trengove, Trengove Consulting*	**Guidelines for batching and mixing new chemistry** *Andrew Hewitt, University of Queensland*	**The development of a more effective zinc phosphide mouse bait** *Steve Henry, CSIRO*	**A seasonal update on the hyper yielding crops project** *Darcy Warren, FAR Australia*
3:10 pm	**Disease panel Q&A session:** *Josh fanning, Grant Holloway, Sam Trengove, Kurt Lindbeck, Steve Marcroft*	**The agronomics of pulses, implications of new varieties and herbicide tolerance traits.** *Jason Brand, Agriculture Victoria*	**Tailoring subsoil amelioration to paddock zones** *Daniel Hendrie, Agriculture Victoria*	**Testing the N Bank Theory across varying soil types** *James Hunt, University of Melbourne*

3:50 pm **AFTERNOON TEA**

4:20 pm **The impact of subsoil water on soil constraints and crop growth.** *Keshia Savage, PHD Candidate*

4:30 pm **Designing legume root ideotypes for SE Australia** *Spencer Fan, PHD Candidate*

4:40 pm **Maintaining a health mindset under pressure** *Kim Huckerby, The Wellbeing Affect*

5:20 pm **DRINKS & FINGER FOOD IN TRADE DISPLAY AREA**

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

GRDC Grains Research Update BENDIGO

	Hall C	Dance studio	Strategem studio	Multi purpose room
9:00 am	**Pulse disease wrap and fungicide resistance status** ***Josh Fanning,*** *Agriculture Victoria*	**A resistance update on broadleaf weeds.** ***Peter Boutsalis,*** *Plant Science Consulting*	**Novel seed traits – An update on recent R & D** ***Greg Rebetzke,*** *CSIRO*	**Emerging Strategies for Long Term Weather Forecasting** ***Dale Grey,*** *Agriculture Victoria*
9:40 am	**Key messages & outputs from the frost learning centre** ***Mick Faulkner,*** *Agrilink Agricultural Consultants*	**Benchmarking attitudes to pest management and results of IPM demos on RLEM control** ***Paul Umina,*** *CESAR*	**Reducing the reliance on artificial fertilisers** ***Therese McBeath,*** *CSIRO*	**Soil amelioration – where will it pay dividends?** ***Roger Armstrong,*** *Agriculture Victoria*
10:20 am	**MORNING TEA**			
10:50 am	**Benchmarking attitudes to pest management and results of IPM demos on RLEM control** ***Paul Umina,*** *CESAR*	**Pulse disease wrap and fungicide resistance status** ***Josh Fanning,*** *Agriculture Victoria*	**Soil amelioration – where will it pay dividends?** ***Roger Armstrong,*** *Agriculture Victoria*	**Amelioration of sandy soils - the key profit levers** ***Therese McBeath,*** *CSIRO*
11:30 am	**Novel seed traits – An update on recent R & D** ***Greg Rebetzke,*** *CSIRO*	**Effectively mitigating yield losses following waterlogging** ***Greta Duff,*** *Southern Farming Systems*	**A resistance update on broadleaf weeds.** ***Peter Boutsalis,*** *Plant Science Consulting*	**Reducing the reliance on artificial fertilisers** ***Therese McBeath,*** *CSIRO*
12:10 pm	**Emerging Strategies for Long Term Weather Forecasting** ***Dale Grey,*** *Agriculture Victoria*	**Effectively mitigating yield losses following waterlogging** ***Greta Duff,*** *Southern Farming Systems*	**Key outputs and messages from the frost learning centre** ***Mick Faulkner,*** *Agrilink Agricultural Consultants*	**Amelioration of sandy soils - the key profit levers** ***Therese McBeath,*** *CSIRO*

12:50 pm **LUNCH**

PLENARY SESSION :

1:50 pm	**Can we survive without glyphosate? Lessons learned from Europe, Canada and Argentina**	***Harm van Rees,*** *Cropfacts*
2:30 pm	**The impact of soil characteristics & environmental factors on Reflex and Overwatch efficacy.**	***Mark Congreve,*** *ICAN*

3:10 pm **CLOSE**

LOOK AROUND YOU.

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

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

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

beyondblue
Depression. Anxiety.

Lifeline
13 11 14
www.lifeline.org.au

Lifeline
13 11 14

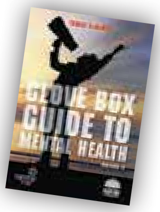
Looking for information on mental wellbeing? Information and support resources are available through:

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

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

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

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



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

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

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

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

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

ifarmwell – growing farmers' wellbeing
Black Dog Institute
Centre for Rural & Remote Mental Health
CORES™
Rural & Remote Mental Health
Heads up – Better mental health in the workplace
National Centre for Farmer Health
National Rural Health Alliance Ltd

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Sowing Guides

Trial results

Long Term Yield Reporter

NVT Disease Ratings

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GRAINS AUSTRALIA

STRATEGIC PLAN 2022/23 – 2024/25

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CHAIR'S STATEMENT

Welcome to Grains Australia's Strategic Plan for July 2022 to June 2025 which sets out the vision, purpose and key objectives that will define the operations and strategic direction of Grains Australia for the next three years.

This Strategic Plan has been developed in consultation with the Board and Grains Australia's Advisory Committee after consideration of the external operating environment and of the key challenges and opportunities facing the industry over coming years. With our new leadership team in place and a clearly articulated strategy for 2022 and beyond, we are able to concentrate our efforts on achieving our goal of being a leader in industry good services that add real value to our stakeholders.

The immediate focus of Grains Australia's leadership team is on completing the establishment of a trusted and sustainably funded organisation. This will enable delivery of more streamlined industry good functions currently delivered by separate organisations, improved connectivity across the value chain, and improved industry influence amongst key domestic and global stakeholders and customers.

We are guided by values to deliver our vision of being the recognised leader in delivering value to the Australian grains industry.

Thank you to Grains Research and Development Corporation and the Australian grains industry for your support. We look forward to continuing to deliver for you, driving innovation and enabling strategic responses to market opportunities and issues.

Terry Enright
Chair, Grains Australia

Values

Responsive

We depend on genuine and sustained stakeholder engagement and responsiveness to stakeholder needs and unforeseen events.

Proactive

We think and act ahead of anticipated events and emphasize planning and risk management.

Ethical

We make the right choices as an organisation, even when they may be difficult.

Effective

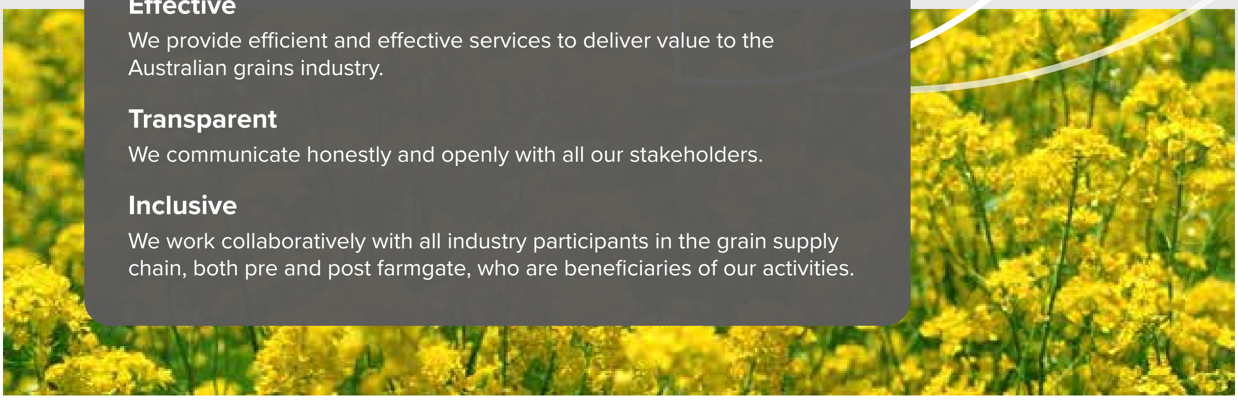
We provide efficient and effective services to deliver value to the Australian grains industry.

Transparent

We communicate honestly and openly with all our stakeholders.

Inclusive

We work collaboratively with all industry participants in the grain supply chain, both pre and post farmgate, who are beneficiaries of our activities.



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WHO WE ARE

Grains Australia is a subsidiary company of Grains Research and Development Corporation (GRDC), which is currently the sole member (effective owner) of Grains Australia.

Grains Australia operates as the industry good organisation that delivers services and functions on behalf of the entire grains value chain.

The operations and business of Grains Australia are governed by a skills-based Board of Directors that has a formal link with an Advisory Committee comprising representatives from GRDC, Grain Growers Ltd (GGL), Grain Producers Australia (GPA) and Grain Trade Australia (GTA).

The Grains Australia Constitution prevents the organisation from carrying out political or advocacy work. We recognise the significant value GGL, GPA and GTA provide as advocates for our industry.

What we do

Grains Australia delivers value to the Australian grains industry by:

1. Engaging and communicating with key industry stakeholders to develop priorities for the whole of the grains industry in relation to our key areas of operation.
2. Establishing and maintaining a market-driven grains variety classification system(s).
3. Providing services to maintain or improve trade and market access.
4. Analysing market and consumer trends to understand demand and identify priorities.
5. Ensuring technical support and training for customers and stakeholders.

Progress at a glance

Since 2020 we have:

- Established Grains Australia Board
- Confirmed multi-year funding with the support of GRDC
- Transferred commodity companies and functions into Grains Australia including:
  - Wheat Quality Australia (WQA)
  - Barley Australia
  - Grains Industry Market Access Forum (GIMAF)
  - National Working Party on Grain Protection (NWPGP)
- Established the executive capability of Grains Australia to support core functions including Classification and Trade & Market Access
- Successfully secured external funding for industry market access priorities under the Federal Government's ATMAC program
- Finalised Strategic Plan 2022/23 to 2024/25
- Developed structure, including Commodity Councils, to deliver on the Strategic Plan
- Launched **grainsaustralia.com.au**

We are seeking to establish Grains Australia as the leader in providing industry good activities that deliver value for the Australian grains industry, which plays a uniquely important role in our national economy and regional communities.

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GRAINS AUSTRALIA

OUR APPROACH

MARKET INSIGHTS

- Trusted international and domestic market insights from all stakeholders
- Information exchange throughout the grains value chain

OPPORTUNITY ANALYSIS

- Research and competitor analysis to prioritise market opportunities
- Focus on stakeholder buy-in

INDUSTRY PRIORITIES

- Whole of industry approach to identifying priorities
- Clear market development strategies

IMPLEMENT

Applied solutions across core functions:

- Classification system(s)
- Trade & market access
- Customers and stakeholder
- Technical functions support and training

MARKET DELIVERY

- Improved trade and market access
- Inform breeding programs of desirable traits and functionalities
- Customer and stakeholder education/value proposition delivered

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GRAINS AUSTRALIA

OUR STRATEGY

VISION

Recognised leader in delivering value to the Australian grains industry

PURPOSE

Grains Australia manages classification, market access, and market information and education to enhance competitiveness and profitability

GOALS

- Improve or maintain access to high value markets
- Effective delivery of core business and technical functions
- Support effective decision-making by the grains industry and its customers

STRATEGIC PRIORITIES	1. Engage and communicate to develop priorities for the grains industry	2. Establish and maintain a market-driven grain variety classification system(s)	3. Provide services to maintain or improve trade and market access	4. Analyse market and consumer trends to understand demand and identify priorities	5. Ensure technical support and training for customers and stakeholders
OUTCOMES	• A whole-of-industry approach to identifying market and commodity priorities • Industry leaders engaging effectively with consistent messages • Technical information, trends and knowledge exchanged across industry	• Consistent, science-based, market-driven grains classifications	• Credible and trusted opportunity analysis • Government's point of contact on international grain trade matters • Strategic responses to trade and market access issues • Greater market diversification • Reduced trade impediments	• Validated and trusted international and domestic market insights • Two-way communication on market, customer and consumer opportunities • Prioritised programs based on market information • Market learnings from customers and consumers	• Technical and market requirements of customers and stakeholders clearly understood • Technical support and training for customers and stakeholders • Technical expertise gaps in the supply chain addressed

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ACTIONS

HORIZON 1	HORIZON 2	HORIZON 3
July to December 2022	**January to July 2023**	**July 2023 to July 2025**
• Establish Commodity Councils • Complete Grains Australia team (people) and establish core culture • Develop and implement Stakeholder Engagement & Communication Plan • Develop 2022/23 Annual Operating Plan and Budget • Implement new 5-year Funding Agreement • Implement fit-for-purpose HR, IT and financial systems and processes • Integrate databases and optimise website and social media • Complete integration of Barley Australia and Wheat Quality Australia • Negotiate and finalise Service Agreement for Information and Education	• Develop 2023/24 Annual Operating Plan and Budget • Classification concept for Pulses and Oats developed and accepted • Implement systems and processes for: - Project workflow - Reporting dashboard - Data management plan • Engage with Pulse Australia on industry good services • Engage with Australian Oilseeds Federation on industry good services • Engage with Grains & Legumes Nutrition Council on industry good services • Membership assessment	• Classification concept for Oilseeds developed and accepted • Develop 2024/25 Annual Operating Plan and Budget • Develop 2025/26 to 2027/28 Strategic Plan

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Notes

Notes

Revisiting the levers to maximise wheat yield – an international perspective

Allan Mayfield, *Allan Mayfield Consulting*

GRDC Award of Excellence, 2021

Keywords

- Europe, high wheat yields, New Zealand, nitrogen.

Take home messages

- Average wheat grain yields have barely increased in the more productive areas of Europe and New Zealand over the past 20 years, except for a small percentage of growers who are pushing the boundaries of world record grain yields.
- Wheat crop area, and so total wheat production, has tended to decrease in Europe due to: the availability of subsidies for alternative land uses, an increase in herbicide resistant blackgrass and the loss of important crop protection chemicals.
- A study of two growers with the highest wheat yields in the world, Tim Lamyman in the UK, and Eric Watson in New Zealand, show a very high attention to detail with their wheat production to ensure that crops rarely have any limitations within their control.

Background

This study was in part a follow-up of a similar study (for a Churchill Fellowship in 2002 and 2003) to assess what practices could be used in Australia to improve wheat grain yields in higher yielding environments. This GRDC Award of Excellence study tour aimed to re-visit many of these people and organisations visited in 2002 to 2003 and to see what has changed since then in the management of cereal crops for high grain yields. This included any changes in crop nutrition, weed control, seeding systems and dates, crop varieties and other management practices that have either increased crop yields further or improved the efficiency of inputs. The study tour included visits to researchers, growers and industry personnel in the UK and Germany in April and May 2022, and New Zealand in December 2022. It has also included attending the GRDC Hyper Yielding Crops field days at Millicent in November 2021 and in Tasmania in November 2022.

Wheat grain yield trends

Wheat grain yields across the UK appear to be static over recent years, generally ranging between 8t/ha to 10t/ha. The area sown to crops has reduced slightly, essentially because of subsidies for alternative 'set-aside' land uses, such as pastures of 'bird seed mixtures' as well as the need to delay sowing of wheat to help control blackgrass. These production trends are likely to continue with the EU plan (known as Farm to Fork) to reduce fertiliser use by 25%, pesticide use by 50% and to at least double the area farmed organically to be at least 25% of the total farm area by 2030.

In contrast, wheat production on the Canterbury Plains of New Zealand is increasing slightly. Competing land uses here, such as dairying, have stabilised and new land uses, including forestry for carbon credits are on non-arable land and mostly further south.

Crop production systems

Crop types and cropping sequences in the UK and Germany are largely driven by subsidies for alternative land uses. While the standard cropping sequence in the UK is something like winter wheat, winter or spring barley or spring oats, and faba beans or oilseed rape, there are relatively large areas of 'set-aside'. A common use of this land is to sow a 'bird seed mixture', containing nine different plant types (barley, triticale, three types of millet, fodder radish, mustard, phacelia and quinoa).

Crop diversity is still very evident on the Canterbury Plains of New Zealand. One grower I visited had 15 different crops, including the usual seed crops of grasses and vegetables for the export market, but no wheat, barley or pulses. Other seed crops include more unusual types, such as phacelia, which is used (with 27 other plant species) in the so-called Regenerative Agriculture seed mixtures. Some New Zealand grain growers also have legume pastures for growing out lambs.

Maximum wheat grain yields

A key feature of growers producing some of the highest cereal grain yields in the world is their attention to detail with crop production. This includes multiple applications of nutrients as well as the standard fungicides and growth regulants. They also carefully select crop varieties that are likely to perform very well in their growing environments. They typically do not have a special 'set-up' year, such as a dense legume pasture, but sow these high yielding crops as part of a normal cropping program.

UK, Lincolnshire grain grower, Tim Lamyman, strives to achieve world record grain yields. His record wheat yield of 16.5t/ha in 2016 has since been surpassed in 2020 by Eric Watson from New Zealand (with 17.4t/ha), but he currently holds the world record for barley at 14.2t/ha. His average wheat yield is 12.2t/ha compared with the regional average of 8t/ha. Over the past ten years, Tim's wheat crops entered in the ADAS (Agricultural Development and Advisory Service) YEN (Yield Enhancement Network) crop comparison program have averaged 14.2t/ha, compared with the next best growers averaging less than 13t/ha. As well as chicken litter before seeding, Tim applies up to 350kg N/ha (in up to five applications) on wheat and 240kg N/ha on barley. Mixtures of many trace elements and other nutrients (such as Xtress and Calflux, from Bionature UK) are also applied. Researchers in the UK have yet to identify what essential components of these products are contributing to these high grain yields. Tim also applies growth regulants at lower rates but quite frequently (up to five times). Fungicides (especially for control of Septoria tritici blotch) are applied regularly. The aim is for 750 wheat heads/square metre for wheat and 1000 heads/square metre for barley and a harvest index of approximately 55%.

New Zealand grower and current world wheat yield record holder, Eric Watson, pays a lot of attention to irrigation regimes and crop nutrition, as well as other aspects of wheat husbandry. Neutron probes are used to monitor soil water and help with irrigation decisions, and paddocks are tested intensively for available nutrients. Lime, P and K are spread at a variable rate across fields according to variation in these nutrients measured in soil tests. Other nutrients applied during the growing season (based on leaf tissue tests) include phosphorus, sulphur, magnesium, zinc and boron. Typically, a long-season European wheat is sown in mid-April, at 135 plants/square metre and to produce at least 1000 heads/square metre. A total of 300kg N/ha is applied, and additional soil reserves are typically 30kg N/ha. Fungicides are applied four times, insecticides (to prevent BYDV) four times and growth regulants twice.

The best wheat grain yields of both of these growers are approximately 70% above the average grain yield for their respective countries, and are at the upper margin of all wheat crops recorded in the ADAS YEN (Yield Enhancement Network) program (Figure 1).

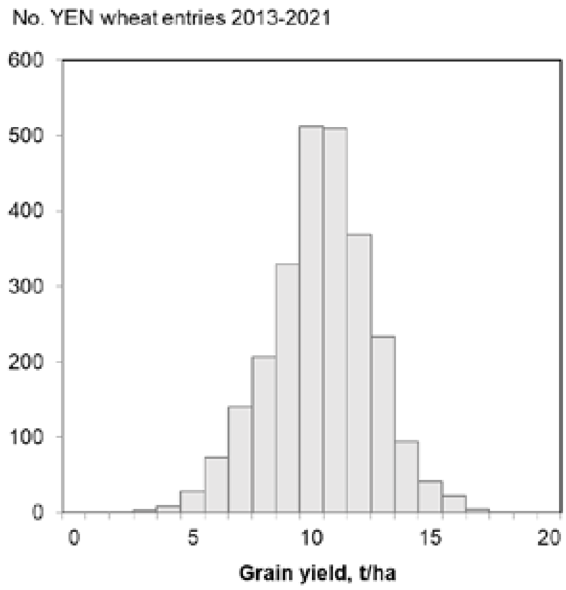

Figure 1. Wheat grain yields from the ADAS YEN program, 2013 to 2021.

This begs the question: what are the key elements of their management that produces these much higher grain yields? Their crop varieties, seeding dates and rotations are similar to other growers, but their attention to detail with crop nutrition, disease control and growth regulant application seems to be much greater. They apply many different nutrients, based on plant tissue and soil tests, as well as anything else required to prevent disease or pest damage. Their aim is to get the maximum amount of light interception by their crop. Their nitrogen fertiliser rates are higher than normal, from 300 to 350kg/ha compared with approximately 220kg/ha for other wheat crops grown in these regions. But as well demonstrated in the hyper yielding wheat yield trials in Tasmania, high wheat grain yields cannot be driven by simply adding more nitrogen fertiliser; other nutrients also need to be added as well, where required. Grain nutrient analyses in the YEN program show that for Tim Lamyman's wheat crop, rarely is there any nutrient lacking, whereas for all of the 155 wheat entries in the YEN program in 2022, more than 80% had at least one nutrient deficient, and more than 50% had more than one nutrient deficient.

The view of Prof. Roger Sylvester-Bradley (ADAS, UK) is that growers with the highest crop yields have very good attention to detail to the extent that crops are usually not limited at any stage by any constraint, such as nutrition or disease. This is known as 'crop momentum'. He also points out that these crops are generally not sink limited. As well, these high yielding crops are grown in ideal cropping environments.

The economics of these systems was not assessed as this would change according to grain prices and the cost of inputs, but there is no doubt that these crops would be profitable. More importantly, these pioneering growers give us an insight as to what is required to continue to increase grain yields here – that is, to ensure (within the economics of crop production systems) that the attention to detail with crop management is as high as possible.

Fertiliser use and decision processes in Europe

Nitrogen use for cereal crops in Europe is relatively static – mostly 200–220kg N/ha in both the UK and Germany, although rates now are a bit lower in 2022 (by approximately 20kg/ha) due to the higher cost of nitrogen fertilisers. Note, the rate allowed in Germany is based on the average grain yield over the past five years and a soil test by the grower or government. This soil value is typically 30–60kg available N/ha.

In larger scale trials by ADAS, in an AHDB (Agriculture and Horticulture Development Board) funded program known as LearN (refer to AHDB Report No. 596), responses to applied nitrogen were assessed on 18 farms over four years (from 2014 to 2017). They found that the variations in grain yield across fields were much greater than responses to applied nitrogen. Also, nitrogen responses were inconsistent between farms and unrelated to the amount of available soil nitrogen. There is also no clear relationship between available soil N pre-sowing (typically 30–60kg available N/ha) and the crop grain yield response to applied fertiliser nitrogen, although in Germany and Denmark ,at least this is taken into account when determining the total amount of nitrogen fertiliser a grower is permitted to use. This emphasises the point that crop nitrogen fertiliser recommendations, at least in the UK, is an inexact. There has been little follow-up study on the underlying reasons for this variation across fields.

There is increasing interest in Europe and New Zealand in managing crops using variable rate application, especially with the freely available imagery from the Sentinel-2 satellite. There are also approximately 2200 N-Sensors in use worldwide. Most of these are in Germany and approximately 250 are in use in the UK. They are also starting to be used in New Zealand. Variable rate nitrogen fertiliser application is generally set to use a higher rate on the better (heavier) soil types with the first application, and more on the poorer (lighter) soil types with the second application.

The main type of nitrogen fertiliser used in the UK is ammonium nitrate, with some ammonium sulphate, urea and UAN also used. In Germany, the main form of N fertiliser is calcium ammonium nitrate. From April 2024 granular urea fertiliser used in the UK needs to be treated with an ammonium inhibitor, such as Agrotain, except for use between 15 January and 31 March in the UK, especially for sugar beet. This inhibitor is required for all timings in Germany.

It was of interest that it was common for growers in the UK to apply foliar applications of magnesium, a nutrient hardly used at all in crops in Australia or in Germany.

Alternative fertilisers were commonly used on the farms visited. These included digestate from silage used for electricity generation and mulched garden waste (from local councils). Some growers are also growing silage crops (such as triticale or maize) for power generation in their own anaerobic digesters and the residues from these is then used as a fertiliser for crop production.

In New Zealand, there are restrictions on the use of nitrogen fertiliser on pastures for the dairy industry, but these restrictions do not apply yet to cropping enterprises. However, New Zealand growers still need to produce a farm 'Environmental Plan' which is then audited. A high quality plan is audited every four years, but a low quality plan needs to be audited monthly.

Crop protection

The loss of chemicals available to growers in Europe, especially for grass control in cereals, is continuing. This is largely due to re-registration requirements and insufficient markets to warrant the high cost of re-registration by companies. Now that the UK is no longer in the EU, companies there now need to have a separate registration process for sales in the EU.

They still have propyzamide and clethodim available for control of grasses in pulses and oilseed rape, but no longer have imidacloprid for insect control in oilseed rape (since 2013) or chlorothalonil for disease control in pulses. The loss of imidacloprid means that European growers have no chemical available for control of cabbage stem flea beetle in oilseed rape crops. Both the larvae and adults can cause substantial damage to these crops. Oilseed rape is most vulnerable at emergence, especially when it is unable to outgrow feeding damage caused by adult beetles leading to crop failure. Larvae damage oilseed rape crops later in the growing season, especially in the petioles, but also less frequently, in the stems. In 2022, approximately 20% of oilseed rape in the UK was lost due to poor establishment from flea beetle. These areas will likely be sown the next year with either spring barley or spring oats. No other chemicals are available for control of flea beetle due to resistance to pyrethroids.

Clearfield varieties of oilseed rape with imidazolinone tolerance are available in Europe. This herbicide tolerance trait is also in sugar beet and sunflowers, but not cereals or pulses.

As far as the availability of glyphosate is concerned, there is every indication that it will no longer be available in some European countries, including Germany, after 2024. There is no indication yet that this will happen in the UK.

In contrast, in New Zealand, there has not been any loss of major crop protection chemicals in recent years.

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GRAINS RESEARCH & DEVELOPMENT CORPORATION

Concurrent session Day 1

Integrating new herbicides into the rotation

Chris Davey,

WeedSmart; YP AG.

Keywords

- annual ryegrass, resistance, stacking and rotating pre-emergent herbicides, WeedSmart Big 6.

Take home messages

- Well above average rainfall in Victoria in 2022 led to a lot of later germinating weeds (and escapes) and/or weed blow-outs in some paddocks.
- Resistance in annual ryegrass to common herbicides is increasing.
- Other weed species developing resistance include brome grass, barley grass, milk thistle, wild radish and Indian hedge mustard.
- Strategic use of new herbicides is paramount to ensure the longevity of these herbicides and prolong the onset of herbicide resistance.
- Consideration should be given to soil type, tillage system, varietal difference and forecast rainfall, when choosing the right pre-emergent herbicide for your crop.

Background

Pre-emergent herbicides have become more important for the control of grass weeds, particularly annual ryegrass, in the past decade, as resistance to post-emergent herbicides has increased. Resistance to trifluralin is now common across many cropping regions of South Australia and Victoria and is increasing in NSW.

Worryingly, resistance to the Group 15 pre-emergent herbicides has also be detected in random weed surveys. In some parts of South Australia and Victoria, resistance to triallate is becoming common. It is likely resistance will further increase, making it more difficult to control annual ryegrass with the current suite of herbicides available.

New pre-emergent herbicides offer an opportunity to expand the suite of products that can be rotated. However, it is important that these are used well to optimise performance while also maintaining their longevity.

Results and discussion

Resistance testing

Weed resistance testing by Plant Science Consulting, through both GRDC random surveys, and targeted sampling by growers and agronomists, has shown an increasing amount of herbicide resistance to a range of weeds.

New pre-emergent herbicides

We have been blessed to have been given the opportunity to use new herbicides that have been recently released into the market. These include Luximax®, Overwatch®, Mateno® Complete, Callisto®, Reflex® and Voraxor®, to name a few.

The introduction of these products has given growers access to brand new chemical mode of action (MOA) groups that have not been utilised before in broadacre cropping in Australia. A few of these new products have different characteristics when applied to the soil, like their solubility and mobility/binding to soil and organic matter. Thought should be given to where the new products best fit in your rotation, with regards to crop type, problem weed species and soil influences.

WeedSmart Big 6

As new chemistry becomes available, it is crucial for all involved to protect the longevity of any new products and minimise the risk of resistance. The WeedSmart Big 6 brings together weed research data with grower experiences to create a set of practical guidelines focused on minimising the weed seedbank without compromising profit.

The WeedSmart Big 6:

- rotate crops and pastures
- double knock – to preserve glyphosate and paraquat
- test, mix and rotate herbicides
- increase crop competition
- stop weed seed set
- adopt harvest weed seed control.

Best practice agronomy is a key component of the Big 6 and pulls together all the aspects of profitable no-till cropping such as precision seeding, timely sowing, targeted nutrition, soil amelioration and crop competition, so that crops have the edge over weeds. Tactics such as harvest weed seed control, cutting hay and diverse rotations are also essential to complement herbicide use including the mix and rotation of herbicides, double or triple knock, and late season crop-topping.

Grower success in reducing weed seedbanks but staying profitable has been achieved through stacking Big 6 tactics over an extended period of time. For example, a diverse rotation with pulses, competitive barley and early sown hybrid canola combined with pre-emergent herbicides, opportunistic double knocks, crop-topping and chaff decks has all the Big 6 tactics stacked together.

Conclusion

New herbicides will continue to form part of our weed management strategies in the future.

The key is to know how to get the best out of them, optimising weed control, while also preventing the onset of herbicide resistance from poor application and overuse.

Old chemistries may still have a fit on your farm, for certain weed species where resistance has not evolved. Resistance test any problem areas of weeds so that you know what you are dealing with, and what herbicides are still active on that weed type.

Adopt as many of the WeedSmart Big 6 principles as possible into your farming system, to complement your herbicide management strategies.

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*WeedSmart has investment from the GRDC and commercial companies and delivers science-backed weed control solutions. GRDC is a Platinum Partner in WeedSmart..

Useful resources

WeedSmart Big 6 - https://www.weedsmart.org.au/big-6/Pre-emergent herbicides fact sheet (https://grdc.com.au/resources-and-publications/all-publications/factsheets/2022/pre-ermergent-herbicides-fact-sheet)

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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Wheat disease update – rust and Septoria

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GRDC project codes: DJPR2104-004RTX, DJP2103-005RTX, DJP2003-011RTX, DJP1905-002SAX

Keywords

- fungicide resistance, green bridge, Septoria tritici blotch, stripe rust.

Take home messages

- Disease pressure going into the 2023 season will be extreme, with carry-over of inoculum from 2022 crops on both stubble (for example, Septoria) and cereal volunteers (for example, rusts).
- Proactive disease management that combines variety selection (avoiding susceptible varieties), paddock selection (use good rotations that reduce cereal intensity) and appropriate fungicide use, provides proven sustainable and economic control of diseases.
- Up-front fungicides, such as flutriafol on fertiliser, will be important to manage the heightened risk posed by cereal rusts.
- The extremely wet conditions (both amount of rain and number of rain days) during August to November placed cereal crops under unprecedented disease pressure resulting in high losses where diseases were not effectively managed.
- Septoria tritici blotch, an important disease in HRZ, caused yield loss (35–43%) in highly susceptible varieties in field trials in the MRZ (Wimmera) during 2022. Fungicides were required to protect grain yield in the MRZ, increasing yield by ~35% with two sprays (Z31 and Z39) in susceptible cultivars.
- Development of resistance to fungicides is increasing in cereal pathogens but can be slowed through the adoption of integrated control strategies and prudent use of fungicides.

2022 in review

Disease pressure on cereal crops during 2022 was extreme. The combination of both the amount (Figure 1) and frequency (Table 1) of rainfall from August to November provided ideal conditions for disease development. Not only was 2022 the wettest August to November in the last 100 years (it exceeded the previous wettest in 1975 by 86 mm), it also had the highest frequency of rain days (rainfall ≥0.1mm), with rain on three out of five days (Table 1). During such a high-pressure year, the benefits of appropriate variety selection and proactive management strategies were demonstrated.

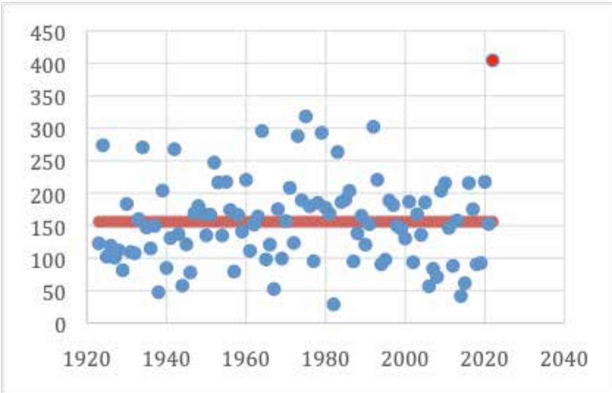

Figure 1. Annual total rainfall (mm) for August to November over 100 years (1923 to 2022) compared to the long-term average (156mm) at Longerenong, Victoria.

Table 1: Number of rain days (≥0.1mm) each month during 2022 compared with the 100-year average (1923 to 2022) at Longerenong, Victoria.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Aug-Nov	Total
2022	3	3	8	4	13	19	19	21	18	19	16	4	74	150
Average	4	4	4	7	11	13	15	15	12	10	7	5	44	107

Cereal rust update

As expected during 2022, due to the substantial opportunity for rust to survive summer on volunteer cereals (the 'green bridge') in northern Australia, rust appeared in Victorian wheat crops earlier than usual. This early rust on-set, along with the favourable conditions for disease development, resulted in a damaging outbreak of stripe rust across Victoria. Industry reports during the season confirmed that strategies of avoiding susceptible cultivars, using up-front fungicides, and timely foliar fungicide applications all contributed towards reduced stripe rust pressure in paddocks. Where control was inadequate, large yield losses due to stripe rust in wheat occurred. There were limited reports of wheat leaf rust and no reports of wheat stem rust in Victoria. There were multiple reports of barley leaf rust later in the season.

Cereal rust management for 2023

The rust risk going into the 2023 season will be extreme. The opportunities for rust to survive summer on volunteer cereals (the 'green bridge') and infect new crops will be immense due to widespread summer cereal volunteers across eastern Australia. Rust outbreaks are more severe following seasons with widespread volunteers, as rust can only survive from one season to the next on living plant material (it doesn't survive on seed, stubble, or soil).

It is therefore essential that growers take the following steps to reduce their risk:

- remove the green bridge (volunteer cereals) by mid-March
- use a current cereal disease guide to check resistance ratings of their varieties and, where possible, avoid susceptible varieties
- develop a fungicide management plan, with an emphasis on up-front options, such as flutriafol on fertiliser, to provide early rust suppression
- download the StripeRustWM App; free for iPads and tablets for support with wheat stripe rust management.

When rust risk is high, the benefits from widespread use of up-front fungicide treatments (such as flutriafol on fertiliser) should not be underestimated in providing regional control. Such a practice on all at-risk cereal varieties on an industry wide scale can greatly reduce the rust risk across a district.

Septoria in wheat

Septoria tritici blotch (STB) was the second most damaging disease of wheat after stripe rust in 2022. The unprecedented spring rains (Figure 1 and Table 1) favoured STB, with the disease able to progress to the top of plants, causing yield losses in many crops where control was inadequate.

Historically, losses due to STB were most common in susceptible cultivars in the high rainfall zone. However, AgVic trials demonstrated losses of ~35–43% in the Wimmera (medium rainfall zone) during 2022 compared with <10% during 2021, clearly demonstrating the role of rainfall in the damage caused by STB. Figure 2 shows the relative progress of STB on a susceptible wheat variety grown in the Victorian low, medium and high rainfall zones (LRZ, MRZ and HRZ) during 2022.

Yield losses can be greatly reduced when resistant varieties are grown in preference to susceptible varieties. Field experiments conducted by AgVic at Longerenong (MRZ) during 2022 demonstrated yield losses of around 35–43% in susceptible (S) and susceptible to very susceptible (SVS) varieties, representing losses of ~1.7t/ha in yield (Table 2). The losses in less susceptible varieties (LRPB Lancer⁽ᴾ⁾ (MS) or Hammer CL Plus⁽ᴾ⁾ (MSS)) were 21% or less, demonstrating the benefit in avoiding highly susceptible cultivars.

Fungicides provided variable control of STB in a field experiment conducted at Longerenong (MRZ) (Table 3). All fungicide treatments reduced STB severity compared to the untreated control, but the early applications of seed only or a single spray at Z31 were not as effective as any of the three treatments that included a fungicide application at Z39. Within this trial, the best economic control of STB was achieved by two foliar fungicide applications at Z31 and Z39 (with or without a seed treatment) increasing grain yield by 37–39%.

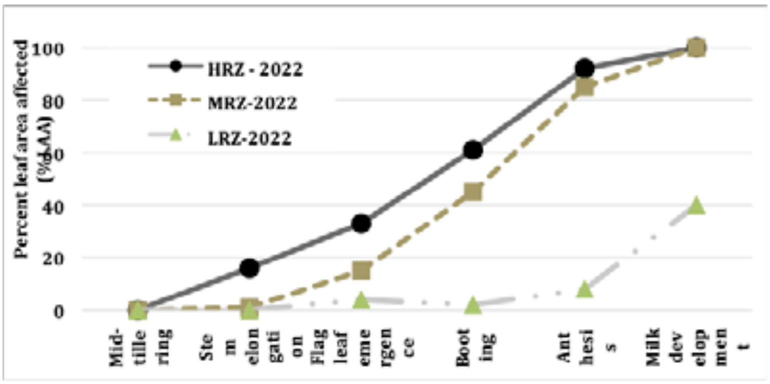

Figure 2. Septoria tritici blotch severity (% leaf area affected) across time in wheat (cv. Razor CL Plus⁽ᴰ⁾, susceptible to very susceptible to STB) at three different rainfall zones in Victoria, during 2022.

Table 2: Septoria tritici blotch severity (% leaf area affected) and yield loss of six wheat varieties treated with and without disease at Longerenong, Victoria, 2022.

Variety	Resistance rating	Disease severityA (% leaf area affected) in Max. disease			Grain yield (t/ha)		Yield loss (%)D
		07-AugB Z37-39	05-Sep Z45-59	18-Oct Z75-77	Max. diseaseC	Min. disease	
LRPB LancerA	MS	3a	8a	75a	4.09	4.93**	17
Hammer CL PlusA	MSS	10b	21b	88b	3.87	4.88**	21
CalibreA	S	14d	34c	98c	3.33	5.11**	35
ScepterA	S	14d	37d	99c	3.07	4.80**	36
LRPB ImpalaA	SVS	12c	34c	100c	3.13	4.83**	35
Razor CL PlusA	SVS	12c	40e	100c	2.25	3.98**	43
P		<0.001	<0.001	<0.001	-		
Lsd (0.05)		1.2	1.7	8.9			

AWithin column means with one letter in common are not significantly different (0.05). ** = statistically significant at 5% Lsd. BDate of assessment made and Zadoks growth stages Z37 flag leaf emergence; Z51 ear emergence; Z75 milk development according to Zadoks et al. (1974). First two assessments were average of single plot assessments, while the third assessment was average of the top three leaves of ten tillers per plot. C Max. disease = Maximum disease treatment; Min. disease = Minimum disease treatment. D Yield loss % for each variety was presented as percentage yield decrease vs the minimum disease treatment.

To minimise losses from STB, avoid highly susceptible varieties (especially those rated S and SVS). If conditions are suitable for STB, then fungicide strategies should include applications at both growth stages Z31 and Z39. Also, avoid sowing wheat into paddocks with one- or two-year-old wheat stubble, noting that early STB infection will also come from wind borne spores from adjacent paddocks.

Table 3: Septoria tritici blotch severity (%) and yield loss in the wheat variety Scepter⚵ (S) in response to different fungicide treatments at Longerenong, Victoria, 2022.

Treatments	Active ingredient (g ai/L)[#]	Rate	Disease severity[A] (% leaf area affected) in Max. treatment[B]			Grain yield (t/ha)[A]	Yield gain %[C]
			17-Aug Z37	5-Sep Z53	19-Oct Z77		
Untreated control	-		15^{d}	39^{e}	95de	3.26^{a}	-
Seed	Fluquinconazole 167g/L	300mL/100kg seed	11^{c}	34^{d}	97^{e}	3.49^{ab}	7
Foliar at Z31	Benzovindiflupyr 40g/L + Propiconazole 250g/L	500mL/ha	9^{b}	24^{c}	91^{d}	3.70^{b}	14
Foliar at Z39	Epoxiconazole 500g/L	125mL/ha	14^{d}	37^{e}	85^{c}	3.97^{c}	22
Foliar at Z31 + Z39	Benzovindiflupyr + Propiconazole at Z31 and Epoxiconazole 500g/L at Z39	500 and 125mL/ha	9^{b}	22^{b}	80^{b}	4.48^{d}	37
Seed + Foliar at Z31 + Z39	Fluquinconazole as seed + Benzovindiflupyr + Propiconazole at Z31 and Epoxiconazole 500g/L at Z39	300mL/100kg seed + 500mL/ha and 125mL/ha	5^{a}	14^{a}	76^{a}	4.54^{d}	39
P			<0.001	<0.001	<0.001	<0.001	
Lsd (0.05)			1.3	2.1	4.2	0.2	

[A]Within a column, means with one letter in common are not significantly different at 0.05. First two assessments were average of single plot assessments while the third assessment was average of the top three leaves of ten tillers per plot. [B]Max. disease = Maximum disease treatment. [C]Yield gain % for each treatment was presented as percentage yield increase vs the untreated control. [#]ai = active ingredient

Fungicide resistance in cereals

Resistance to fungicides is becoming an increasing threat to Australian cereal crops. Recent research by the rust research team at the University of Sydney have convincing evidence from growth room studies of insensitivity (resistance) to several DMI fungicides in the leaf rust pathogens of wheat and barley. These findings come from the screening of more than 800 cereal rust isolates of wheat (stem rust, leaf rust, stripe rust), barley (leaf rust) and oat (crown rust, stem rust) for sensitivity to the DMI fungicide tebuconazole in recent years. In both cases, the insensitivity was to not only tebuconazole, but also triadimefon, propiconazole and prothioconazole. At this stage field failures have not been observed and further field validation of these findings are required.

In barley leaf rust, the insensitivity was found in the most common isolates in Australia. The insensitive isolates were able to grow and sporulate despite rates of tebuconazole (not registered for control of leaf rust in barley) of more than 10 times the recommended high field rate of 290mL/ha.

Within wheat leaf rust, insensitivity to four DMI fungicides was identified in a single pathotype (93-

3,4,7,10,12 +Lr37). Fortunately, nationally this pathotype is only present at low levels, but it could grow and sporulate on leaves treated with rates of tebuconazole up to 25 times the recommended high field application of 290mL/ha. Further field validation of these findings are required.

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.** Use fungicide mixtures formulated with more than one mode of action, 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

Wheat head diseases in 2022

There was widespread disease in the heads of wheat crops during 2022 which resulted in shrivelled grain and/or reduced grain number. Work is on-going to define all the causes, but preliminary results indicate that the primary cause, in many cases, was stripe rust damage to the head, with other pathogens and saprophytes also involved.

Molecular testing of affected wheat heads in collaboration with SARDI found stripe rust in all samples tested, along with *Septoria tritici*. The pathogen causing yellow leaf spot was common, but not in all samples. The crown rot fungus, *Fusarium pseudograminearum*, was identified in wheat heads but generally at low levels. No other *Fusarium* spp. have been identified at this stage.

Symptoms of false or pseudo black chaff (a physiological condition associated with the stem rust resistance gene *Sr*2) were often confused with glume blotch. Subsequent testing identified *Stagnospora nodorum* (glume blotch pathogen) in a small number of samples, but this was generally at low levels and not a widespread issue.

The major causes of the wheat head issues during 2022 were most likely the exceptionally wet conditions during flowering and grain fill (Figure 1 and Table 1) and high levels of stripe rust. It is recommended that seed lots for 2023 sowing are tested for germination and vigour.

Conclusion

In the absence of proactive disease control, yield losses due to diseases can be greater than 20%. The risk from rust diseases in 2023 will be high due to widespread volunteer cereals carrying rust inoculum from last season. Given this heightened rust risk this season, the widespread use of up-front fungicides (for example, flutriafol on fertiliser) is highly recommended, especially on rust susceptible varieties, to help with early season control. Disease management plans should consider paddock and variety selection and, where the risk warrants it, the proactive and prudent use of fungicides that avoid overuse to protect their longevity.

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Field crop diseases Victoria (https://extensionaus.com.au/FieldCropDiseasesVic/)

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Notes

Maximising growth and yield – canopy management is more important in seasons of better potential

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Keywords

- canopy management, light, temperature, yield potential.

Take home messages

- Light and temperature are more likely to set the boundary of yield potential than rainfall in higher productivity zones and seasons.
- Release of cultivars with high yield potential and sowing dates that better align crops to maximise light interception during the critical period has increased yield in the HRZ.
- Improved genetic resistance and disease management strategies were essential to achieve the yield potential and close the yield gap in the HRZ , especially in seasons like 2022.
- Additional nitrogen (N) supply and increased fungicide application were more important than cultivar and plant growth regulator (PGR) application to achieve high yields in 2022.
- Building more fertile farming systems with higher levels of organic N supply to supplement fertiliser applications will be necessary to support higher yield potentials.

Background

While most crops in Australia are water limited, an important realisation is the fact that, in high rainfall seasons, other factors such as the availability of the key resources – light, temperature, and nutrients (especially nitrogen) – are more likely than rainfall to set the boundary of yield potential. The 2022 April–November rainfall was well above average in most regions of south-eastern Australia, with enough water supply to achieve yields approaching 8–10t/ha, consistent with those regularly achieved in the high rainfall zones (Table 1). The question is, how do growers achieve high yields in seasons of better potential? The GRDC Hyper Yielding Crops Initiative (HYC) has shed light on the agronomic and environmental factors required to achieve high yields and can also be useful to guide growers in the low to medium rainfall zones in high rainfall seasons like 2022.

Principles of building and protecting high yields

Building high yielding crops in wet and mild environments (seasons) is primarily achieved by increasing grain number. Grain number is predominantly determined by the amount of growth (or dry matter accumulation) during late spike development in the period between emergence of the penultimate leaf (flag -1) and shortly after flowering. This period is known as the critical period for yield determination. Grain number, and thus yield, are very sensitive to stress during this time (Fischer 1985). Building yield relies upon adopting techniques that allow crops to intercept more radiation (sunlight) and transpire more water into productive biomass at the right time of the season.

Harvest indices (resulting from the conversion of biomass into yield) of greater than 50% should be possible with good management. Therefore, to achieve 8–10t/ha cereal grain yields, the final biomass needs to be greater than 16–20t/ha. Other constraints, such as disease, lodging, head loss and extreme weather shocks, will either chip away at the potential or reduce harvest index and need to be managed if possible.

Critical resources define yield potential

Water supply

The water-limited potential yield (PYW) for cereals and canola can be estimated using the well-known French and Schultz (1984) approach, which has been updated for cereals by Sadras and Angus (2006). In this approach, the water supply to the crop is estimated using readily available rainfall data (in-season rainfall + estimate of stored fallow rainfall – evaporation) and converted to yield using the recently published upper limits for transpiration efficiency in the best cereal crops of 25kg grain per ha for each mm of water supply (Sadras and McDonald 2012). The minimum evaporation in the best crops reported in the literature is generally 60mm. While there are other considerations and assumptions that can be taken into account, for simplicity this approach is informative for benchmarking.

Temperature and solar radiation

Yield formation is sensitive to the ratio of solar radiation to temperature (referred to as photothermal quotient or PTQ) experienced during the critical period. The relationship between PTQ and potential yield of wheat published by Rawson (1988) has been verified by a number of hyper yielding sites and high yields worldwide, for example, the world record wheat yield in NZ. The world record canola yield was achieved at Oberon NSW (7.2t/ha) assisted by temperatures being moderated by altitude (1000m asl) under bright conditions. A high PTQ equates to high yield potential and can be achieved by bright, sunny conditions or long days of solar radiation to drive growth (photosynthesis) combined with low temperatures that extend the critical period as long as possible. The PTQ derived yield potential was less at Millicent SA in 2022 because temperatures were average or slightly higher during the critical period (October), but solar radiation was lower, generating a lower PTQ, reduced photosynthesis and lower grain number (Figure 1). The relationship between PTQ and yield assumes no other major stresses in the critical period, such as extreme temperature, water or N stress and no pests or disease, and assumes ideal growing conditions outside of the critical period for conversion to yield.

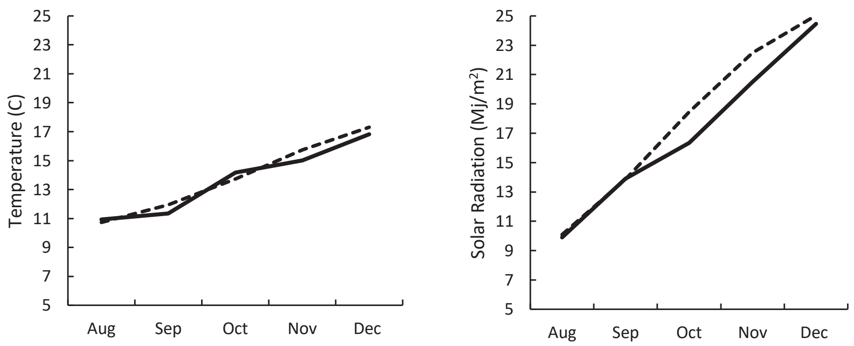

Figure 1. Long term (- - - -) and 2022 (–) monthly mean temperatures and solar radiation for Millicent, SA.

2022 yield potential

Using a water use efficiency of 25kg/ha/mm, estimated water limited yields were higher than the long term averages across a number of locations in 2022 (Table 1). Another defining feature of 2022 was that while temperatures were consistent or slightly warmer than long term trends, solar radiation was lower than average, and thus, low PTQs were limiting yield potential more often than water supply. This was especially the case at coastal sites (for example, Millicent, Kingscote), and where water supply exceeded 400mm. While 2022 was clearly a wetter than average year, it is worthwhile considering the frequency with which PTQ is likely to limit yield potential compared to water. At Millicent for example, PTQ has likely limited yield potential in 27 of the last 33 years, at Cummins SA and Giles Corner SA, only 6 of the last 33 years.

Table 1: Selected southern Australian sites and calculated water limited and photothermal quotient yield potentials for 2022. Shaded cells indicate sites where the PTQ was limiting yield potential and not water supply based on a 25kg/ha/mm transpiration efficiency.

Site (Nearest town)	Water Supply (mm)	Water Limited Potential Yield (t/ha)	Assumed Flowering Date	Photothermal Quotient Yield potential (t/ha)
Waikerie (SA)	281	7.0	28 Aug	6.0
Maitland (SA)	317	7.9	20 Sep	8.7
Lameroo (SA)	319	8.0	7 Sep	8.8
Cleve (SA)	332	8.3	9 Sep	7.7
Culgoa (Vic)	361	9.0	10 Sep	9.6
Booleroo Centre (SA)	368	9.2	3 Sep	10.1
Hart (SA)	377	9.4	20 Sep	10.0
Kingscote (SA)	378	9.5	28 Sep	7.1
Walpeup (Vic)	394	9.9	11 Sep	8.6
Bordertown (SA)	407	10.2	7 Oct	8.3
Cummins (SA)	411	10.3	15 Sep	7.9
Charlton (Vic)	436	10.9	23 Sep	8.7
Giles Corner (SA)	457	11.4	17 Sep	10.5
Spalding (SA)	468	11.7	25 Sep	11.5
Longerenong (Vic)	552	>12.5	7 Oct	9.0
Inverleigh (Vic)	564	>12.5	20 Oct	9.9
Yarrawonga (Vic)	582	>12.5	28 Sep	8.5
Hamilton (Vic)	627	>12.5	25 Oct	9.9
Millicent (SA)	647	>12.5	30 Oct	9.7
Hagley (Tas)	700	>12.5	10 Nov	11.5

Managing resources in the critical period – putting canopy management into practice

Interception of light is more important in seasons of better water limited potential, and therefore, crop agronomy needs to focus on strategies that keep green leaves photosynthesising in the critical period. Learnings from the GRDC HYC and NGN experiments for barley in 2022 present a case study as to how to achieve yield potential in low to medium rainfall zones using management strategies more common in high rainfall zones.

Barley experiments on canopy management for achieving yield potential

Materials and methods

Sowing dates were utilised to shift flowering time and critical periods. Nitrogen rates were adjusted in winter with topdressing to achieve yield potentials for a decile 3 and 8 water limited yield. Low and high intensity fungicide treatments aimed to protect green leaf area and maximise yield were applied to determine the effect of disease control on the yield. Additional treatments such as plant growth regulators and defoliation were utilised to determine the benefit of keeping crops standing. Cultivars of known differences in yield potential and lodging susceptibility were included for comparison.

Table 2: Average effect of in-crop canopy management interventions on yield (t/ha) across both sowing dates at Hart field site (SA), and Birchip field site (Nullawil Vic) in 2022. Shaded numbers are the highest yields for each cultivar.

Canopy management interventions			**2022 Hart Field-Site SA**			**2022 Birchip Field Site Vic (Nullawil)**		
Nitrogen Input[1]	Fungicide Intensity[2]	Canopy controls[3],[4]	Cyclops⍉	Leabrook⍉	Planet⍉	Cyclops⍉	Leabrook⍉	Planet⍉
Low	Nil	-	4.7 d	4.4 bc	5.8 jk	3.9 a	4.1 ab	4.3 bcd
Low	Low	-	5.1 fg	4.9 e	6.0 klm	4.5 de	4.8 ef	5.3 g
Low	High	-	5.6 i	5.2 gh	6.3 n	5.2 g	5.2 g	5.9 h
High	Nil	-	4.6 cd	4.4 b	5.7 ij	4.2 bc	4.4 cd	4.8 f
High	Low	-	5.6 i	5.3 h	6.5 no	5.2 g	5.2 g	5.9 hi
High	High	-	6.0 klm	5.7 ij	6.6 op	6.1 hij	6.2 ij	6.8 kl
High	High	+PGR3	6.1 lm	5.8 jk	6.7 op	6.3 j	6.2 hij	6.7 k
High	High	+Defoliation	6.1 m	5.9 kl	6.8 p	6.3 j	6.0 hij	7.1 l
Nil	High		4.3 b	4.1 a	5.0 ef	-	-	-

1Nitrogen Inputs

Starting soil N supply (0–60cm) = 77kg N at Nullawil, and 93kg N at Hart.

Low Nitrogen = 60kg N (Nullawil) and 55kg N (Hart) applied in season to achieve decile 3 (N inputs for a 3.5t/ha and 3.6t/ha yield potential)

High Nitrogen = 160kg N (Nullawil), and 135kg N (Hart) applied in season to achieve decile 8 (N inputs for a 6t/ha and 5.7t/ha yield potential)

2Fungicide Intensity

Low = 1 x foliar fungicide unit - Prothioconazole/Tebuconazole (Prosaro® 300mL/ha) @GS31

High = 4 x fungicide units - Systiva® seed treatment, 3 x foliar fungicides including QoI (strobilurin) and SDHI combinations with DMIs)

3Plant growth regulation (PGR) (Moddus® Evo 200mL/ha @GS30 and Moddus Evo 200mL/ha @GS33-37).

4Defoliation = simulated grazing @GS16 (TOS 1 and 2) and GS30 (TOS 1 only)

Learning 1 - Protect upper crop canopy during critical period

Ensure a high proportion of the upper crop canopy leaves remain intercepting light (retain green leaf area via disease management) during the 'critical period' for grain number formation. Irrespective of whether it is a low, medium or high rainfall zone (M-HRZ), it is essential growers and advisers consider disease management as one of the most important components of growing high yielding cereal crops in seasons with high yield potential. For example, responses to fungicide timing and number of applications in 2022 across all rainfall zones saw yield increases greater than two- to three-fold. When N wasn't limited yields of Planet⍉ barley increased from 5.7t/ha to 6.6t/ha at Hart, and from 4.8t/ha to 6.8t/ha at Nullawil under high fungicide intensity (Table 2). Note Millicent Planet⍉ yields in Table 3 are less than lower rainfall sites and below potential despite treatments for disease and canopy control. The disease pressure in the high rainfall zone has revealed that genetics with improved disease resistance are now likely required to improve yields.

Learning 2 - Optimise crop development

A fundamental principle that is relevant across all agroecological zones is to ensure crop development and flowering are matched to the environment. This is best optimised by sowing the right variety at the right time to ensure it flowers in the optimum window when the combined risk of heat, frost and drought is low, and when the critical period is best aligned with cool and sunny conditions. The following examples in 2022 highlight the reduction in Planet⍉ yield potential from flowering earlier than the optimum due to excessive PTQ (radiation and temperature). For example, at Birchip yield potential increased from 7.6t/ha when flowering on 28 August, to 9t/ha when flowering on the 13 September – achieved by delaying the sowing date.

Table 3: 2022 grain yields of Planetɸ barley managed for disease and lodging across three diverse agroecological zones and sowing times compared to long term (1990–2022) and 2022 water limited (WYP), and photothermal quotient limited yield (PTQ) potential.

Sow date	Water Supply (mm)	WYP (t/ha)	Target/ Awn Peep	Mean Radiation Mj/m2	Mean Temp. (°C)	PTQYP (t/ha)	Achieved Yield (t/ha)
LRZ Birchip Long Term	179	4.5	10 Sep	13.1	10.8	8.9	ɸ
2022 4 May	361	9.0	28 Aug	11.3	10.3	7.6	6.4
2022 20 May	361	9.0	13 Sep	12.8	10.5	9.0	7.3
MRZ Hart long term	279	7.0	18 Sep	15.2	12.4	9.1	-
2022 27 Apr*(30 May)	377	9.4	12 Sep	14.3	10.8	10.2	6.8
2022 17 June	377	9.4	28 Sep	15.2	12.2	9.2	6.7
HRZ Millicent long term	580	>12.5	15 Oct*	17.1	13.1	10.0	-
2022 21 Apr	647	>12.5	19 Sep	13.0	11.1	8.5	6.1
2022 11 May	647	>12.5	10 Oct	15.8	12.5	9.5	5.8

**dry sown effective sow date in brackets*

Learning 3 – Keep the crop standing and improve harvest logistics

In high production conditions, excessive growth prior to stem elongation is unproductive and leads to lodging, shading and poorer light interception in the critical period. Poor canopy structure can extend beyond this phase by reducing conversion of biomass into yield post-flowering. Disease control and the combined application of PGRs and timely harvest ensures pre-harvest yield losses are reduced, particularly in barley. This reduced the incidence of lodging, brackling, and head loss in 2022, for example at Hart (Figure 2). While this did not translate to yield differences in small plot trials harvested on time, previous experience suggests PGRs and varieties with improved head retention do not lose yield as quickly when harvest is delayed.

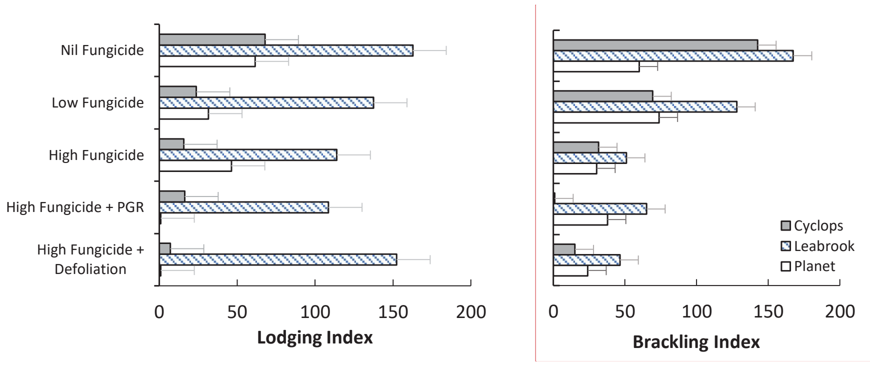

Figure. Incidence of lodging and brackling in three barley varieties at Hart in 2022 across canopy interventions.

Learning 4- Ensure the farming system can support a higher N demand

Cereal crops need to be supplied with roughly 40kg N/ha for every tonne of potential yield. To achieve an 8t/ha cereal yield, the crop will need about 320kg N/ha from the soil and fertiliser. Supplying this amount of total N with fertiliser N alone will be very costly. Crop responses to added fertiliser has reached a plateau in the HYC research at many sites, even when the N requirement for the yield achieved was high, indicating a large proportion of N is being supplied by the soil. This is where a fertile farming system becomes important, supplying large amounts of N from soil organic matter, manures or legume residues during critical periods of growth and supporting high yields with manageable levels of fertiliser N. The data from Hart and BCG field sites suggest more N is required than current district practice to ensure yield potentials are met in seasons like 2022. While this was achieved with applied N, a more effective long-term approach would be to maintain soil fertility and organic matter using pasture or legume phases, crop residues and limited tillage. Addition of manures and composts may also support this system to ensure 'mining' of soil nutrients does not occur at higher yield levels.

Conclusion

Recent research has demonstrated that other than appropriate variety selection, maximising growth in the critical period through canopy management using fungicides, sowing time, N and plant growth regulation can generate yield responses ranging from 3t/ha to 8t/ha within similar genetics in cool and mild production environments when rainfall is not limiting. In barley, there may be more scope to close the yield gap in the short to medium term, with further improvements in disease management, head loss, brackling and lodging control, but this has not yet been realised.

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Tailoring subsoil amelioration to paddock zones in southern Australia – a two-year update

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GRDC project codes: VGIP2a, DJP2209-002RTX

Keywords

- economic decisions, paddock zoning, soil type, subsoil amelioration.

Take home messages

- Soil amelioration with nutrient rich amendments increased grain yields by 34–65% on duplex soils in the first two years after amelioration, while on heavy textured soil sections within the same paddocks, there were no yield responses.
- Tailoring the right amelioration strategy (including not ameliorating) to each different soil type within a paddock can markedly change returns from amelioration.
- Identifying soil types and the location and severity of soil constraints within a paddock is critical when selecting amelioration strategies.

Background

Physical and chemical subsoil constraints in dryland cropping systems limit crop productivity by reducing the ability of crop roots to access soil resources, particularly subsoil water. It is estimated that subsoil constraints occur on as much as 75% of the cropping soils across Australia (Dang and Moody 2016). Seasonal conditions affect the severity of subsoil constraints on crop production, and therefore they are expected to become more limiting in our drying climate.

Attempts to manage soil constraints using subsoil amelioration with various organic and inorganic amendments in the Southern region have produced variable responses in yields, ranging from none to >60% (Armstrong et al. 2023, Uddin et al. 2022). While this experimentation has focused on singular soil types at experimental sites, soil types and associated soil constraints can vary greatly within paddocks and across landforms. Given this variability and the high upfront expense of subsoil amelioration, we sought to investigate how different soil types and landforms within paddocks will respond to different amelioration strategies. We then calculated if tailoring these different amelioration strategies to different soils in a paddock, rather than blanket application of amendments, can reduce the financial risk of subsoil amelioration by reducing amelioration costs whilst maximising yield responses.

Method

Paddock zoning

As part of identifying and categorising the relative importance of subsoil constraints on a 3-D scale in the broader VGIP2a project, three paddocks in the Wimmera MRZ and one in the Southern Grampians HRZ region were mapped into high and low producing zones (Table 1) using a combination of NDVI, electromagnetic induction (EMI) and gamma radiometric surveying (GRS). At each of the Wimmera MRZ sites (Nurcoung, Nurrabiel and Wallup) the zoning identified the two main soil types in each paddock, whilst at the HRZ site (Wickliffe) the zoning was more dependent on landform position in the paddock and the soil type (yellow chromosol) was consistent across both.

Table 1: Soil zoning and characterisation at each experimental site.

Site	Soil Zone 1	Soil Zone 2	2021 Rainfall (mm)		2022 Rainfall (mm)	
			GSR[a]	Annual	GSR[a]	Annual
Nurcoung	Sodosol	Sodic Vertosol	221	311	381	524
Nurrabiel	Sodosol	Sodic Vertosol	271	362	499	732
Wallup	Calcarosol	Vertosol	198	308	339	501
Wickliffe	Upper plateau	Lower slope	427	552	490	701

Growing season rainfall (GSR) is April to October rainfall

Trial design and sampling

In March 2021, six subsoil amelioration treatments were applied at a maximum depth of 35–38cm in 18m long by 4m wide adjoining plots using a custom-made subsoiler with 60cm tine spacing. At each paddock, these treatments were replicated in four randomised blocks in each of the two soil zones (n=48 plots/site). The six treatments applied at the Wimmera MRZ sites were:

A. Control

B. Deep ripping alone

C. Deep gypsum (2.5t/ha)

D. Surface lucerne pellets (12.5t/ha) + gypsum (2.5t/ha)

E. Deep lucerne pellets (12.5t/ha) + gypsum (2.5t/ha)

F. Deep matched nutrients

At the HRZ Wickliffe site, poultry litter pellets (15t/ha) were applied instead of lucerne pellets. The matched nutrient treatment contained a mixture of inorganic fertilisers to apply the equivalent quantities of N, P, K, and S as contained in the respective lucerne (400:29:264:41kg/ha of N:P:K:S, respectively) or poultry litter (436:118:267:35kg/ha of N:P:K:S, respectively) pellets. This matched nutrient treatment allows us to investigate whether the crop is responding to just improved nutrient supply, or any additional improvement in soil structure from the added organic matter.

During each growing season, crop development was monitored with biomass sampling and NDVI measurements before grain yield and components were measured at harvest. Soil moisture was measured by neutron probe and EM38 mapping. Statistical analysis of soil zone and treatment effects on measured variables was performed by analysis of variance.

Economic analysis

A preliminary analysis of the profitability of investing in subsoil amelioration was undertaken for the Nurrabiel site. The economic analysis relied on crop yields in each soil zone, grain prices and upfront costs of amelioration (Table 2). Only crop yields measured in year one of the trial were used. To account for the residual effect of the different amelioration treatments, using knowledge derived from the DAV00149 project, it was assumed that amelioration costs could be amortised/split over four years. At the conclusion of this project, a time series of yield data will be collated for a fully formulated capital budget.

Economic advantage in year one was evaluated using:

- Net benefit (NB, $/ha), the additional $-returns minus each $ invested in amelioration. If NB >0, then the ameliorant is profitable.
- Benefit Cost Ratio (BCR), the additional $-returns divided by each $ invested in amelioration. If BCR >1, then the amelioration strategy is profitable.

Additional $-returns were calculated from yield gains multiplied by the 10-year average grain price, which for canola in 2021 was a net $578/t. Costs comprise of the cost of both the amendments (excluding delivery) and incorporation costs, including ‘fixed’ machinery ownership costs, and ‘variable’ costs that are proportional to machinery usage (for example, labour, fuel, and lubricants).

Table 2: Amelioration strategy amendment and application costs.				
Treatments	Application Rate (t/ha)	Amendment cost ($/ha)	Machinery cost ($/ha)	Total costs, amortised ($/ha p.a.)[a]
A Control (no amelioration)	0	0	0	0
B Deep rip only	0	0	40	11
C Deep gypsum	2.5	72	137	59
D Surface lucerne + gypsum	12.5	1572	19	449
E Deep lucerne + gypsum	12.5	1572	137	482
F Deep nutrients	1.5	827	137	272

Total up-front amelioration costs were amortised over four years using a real 5% discount rate (7% nominal, adjusted for 3% inflation).

Results and discussion

Amelioration treatment effects on grain yields

Soil amelioration and the application of nutrient rich amendments greatly increased crop productivity and yields on some soil types and not others within the four paddocks in 2021 and 2022. The greatest yield responses have occurred in the sodosols, which consist of texture contrast sand-over-sodic clay duplexes, at Nurcoung (Figure 1) and Nurrabiel (Figure 2). In these soils, the application of the deep nutrient treatment increased faba bean yield at Nurcoung by 65% over that of the untreated control in 2021 (P=0.005), and in 2022 canola yields were increased by as much as 58% over the control (P=0.003). At Nurrabiel, the deep nutrient treatment increased canola yield by 34% in 2021 (P=0.100) and wheat yield by 43% in 2022 (P=0.055) over the untreated control treatment. As well as yield effects, large increases in canola and wheat protein contents were measured at both sites. The positive first year yield responses to the deep ripping only and deep gypsum treatments at both sites did not occur at either site in the second year, suggesting that the addition of nutrient rich amendments is required to sustain amelioration responses when ameliorating these duplex sodosols.

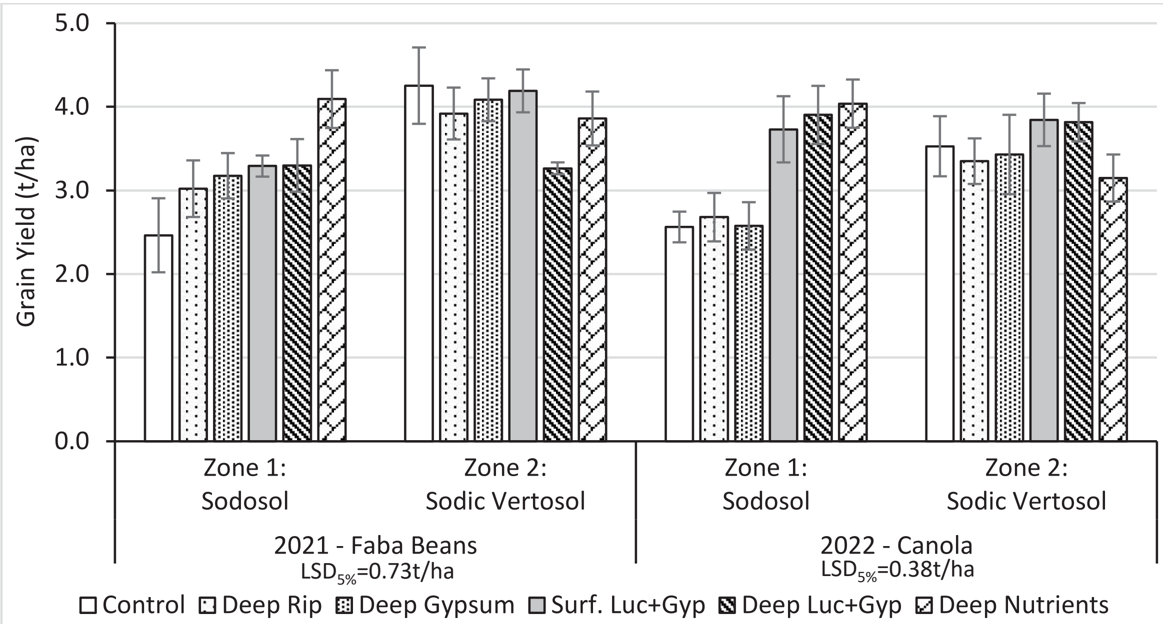

Figure 1. Amelioration treatment effect on faba bean and canola yield at Nurcoung in 2021 and 2022.

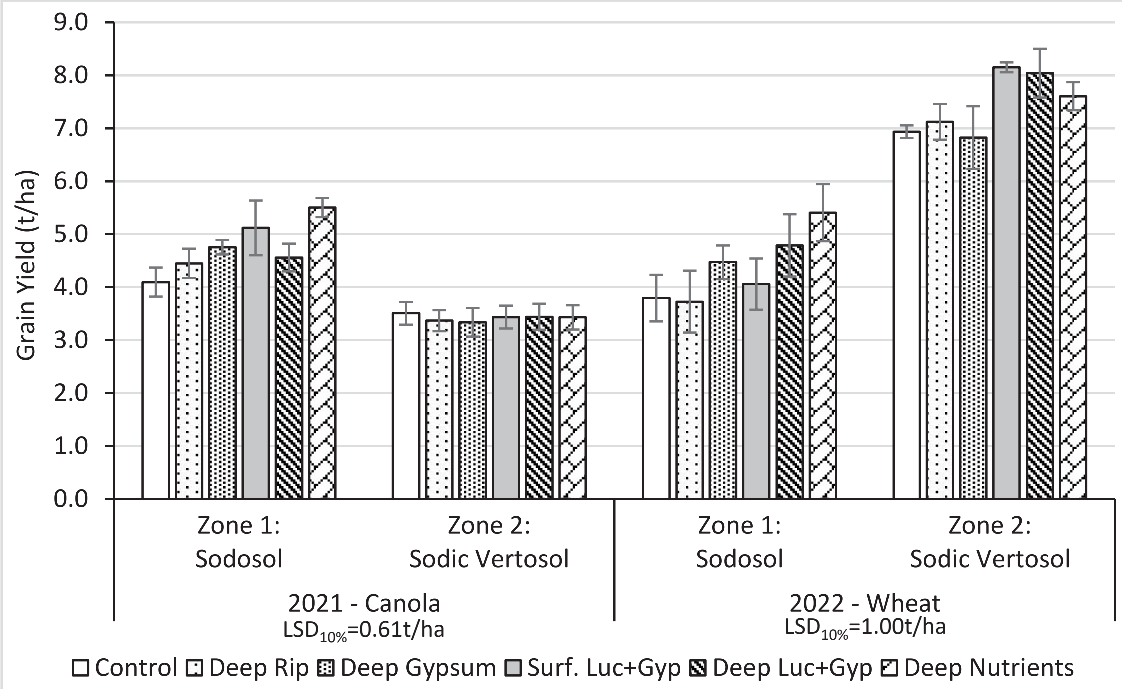

Figure 2. Amelioration treatment effects on canola and wheat yield at Nurrabiel in 2021 and 2022.

While large treatment effects occurred on the sodosols, no treatment effects occurred on the sodic clay vertosols in soil zone 2 at either site in 2021, while only relatively small treatment effects occurred at the Nurrabiel site in 2022. There are two potential reasons that these soils zones have been unresponsive to our subsoil amelioration treatments so far. Firstly, it is possible that ripping and incorporating amendments to a depth of 35–38cm is insufficient to ameliorate subsoil constraints which only become limiting at greater depths and to promote crop productivity on these sodic vertosols. Secondly, despite dry starts in both years, the growing season rainfall and greater topsoil water holding capacity of these soils compared to the sand-over-clay sodosols may have provided sufficient moisture in the top part of the soil profile for crop production without constraints located deeper in the subsoil limiting crop production in these years.

This latter point may also hold true for the HRZ Wickliffe site, where there were neither soil zone (P=0.467) nor amelioration treatment (P=0.672) effects on wheat yield in 2021, which averaged 8.5±0.5t/ha across all treatments (data not shown). Large early season crop growth responses to the deep manure with gypsum and deep nutrient treatments in both soil zones did not translate into grain yield benefits as the crop in these treatments experienced haying off during grain filling, but grain protein in these treatments was increased over the controls in both soil zones (P<0.001). In 2022, there were again no soil zone (P=0.621) or amelioration treatment (P=0.653) effects on the faba beans grown at Wickliffe which suffered extensive waterlogging throughout the season and yielded only 2.3±0.3t/ha on average (data not shown). A regression analysis to investigate potential slope by deep ripping effects on soil drainage was unable to show any correlation (P=0.862).

At Wallup, the deep ripping only and the deep gypsum treatment had no effect on wheat yield in 2021 (Figure 3), whereas the application of the nutrient rich surface and deep applied lucerne with gypsum, and deep nutrient treatments, increased wheat yields by 34–42% in the calcarosol in soil zone 1 and by 10–33% in the grey vertosol in soil zone 2 (P<0.001). Wheat protein was also increased by an average of 30% and 23% in soil zones 1 and 2, respectively by these treatments (P<0.001, data not shown). In 2022, these positive treatment effects persisted for faba bean yields in the calcarosol (P=0.023), with the deep ripping only and the deep gypsum treatments also producing greater yields than the control. However, the effects of the amelioration treatment occurred in the grey vertosol in soil zone 2 in 2021, did not occur again in 2022.

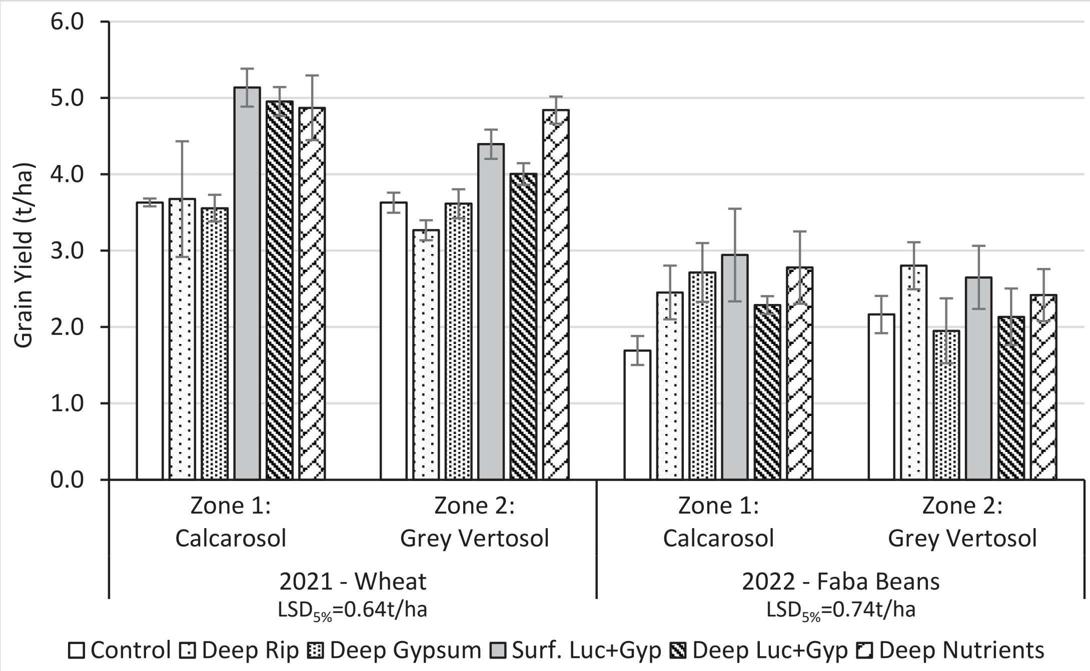

Figure 3. Amelioration treatment effects on wheat and faba bean yield at Wallup in 2021 and 2022.

While positive responses to each of the deep ripping treatments have occurred in the calcarosol at Wallup, the most productive treatment overall has been the surface applied lucerne with gypsum. This likely indicates that the greatest factor driving crop yield in this soil zone is nutrition and yield benefits can be achieved without the need for expensive deep incorporation. This result highlights the importance of understanding what constraints, whether physical, chemical, or nutritional, are the most limiting to crop production before undertaking subsoil amelioration.

Economic analysis

The NB and BCR of applying all combinations of the six different amelioration strategies to the two different soil types at Nurrabiel in 2021 were calculated and ranked on NB (Table 3).

Without any amelioration, the gross margin of the canola at Nurrabiel in 2021 across the entire paddock was $1,835/ha. If the deep lucerne with gypsum treatment, the most expensive amelioration strategy, was applied to the entire paddock, the grower would have been $205/ha worse off. If, however, the sodosol soil in zone 1 is ameliorated with deep nutrients and the sodic vertosol soil in zone 2 (where there was no yield response) is not ameliorated, then a net additional benefit of $461/ha on top of the initial $1,835/ha gross margin would be achieved, producing a benefit cost ratio of 3.3.

Table 3: Benefit Cost Ratio (BCR) and net benefits (NB, $/ha) in 2021 for blanket applied and soil zone tailored subsoil amelioration strategies (top 10 only) ranked on net benefits at Nurrabiel.

Amelioration strategy	Amortised cost ($/ha/yr)	Additional $-returns ($/ha)	BCR	NB ($/ha)	Option rank
Uniform application across paddock					
A Control (no amelioration)	0	0	0.0	0	25
B Deep rip only	11	126	11.2	115	17
C Deep gypsum	59	249	4.2	190	9
D Surface lucerne + gypsum	449	512	1.1	63	21
E Deep lucerne + gypsum	482	277	0.6	-205	36
F Deep nutrients	272	673	2.5	401	4
Split application in Soil Zone 1 + Soil Zone 2					
F+A	199	660	3.3	461	1
F+B	202	639	3.2	437	2
F+C	215	634	3.0	419	3
F+D	319	673	2.1	353	5
F+E	328	674	2.1	346	6
C+A	43	275	6.4	232	7
C+B	46	253	5.5	207	8
C+F	116	288	2.5	171	10

Conclusion

Preliminary results from the first two years of this project suggest that yield responses to soil amelioration differ between soil types within paddocks. Therefore, tailoring different amelioration strategies to these soil types will produce substantial savings in upfront amelioration costs and increase net returns on investment, as shown for the Nurrabiel site. Continued monitoring is required to measure residual effects of the amelioration and to collect durable data for a more robust economic analysis of the returns from tailoring subsoil amelioration treatments to different soil types within paddocks.

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 also thanks the McRae, Mewett, Vallance and Wilson families, and Agriculture Victoria.

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Useful Resources

3D mapping profiles soil-based constraints (https://groundcover.grdc.com.au/agronomy/soil-and-nutrition/3d-mapping-profiles-soil-based-constraints)

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Hyper yielding cereal agronomy – key levers and their interactions; varieties, N and lessons learnt

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GRDC project codes: FAR2004-002SAX, FAR00003

Keywords

- disease management strategies, photothermal quotient (PTQ), red grained feed wheats, yield potential.

Take home messages

- The Hyper Yielding Crops (HYC) project has successfully indicated new benchmarks for productivity of cereals in the more productive regions of Australia over the last three years.
- **Hyper yielding cereal crops cannot be produced with artificial fertiliser alone.** Rotations, which lead to high levels of inherent fertility, are essential to underpin high yields and the large N offtakes associated with bigger crop canopies.
- The biggest agronomy lever for hyper yielding wheat and closing the yield gap over the last three years has been the correct disease management strategy, which had elevated importance in 2022.
- At the Victorian HYC site, the most prevalent wheat diseases were Septoria tritici blotch (STB) and stripe rust, with the latter affecting some varieties that showed good disease control in 2021.
- Robust fungicide management strategies gave over 3t/ha yield benefit in some varieties where good disease suppression was observed, however variety choice was key for stripe rust control.

Hyper Yielding Crops research and adoption

The Hyper Yielding Crops (HYC) project, with assistance from three relatively mild springs, has been able to demonstrate new yield boundaries of wheat, barley and canola, both in research and on farm in southern regions of Australia with higher yield potential. Five HYC research sites, with associated focus farms and innovation grower groups, have helped establish that wheat yields in excess of 11t/ha are possible at higher altitudes in southern NSW (Wallendbeen), in the southern Victoria and SA HRZ (Gnarwarre and Millicent) and Tasmania (Hagley). In the shorter season environments of WA, 7–9t/ha has been demonstrated at FAR's Crop Technology Centres in Frankland River and Esperance.

Yield potential

Over the last three years, the relative absence of soil moisture stress at HYC locations has allowed the project team to look more closely at yield potential from the perspective of solar radiation and temperature. **High yielding crops of wheat and barley are about producing more grains per unit area.** This has been demonstrated in several projects and is a key factor in producing very high yields. Whilst head number clearly contributes to high yields, there is a limit to the extent to which head number can be used to increase yields. In most cases, with yields of 10–15t/ha, 500–600 heads/m^2 should be adequate to fulfil the potential.

So how do we increase grains per m^2

Whilst heads/m^2 contribute to more grain sites per unit area, it is typically grains per head at harvest that generates high yields. It has been acknowledged for several years that increasing grain number is related to growing conditions prevalent in the period from mid-stem elongation to start of flowering (approximately GS33–GS61). This window of growth in cereals covers the period approximately 3–4 weeks (~300^{0}C days) prior to flowering and is described as the '**critical period'.**

This encompasses the period when the grain sites are differentiating and developing, and male and female parts of the plant are forming (meiosis). If conditions during this period of development are conducive to growth, with high solar radiation and relatively cool conditions (avoiding heat stress), then more growth goes into developing grain number per head and, therefore, per unit area for a given head population. The photothermal quotient (PTQ) or cool sunny index is a simple formula (daily solar radiation/ average daily temperature) that describes how conducive conditions are for growth and, when applied to the critical period, assists in determining the yield potential. When applied to the critical period, a high PTQ means more photosynthesis for more days and more grain and more yield. The relative importance of PTQ is increased in seasons where soil moisture stress is not a factor (since soil moisture stress limits the ability of the crop to grain fill and fulfil its potential). Based on a flowering date of 20 October, the PTQ for 2022 was lower (PTQ 1.33) than 2021 (PTQ 1.41) at our Victorian HYC site. Using the graphed relationship established between yield and PTQ, it is indicated that yield potential was slightly reduced by around 0.82t/ha in 2022 (Figure 1). This is without taking account of the effects of waterlogging and management of the crop more generally, indicating that yield potential was lower relative to 2021 and the long-term average.

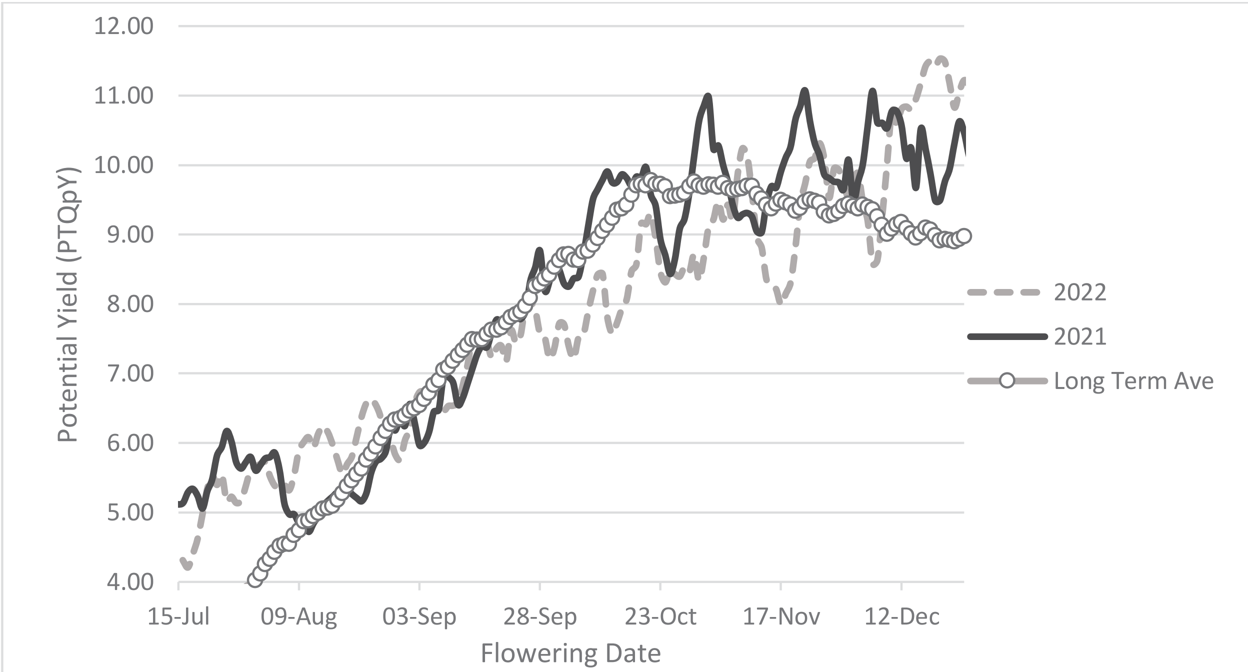

Figure 1. Long-term (1990–2022) yield potential and relationship with flowering date at the FAR VIC CTC based on the photothermal quotient (PTQ) compared to 2021, and 2022. Note this is the upper ceiling of yield potential and does not factor in frost and heat risk, and assumes water is non limiting. Based on She Oaks BOM data. Critical period based on 28 days in this calculation.

As advisers, we are already aware of the importance of cereal flowering date in order to minimise frost risk and heat stress/moisture stress, however in high yielding crops, where moisture and heat stress are less problematic, optimising the flowering date enables us to maximise growth in the critical period for generating grain number per unit area.

Realising yield potential

It is one thing to create yield potential by maximising grain number per unit area, however higher grain numbers established during the critical period still must be realised during grain fill. For example, a very late developing wheat cultivar could benefit from better growing conditions associated with a later flowering date and critical period, that is, longer sunny days that are not excessively hot. This might well maximise final harvest dry matter and growth during the critical period but not the final grain yield, as the crop does not have a sufficiently high PTQ to maximise growth during grain fill post-flowering (that is, it's too hot post-flowering with later development and the crop has a low harvest index). This has been noted at all the HYC sites relative to the optimum flowering period for those sites. Interestingly, in 2021, the highest yield recorded in the HYC project so far (12.74t/ha) was achieved with a wheat cultivar that originated from the UK, cv Reflection (a red grained winter wheat). Traditionally, this cultivar is considered too long season (that is, very slow developing) for an Australian mainland

HRZ environment, but in 2021, the mild spring and summer grain fill period allowed this cultivar to complete grain fill under more optimal conditions, something not typically observed. The indication that the higher yield was underpinned by more grains per unit area was indicated by considerably smaller seeds and lower thousand grain weight TGW (Figure 2). Whilst grains per head in this case were not assessed, it was clear that to have achieved such a high yield with such small grains must have indicated a high number of grains per unit area.

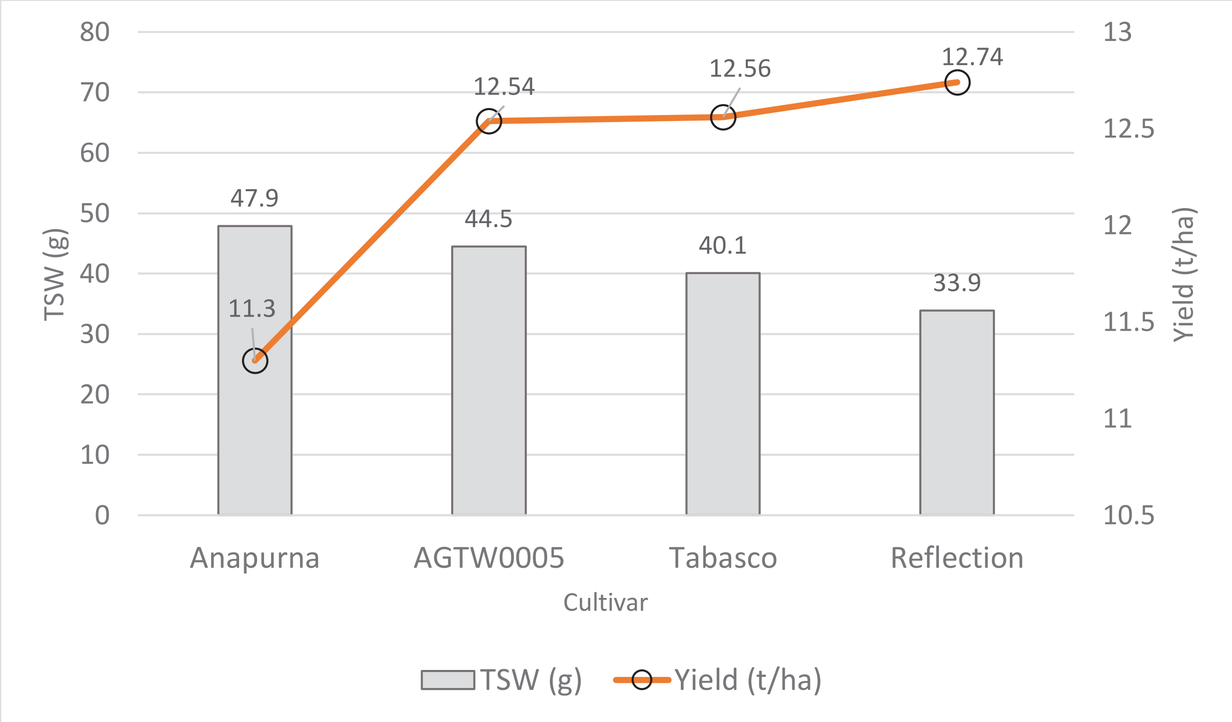

Figure 2. Relationship between highest yielding wheat cultivars in the HYC Elite Screen and thousand seed weight (tsw) – Millicent SA 2021. All cultivars presented are protected by Plant Breeder rights.

In 2022, the critical period, flowering, and grain fill period for the south-west of Victoria were all characterised by high and frequent rainfall events (Figure 3). This higher-than-average rainfall was the cause of widespread waterlogging damage in many areas of the state and a likely reduction of yield potential in affected areas.

Samples of wheat are currently being examined to assess whether flowering itself was disrupted by October rainfall or the grain fill of those grain sites that successfully fertilised.

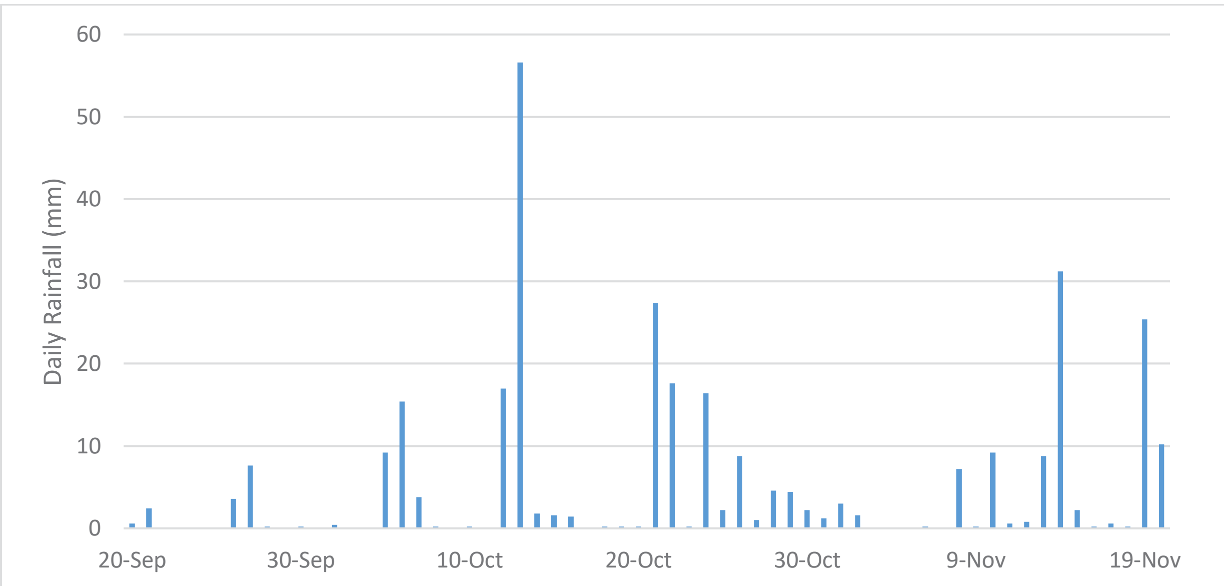

Figure 3. Daily rainfall across the critical period, flowering, and early grain fill period for wheat at the HYC research site at Gnarwarre in south-west Victoria. Rainfall for October was 159.6mm, well above the long-term average of 56.0mm for the month (Winchelsea (Post Office) BOM station).

Nutrition and rotation for hyper yielding wheat – farming system fertility to establish yield potential

The most notable results observed in the HYC project to date relate to nitrogen fertiliser. In results to date, it is clear that high yielding cereal crops contain very large amounts of nitrogen (N) at harvest (275–400kg N/ha not being uncommon), however so far it's clear **that simply applying more and more N fertiliser is not the route to achieving big yields,** even though replacing that N has to be an objective if we are to have a sustainable farming system overall**.** Results from our southern NSW site at Wallendbeen provide an example of the conundrum with hyper yielding wheat crops. Established in a mixed farming system based on a leguminous pasture and cropping phase, winter feed wheat cv Accroc⚅ achieved a yield of approximately 9t/ha, however the application of N above 80kg N/ha in this scenario only served to reduce yield (Figure 4), a result observed in previous high yielding trials. Despite an application of PGR Moddus® **Evo** 0.2 + Errex® 1.3L/ha at GS31, applied N fertilisers only served to increase head numbers (above the optimum), increase lodging during grain fill (data not shown) and reduce yield.

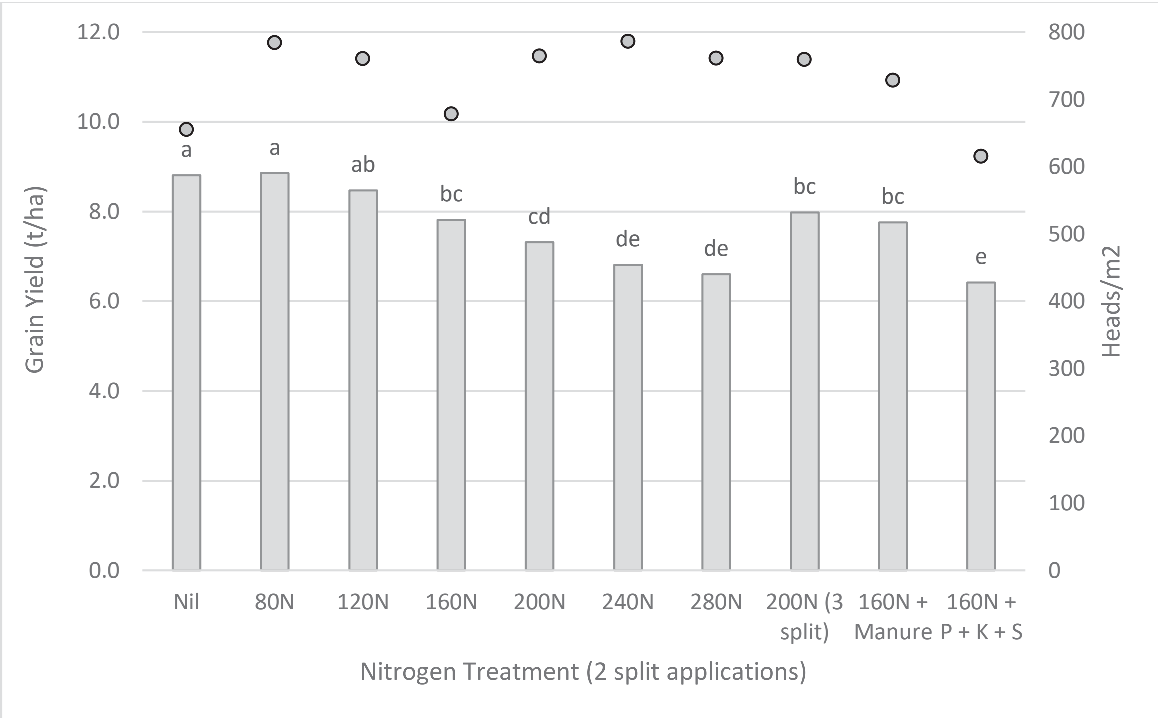

Figure 4. Influence of applied nitrogen, manure and other nutrients on yield and head number – HYC Wallendbeen, NSW 2022. Columns denote grain yield and dots show heads/m^2.

Notes: N applied as urea (46% N) was timed at tillering (21st June) and GS31 (27th August)
Soil available N in winter (4 Jul) - 0-10cm 39kg N, 10-30cm 56kg N, 30-60cm 46kg N
Chicken manure pellets applied at 5t/ha with an analysis of N 3.5%, P 1.8%, K 1.8% and S 0.5%. Columns with different letters are statistically different P = 0.05, LSD: 0.79t/ha

Table 1. 160 kg/N ha, with additional N, P, K & S was applied as follows to replicate the addition of manure as in the 160N + P + K + S column in Figure 3 above.

	kg/ha	N	P	K	S	Date Applied
MonoPotassium Phosphate	315	0	90	72	0	Sowing
MOP	36	0	0	18	0	21 June
Amm. Sulphate	104	21	0	0	25	21 June
Urea	335	154	0	0	0	21 June
Total		**175**	**90**	**90**	**25**	

The results serve to illustrate that, given moist soils, fertile farming systems have an enormous potential to create high yields even before the use of N fertilisers are considered. It should be stressed at this point that HYC research is not suggesting that nitrogenous fertilisers are unimportant in the pursuit of high yields, but rather that, in most trials, there is a limit above which crops will not respond in the year that fertiliser is applied. In fact since 2016, in HYC trial work, optimum applied fertiliser N levels have rarely exceeded 200kg N/ha for the highest yielding crops, even though the crop canopies that these yields are dependent on are observed to remove far more N than that (assuming N is baled or burnt at harvest).

Protecting yield potential

Many regions experienced just how important it is to protect yield potential in 2022, with many describing the stripe rust epidemic in 2022 as the worst in 20 if not 50 years. Many low rainfall zone (LRZ) regions experienced HRZ conditions for disease in all crops of the farm rotation. Disease management over the last three years has been shown to be one of, if not, the most important factors in securing high yielding crops in HYC project trials. It has also been demonstrated to be one of the most important factors in securing higher yields and closing the yield gap in better seasons in L-MRZ regions. At the Victorian HYC site, varieties gave up to a 3t/ha difference (Accroc⁽ᶲ⁾) under a full fungicide management program where STB and stripe rust were partially controlled. Susceptible varieties such as LongReach Beaufort⁽ᶲ⁾ (rated as MSS for STB) experienced such high STB pressure that, even under a full fungicide management program (Systiva® plus three foliar applications), STB was not properly controlled. As a result, little yield improvement was seen when compared to untreated (Table 5). When sowing date was delayed from 28 April to 20 May, yield of LongReach Beaufort⁽ᶲ⁾ was increased and disease pressure reduced, ironically generating higher responses to fungicide application as fungicide programs were more effective. Coded lines AGFWH004818, SFR86-085 (RGT Waugh) and Reflection showed good yields where disease was controlled and provided intermediate disease resistance. AGTW0005 was the only variety tested in this trial to show no significant difference (LSD (p=0.05) 0.50 t/ha) in yield between fully treated with fungicide and untreated, indicating good inherent disease resistance. Expected to be released in 2024, this French red grained feed wheat has now been tested for three years in HYC trials and has excellent yield potential, ideal phenology (compared to Reflection), good disease resistance and standing power.

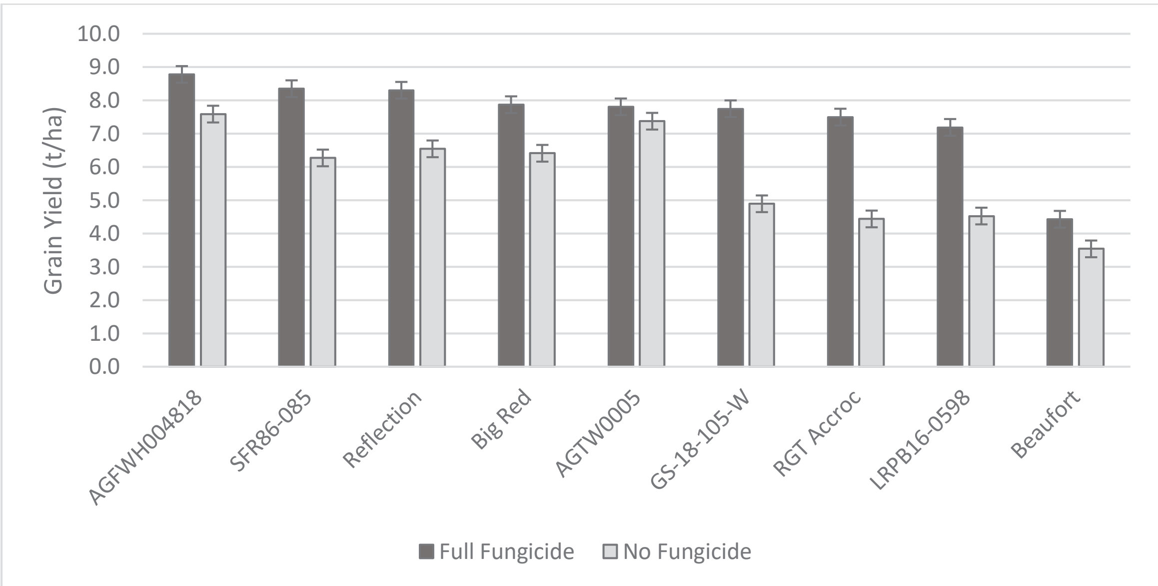

Figure 5. Grain yield (t/ha) of 'HYC elite screen' varieties tested at the Victorian HYC site – sown 28 April.

Further investigation into fungicide management programs was conducted on site, with four varieties selected: RGT_Cesario⁽ᶲ⁾ (MR for STB), Anapurna (MR/MS), Accroc⁽ᶲ⁾ (MR/MS) and SQP Revenue⁽ᶲ⁾ (MSS), ranging from most STB resistant to most susceptible, respectively. The fungicide management programs were as follows:

- Nil – untreated control
- A single flag leaf fungicide applied at GS39 – FAR F1-19
- A two-spray approach at GS33 (3^{rd} node) FAR F1-19 and GS59 (head emergence) Opus® 500mL/ha

- A four-unit approach combining at sowing Systiva with three foliar sprays – GS31 Prosaro® 300mL/ha, GS39 and GS59 (as stated above)

The principal disease was STB caused by the pathogen *Zymoseptoria tritici*, with lower levels of stripe rust (pathogen *Puccinia striiformis* f.sp. *tritici*). Stripe rust was most apparent in Accroc⍉ and RGT_Cesario⍉. STB was so severe in 2022 that not even the four-unit approach to disease management could be described as giving full control in the more STB-susceptible cultivars. None of the cultivars had sufficient genetic resistance to be farmed more profitably with no fungicides. RGT_Cesario⍉, which in 2021 gave very little response to fungicides, suffered more STB and stripe rust pressure in 2022, but overall, was the cultivar with the lowest disease levels when disease management was applied (Figure 6). There were no statistically significant differences (LSD (p=0.05) 17.9) in STB levels amongst one, two and four units of fungicide when applied to RGT Cesario⍉, suggesting that it still maintains strong genetic resistance to the disease relative to other cultivars tested. In fact, all varieties performed as expected in response to STB, with an average of 64.1% of flag leaf area infected with STB in the susceptible SQP Revenue⍉ under full fungicide control compared to just 3.1% in the more resistant RGT_Cesario⍉.

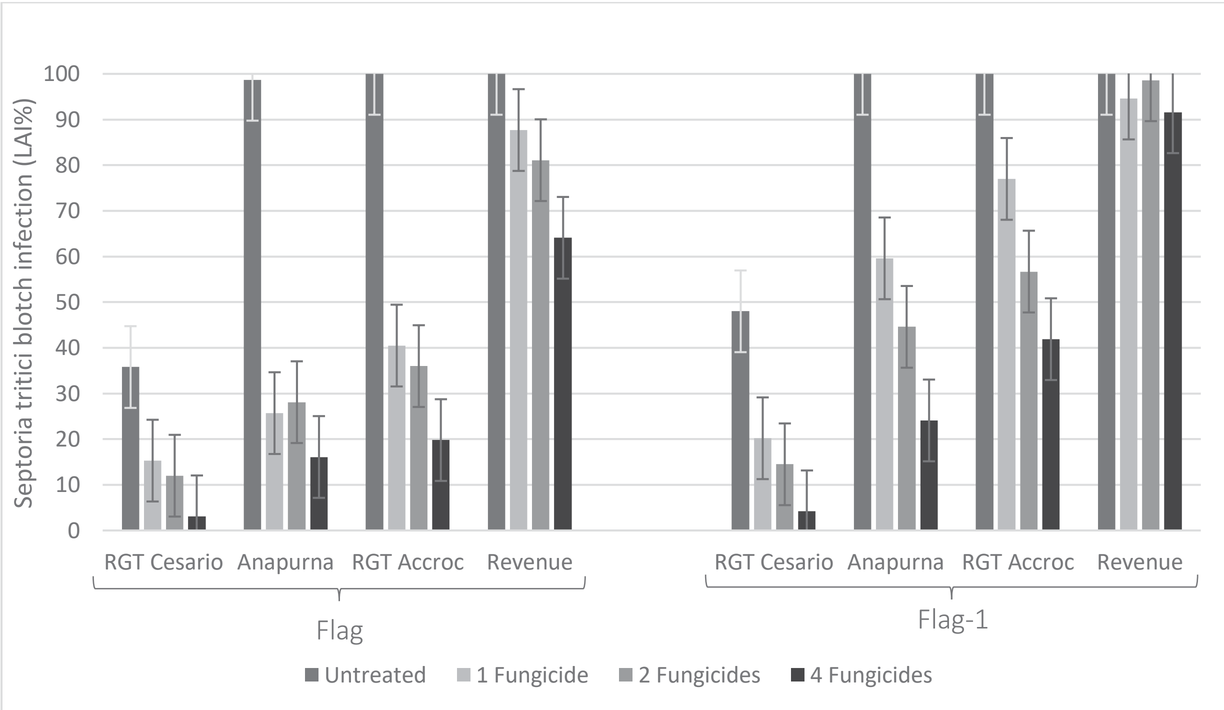

Figure 6. Percentage leaf area infected (LAI%) with Septoria tritici blotch on flag and flag-1 when assessed on 22 November at the start of grain fill.

Whilst fungicides can only be considered an insurance (that is, we don't know what the economic return will be when they are applied), it is clear that when the stem elongation period is wet as the principal upper canopy leaves emerge (flag, flag-1, flag-2), fungicide application is essential to protect yield potential created by nutrition and environmental conditions. Infection was so severe in 2022 that fungicide timing and the strength of the active ingredients being used made profound differences in productivity. Long 'calendar gaps' of over four weeks between fungicides (the case in our own work) resulted in many crops losing control of the epidemic as unprotected leaves became badly infected in the period between sprays and applications became more dependent on curative activity rather than protectant activity.

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More results from previous HYC research can be found on the FAR website https://faraustralia.com.au/resource

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Notes

Using zinc phosphide to control wild house mice

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GRDC project code: CSP1804-012RTX

Keywords

- background food, LD50, zinc phosphide.

Take home messages

- Mice are not as sensitive to zinc phosphide (ZnP) as was first reported in studies in the 1980s.
- 2mg of ZnP is required on each grain to deliver a lethal dose to a 15g mouse.
- Grain bait mixed at 50g ZnP/kg wheat is significantly more effective than bait mixed at the previously registered rate of 25g ZnP/kg wheat.
- Reducing background food could be critical to achieving effective bait uptake.
- Timely application of ZnP grain bait at the prescribed rate is vital for reducing the impact that mice have on crops at sowing.
- Strategic use of bait is more effective than frequent use of bait.

Background

The content of this paper relates primarily to the GRDC investment, Determining the effectiveness of zinc phosphide rodenticide bait in the presence of alternative food supply. Growers were reporting concerns regarding the effectiveness of commercially prepared zinc phosphide (ZnP) wheat-based baits. In response, we conducted three experiments to examine the efficacy of ZnP bait. The initial experiment set out to identify a more attractive bait substrate, but the results of this work identified unexpected questions regarding the sensitivity of mice to ZnP. The second experiment re-assessed the acute oral toxicity of ZnP for wild house mice. The results of this work showed a significant difference between the previously reported LD50 of 32.68mg ZnP/kg body weight and our re-calculated LD50 of 72–75mg ZnP/kg body weight. We then quantified the efficacy of the higher lethal dose (~2mg ZnP per grain) compared to the registered rate (~1mg ZnP per grain) in a field trial. The results suggest that a kill rate of >80% could be achieved 90% of the time for the higher rate compared to the registered rate for which an 80% kill rate would be observed only 20% of the time. These results are helping to inform how and when growers and agronomists manage mice in cropping systems in Australia.

Experiment 1: Effects of background food on alternative grain uptake and zinc phosphide efficacy in wild house mice.

The initial trial to determine what was driving the reduced efficacy of the bait sought to test potential new bait substrates that might be more attractive to mice.

Experiment 1a: Two choice grain preference

Mice were held on a background food type (barley, lentils or wheat) and then offered the choice of an alternative grain type (malt barley, durum wheat or lentils) for five nights. Mice displayed a strong preference towards cereal grains, with a slight preference towards malt barley.

Experiment 1b: Toxic bait take against different background grains

Mice were held on a background food type (lentils, barley or wheat) then offered ZnP-baited grain (25g ZnP/kg grain) for three consecutive nights. Mice consumed toxic bait grains regardless of bait substrate although background food type had a strong influence on the amount of toxic bait consumed. Most of the mice in this experiment consumed what was considered to be a lethal dose, however the mortality rate was significantly lower than expected (Table 1) (Henry et al. 2022). Furthermore, animals that consumed toxic grains and didn't die, stopped eating toxic grains (that is, became averse).

Table 1: Percentage mortality from ZnP bait (25g ZnP/kg grain) and the average number of toxic grains consumed for each background food type on night one of the study (Henry et al. 2022).

Background food	n	Mortality (%)	Toxic grains eaten (av.)
Lentils	30	86	7.3 ± 2.5
Barley	30	53	4.5 ± 2.9
Wheat	30	47	2.1 ± 1.6

Bait substrate key results

Mortality was not as high as expected in mice that consumed toxic grains. The development of aversion was rapid although its duration is unknown. These results identified questions relating to the sensitivity of mice to ZnP (Henry et al. 2022). Had we been selecting for mice that were less sensitive to ZnP through frequent application of bait over a 20-year period? Or were mice just less sensitive to ZnP than had been reported in the past?

Experiment 2: Acute oral toxicity of zinc phosphide: an assessment for wild house mice *(Mus musculus)*.

This experiment re-assessed the acute oral toxicity of ZnP for wild house mice using an oral gavage technique, where known doses of ZnP were delivered directly into the stomachs of mice. The responses of three different groups of mice were assessed and compared: (1) wild mice from an area where ZnP had been spread frequently (exposed), (2) wild mice from an area where ZnP had never been used (naïve), and (3) laboratory mice (Swiss outbred). The proportion of mice that died at each dose was used to calculate a dose-response curve for each of the groups of mice (Figure 1) (Hinds et al. 2022).

Acute oral toxicity key results

The results showed no significant differences in the sensitivity of any of the groups of mice to ZnP, indicating that there has been no selection for tolerant mice in areas where mice had frequent exposure to ZnP. However, there was a significant difference between the previously reported LD50 of 32.68mg ZnP/kg body weight (Li and Marsh 1988) and our re-calculated LD50 of 72–75mg ZnP/kg body weight. These results mean that 2mg of ZnP/grain is needed instead of 1mg of ZnP/grain to kill a 15g mouse (Hinds et al. 2022).

Lab – Swiss outbred

LD50 = 79.18 ± 6.24mg ZnP/kg

Naïve wild mice

LD50 = 72.11 ± 9.09mg ZnP/kg

Exposed wild mice

LD50 = 75.22 ± 4.39mg ZnP/kg

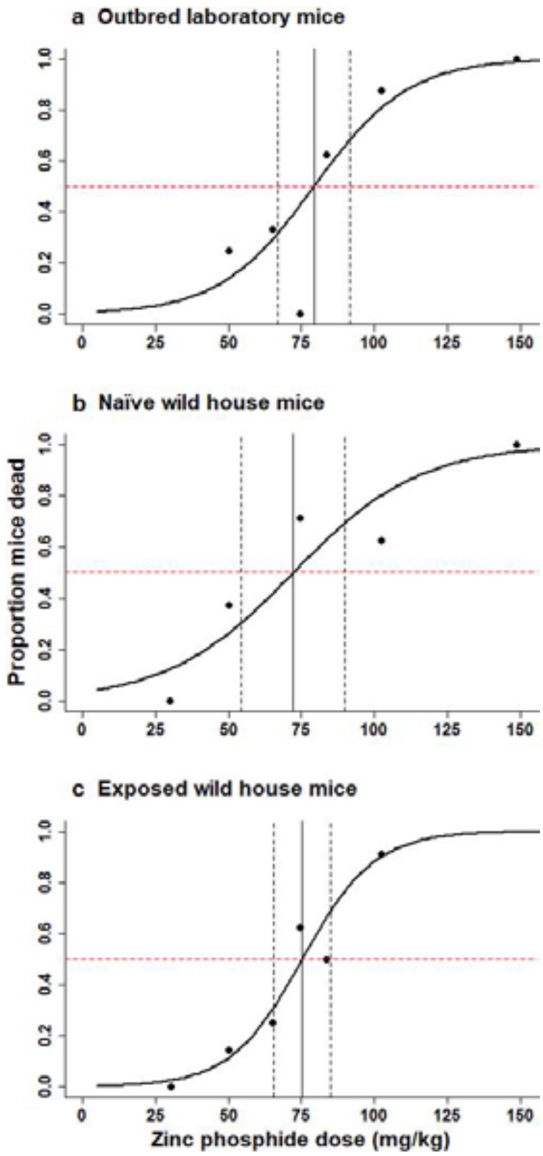

Figure 1. Proportion of mice dying after oral gavage with different ZnP concentrations (mg ZnP/kg body weight). Calculated dose response curves for (a) outbred laboratory mice, (b) naïve wild house mice, and (c) exposed wild house mice. Horizontal dashed line represents 50% mortality; vertical solid line equates to LD50 value; vertical dashed lines represent standard error for the LD50 estimate. N>four animals per test dose, with a mix of males and females (Hinds et al. 2022).

Experiment 3: Improved house mouse control in the field with a higher dose zinc phosphide bait.

This experiment addressed the efficacy of the two different bait types, ZnP25 (25g ZnP/kg bait, ~1mg ZnP/grain) applied at 1kg bait/ha and the new formulation, ZnP50 (50g ZnP/kg bait, ~2mg ZnP/grain), applied at 1kg bait/ha.

Nine sites were selected on farms in the area surrounding Parkes in central NSW, three un-baited control sites, three sites baited with ZnP25 (25g ZnP/kg bait), and three sites baited with ZnP50 (50g ZnP/kg bait). All sites were trapped prior to baiting to establish population sizes and then again after baiting to determine changes in population.

Field trial key results

Baiting with ZnP50 led to a median reduction in mouse numbers of >85%. Modelling showed that under similar circumstances, using the ZnP50 formulation should deliver >80% reduction in population size most (>90%) of the time. In contrast, the current registered bait (ZnP25) achieved approximately 70% reduction in population size, but with more variable results. We would be confident of getting an 80% reduction in population size only 20% of the time if using the currently registered ZnP25 bait under similar field conditions (Figure 2) (Ruscoe et al. 2022).

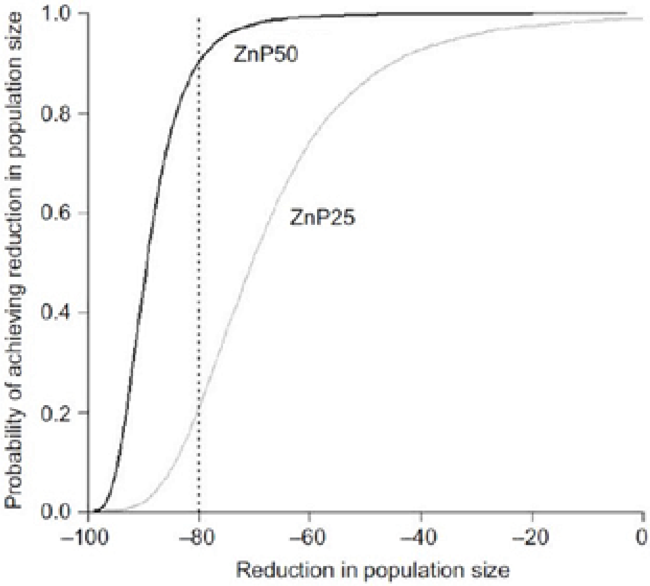

Figure 2. The probability of achieving a certain reduction in population size or better by using the ZnP50 bait (solid black line) and the ZnP25 bait (solid grey line). The dotted vertical line shows that there is a ~90% chance of getting a >80% reduction in population size by using ZnP50, but only a 20% chance of achieving that outcome by using ZnP25 (Ruscoe et al. 2022).

Conclusion

- Mice are not as sensitive to ZnP as was first reported in studies in the 1980s.
- 2mg of ZnP is required on each grain to deliver a lethal dose to a 15g mouse.
- ZnP grain bait mixed at 50g ZnP/kg wheat is significantly more effective than bait mixed at the previously registered rate of 25g ZnP/kg wheat.

Future research

Substantial grain loss, pre- and post-harvest is common in zero and no-till cropping systems. In 2022, it was estimated that $300 million worth of grain (GRDC project code GGA2110-001SAX) was left on the ground post-harvest in WA alone and reports of losses of 1t/ha are not uncommon (pers. comm). Bait spread at 1kg/ha equates to approximately three toxic grains per square metre. If there have been losses of 1t/ha, equivalent to about 2200 grains per square metre, finding a toxic grain becomes a game of hide and seek for mice (Figure 3). Understanding the role that background food plays in the uptake of ZnP bait will be critical to achieving effective mouse control.

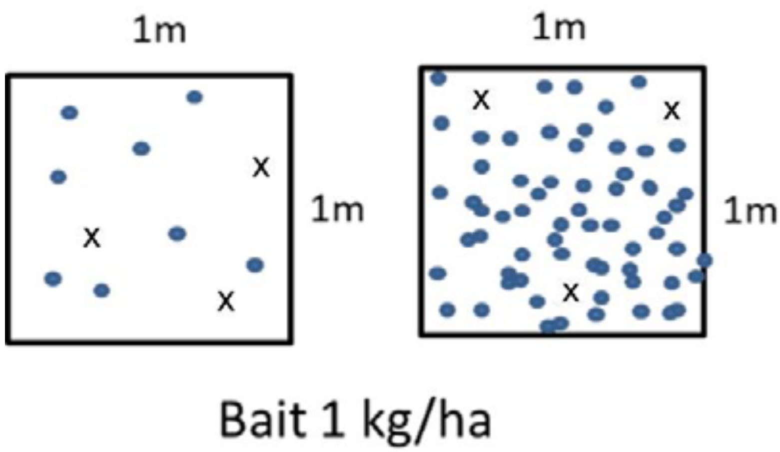

Figure 3. Representation of detectability of toxic grains at different levels of background food. The dots represent grains and crosses represent toxic grains.

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White B, (2022)

Measuring Harvester Losses in Western Australia. GRDC project code GGA2110-001SAX

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Fungicide resistant wheat powdery mildew – update on management and resistance testing

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GRDC project code – TRE2204-001RTX

Keywords

- wheat powdery mildew, fungicide resistance.

Take home messages

- Varietal resistance can play an important role in managing wheat powdery mildew. The variety Grenade CL Plus⦶ (MS) had less powdery mildew infection in the untreated than Chief CL Plus⦶ and Scepter⦶ (SVS) treated with a two-spray fungicide strategy. However, Scepter was the highest yielding variety regardless.
- 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 initially.
- Multiple diseases were present at trial sites this season. Fungicides providing broad-spectrum disease control, particularly for stripe rust, were the highest yielding treatments.
- A permit has been issued for the use of Legend® and other registered quinoxyfen (250g/L) products for control of powdery mildew in wheat. Legend provided good control of WPM at Bute in 2022.
- WPM head infection reduced yield at Port Neill when severity exceeded 40% head infection.

Background

Wheat powdery mildew (WPM) was widespread across south-eastern Australia in the 2022 season, occurring 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, early crop establishment in many regions in 2022, 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 were reported in many regions. Increasing prevalence of resistance and reduced sensitivity to group 11 QoI and group 3 DMI fungicides has been implicated in these control failures. Following recent SAGIT project (TC120) findings, investment by GRDC (TRE2204-001RTX) is seeking to quantify the extent of resistance development across the regions and identify management strategies for WPM given resistance development.

Method

Small plot trials were established at four locations in 2022, at Port Neill, Bute and Malinong, SA and Katamatite, Vic. In a range of WPM resistance populations, these trials investigated, post emergent fungicide efficacy, pre-emergent fungicide efficacy, fungicide timing and varietal resistance interactions. Season 2022 was conducive for development of a range of diseases, including Septoria, stripe rust and leaf rust. Three of the four locations were impacted by moderate to high levels of stripe rust, assessments endeavoured to account for these and quantify their impacts in addition to WPM. Assessments included disease incidence and severity, grain yield and grain quality. WPM samples were collected in a Nucleic Acid Preservation (NAP) buffer solution to assess change in resistance frequencies of mutations G143A at CytB, that indicate resistance to QoI, and Y136F at Cyp51 that is associated to other mutations conferring reduced sensitivity to DMI fungicides.

Variety trial: located at Bute, SA. Six varieties including Chief CL (SVS), Scepter (SVS), Mace (MSS), Grenade CL Plus (MS), Calibre (S) and Brumby (R). Four fungicide strategies were applied to Chief CL, Scepter, Mace and Grenade CL Plus, they were

- Nil = no fungicide applied
- Strategy 1 = Amistar Xtra @ 400mL GS39
- Strategy 2 = Epoxiconazole125 @ 500mL/ha GS31 *fb* Amistar Xtra @ 400mL/ha GS39
- Complete = complete control of powdery mildew

Fungicide efficacy trials: four product trials were implemented as small plot randomised complete block designs with 3 or 4 replicates. Trials were located at Bute, Port Neill, Malinong and Katamatite. Bute and Port Neill trials will be discussed in this paper, Bute treatments are shown in table 3. Product rates at Bute were the high label rate, unless specified otherwise in Table 3. The Port Neill trial was assessing fungicide performance at head emergence timing. The trial site was located within a farmer sown crop that was boom sprayed with Prothio T 420 fungicide at 300ml/ha on 16th August when the crop was at GS33-39.

Table 1: site details for fungicide efficacy trials at Bute and Port Neill.

Site	Variety	Date of trial treatments	Growth stage	Number of Treatments	Replicates
Bute	Chief CL Plus	16/08/22 12/9/22	GS31 GS39	21	4
Port Neill	Vixen	5/09/2022	GS55	18	3

A field survey was conducted with triplicate samples of WPM collected in NAP buffer solution from 145 commercial paddocks in late September and early October for assessing the resistance frequency status of mutations G143A at CytB and Y136F at Cyp51 in regions across SA and Vic, including the Eyre Peninsula, SA Mallee and Upper SE of SA. These add to the database of 51 paddocks sampled from the Yorke Peninsula and Mid North SA in 2021 and 22 paddocks sampled from NE Vic and southern NSW in 2020. The results are not available at the time of writing the paper but will be presented at the updates.

Results and discussion

Varietal resistance to wheat powdery mildew

The benefit of varietal resistance in limiting WPM build up is clear in untreated plots, where WPM pustule number typically follow the variety resistance rating (Figure 1). This is consistent with findings in both 2020 and 2021 (Trengove et al 2021, Trengove et al 2022). In the Bute region, Calibre has performed better than its S rating in both 2022 and 2021 (Trengove at al 2022), being more closely aligned with Mace (MSS) and Grenade CL Plus (MS) in those seasons, respectively. WPM is a highly variable pathogen, and this deviation from expected performance based on resistance rating may reflect the local pathotype that is present. Brumby all but eliminated WPM development, highlighting its R status. Brumby's resistance is derived from a single major gene. Due to the high genetic variability in WPM, pathotypes may already exist that can overcome this resistance and have virulence on this variety. This was observed in a small isolated hot spot in 2021 and may become the more dominant pathotype if continually selected for. Therefore, Brumby is expected to provide excellent resistance when first grown in a region but is at risk of being overcome by more virulent pathotypes if they are selected across a wide area on a repeated basis. This occurred when Chief CL was released, having a provisional rating of R when released in 2018, but downgraded to SVS when overcome by more virulent pathotypes in the field. This makes rotating varieties an important strategy in managing WPM.

In a SVS variety like Chief CL a robust fungicide program like strategy 2 was required to reduce WPM levels significantly, but still had more WPM than Grenade CL (MS) with no fungicide treatment. Untreated plots were severely affected by stripe rust and leaf rust late in the season, being the main influence on yield in those plots (data not shown). With the nil plots excluded due to stripe rust, within variety, there was no grain yield difference between fungicide programs, except for the variety Chief CL (Figure 2). WPM continued to develop late in the season in Chief CL resulting in a 0.67t/ha difference between Strategy 2 and complete WPM control. Responses of similar magnitude were recorded in SVS varieties in 2020 and 2021 to WPM control (Trengove et al 2021, Trengove et al 2022).

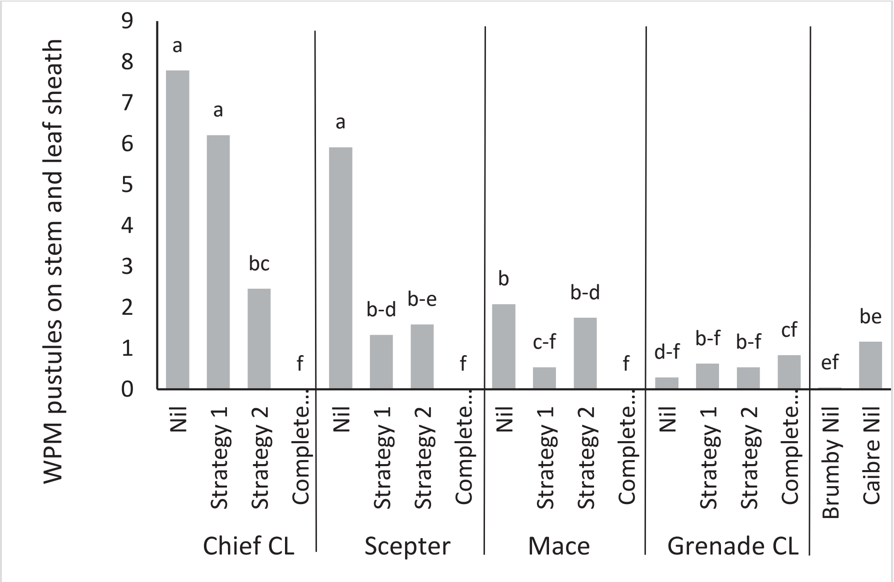

Figure 1: Variety by fungicide trial at Bute 2022. WPM pustules on the stem and leaf sheath assessed 27/9/2022 (Pr(>F) = <0.001).

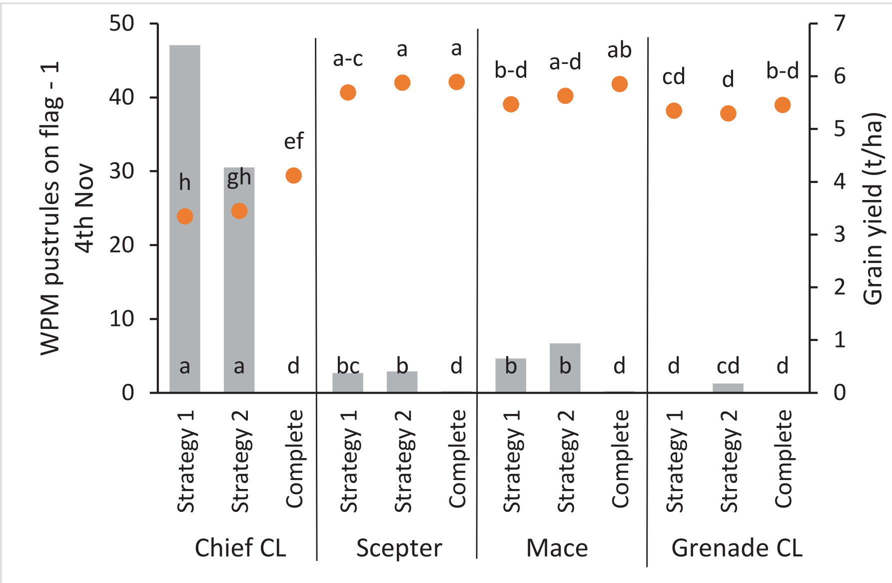

Figure 2: Variety by fungicide trial at Bute 2022. WPM pustules on the Flag minus 1, assessed 4/11/2022 (Pr(>F) = <0.001) and final grain yield (Pr(>F) = <0.001).

Wheat powdery mildew fungicide resistance and post-emergent fungicide performance

Mutation frequency for Y136F at Cyp51 was high at all trial sites averaging over 99%, regardless of treatment. This indicates that the gateway mutation associated with reduced sensitivity to group 3 fungicides is saturated at all trial site locations likely due to the strong selection pressure that wheat powdery mildew populations are under because of the reliance on DMI fungicides. Trial sites at Bute in 2020 and 2021 had 70% and 87% frequency of Y136F mutation and is consistent with survey data indicating this reached saturation in a relatively short time period.

Mutation frequency for G143A at CytB that confers resistance to group 11 QoI fungicides ranged from 1.2-24% across sites in the untreated control (Table 2). There is a trend for treatments containing the group 11 fungicide azoxystrobin to increase this frequency across the sites. This is expected, where the continual use of group 11 QoI fungicides maintains selection pressure on the population. This is consistent with 2021 results from Bute where treatments including azoxystrobin increased mutation frequency from 19 to 48.5% (Trengove et al 2022).

Table 2: Fungicide treatment effect in four product efficacy trials on frequency of G143A mutation at CytB, conferring resistance to group 11 QoI fungicides. Letters denote treatments that are significantly different.

Treatment	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 (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 (3)			53	ab			
Veritas (3 + 11)			79	a			
Prothioconazole (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	

WPM control at Bute was poor with single active DMI products being no better than the untreated (Table 3). Dual active DMI Prosaro® provided some control. Azoxystrobin reduced WPM infection, both standalone and in the dual active group 3 and 11 mixtures. Given low levels of QoI resistance at the site this is not unexpected, however is not likely to be a long-term solution given ongoing selection for resistant individuals (Table 2). Aviator Xpro® is a DMI plus SDHI mix but is no better than the standalone prothioconazole DMI component (Proviso® 250EC), which is consistent with previous results. Telbek® Adavelt® is a new group 21 fungicide and provided useful WPM control at this site.

Legend® fungicide and other registered products with quinoxyfen (250g/L) have been issued Permit 93197 for use in wheat for the control of powdery mildew at use rates of 200-300mL/ha. The permit is in place for 18 months. Critical use comments from the label include;

Apply at the first signs of infection as a protectant treatment only.

Monitor crops regularly from early tillering and apply at or before GS31.

Monitor if conditions favour disease development and reapply from 21 to 28 days after the first application and no later than GS39.

Apply foliar application by ground boom.

Use higher rates where conditions favour disease development.

Use a spray volume of 50-100 L/ha.

DO NOT apply more than 2 applications per crop.

DO NOT apply less than 21 days after the initial treatment.

DO NOT apply after the growth stage GS39.

Apply quinoxyfen in accordance with the current CropLife Fungicide Resistance Management Strategy.

These comments will need to be factored in when planning to use Legend for WPM control.

Legend® provided high levels of WPM control at Bute in 2022 (Table 3), and this result is consistent with trial results in 2020 and 2021. Several experimental products tested also provided high levels of control. It is important to note that diseases do not occur in isolation though, and broad-spectrum fungicides were required to control all diseases present at the site including stripe rust, Septoria tritici, Wirrega blotch and WPM. Stripe rust infection and its control was the biggest determinant of grain yield and products that controlled stripe rust were the highest yielding, where the untreated control yielded 20% of the best treatments. Legend® and the experimental products provided no stripe rust control and were only marginally better than untreated control for grain yield. Mildew specific fungicides such as Legend® will need to be applied with an appropriate mix partner to provide broad spectrum disease control.

Table 3: Fungicide effect on wheat powdery mildew, Wirrega blotch & Septoria tritici, stripe rust and grain yield in Chief CL wheat at Bute, SA, 2022.

Product	WPM canopy score 28th Sept		[a] WPM pustules/stem 28th Sept		[b] Blotch Score 28th Sept		Rust canopy score 16th Oct		Rust canopy score 4th Nov		Grain yield (t/ha)	
Nil	3.0	a	1.0	a	37	bc	9.3	a	9.9	a	0.66	j
Tebuconazole430	2.8	a	0.8	a-d	18	f-h	1.5	h	4.1	h	2.69	d-f
Opus® 250mL/ha (GS39 only)	2.6	ab	0.9	ab	33	b-e	1.5	h	4.0	hi	2.53	d-g
Opus® 500mL/ha	2.6	ab	0.9	a-c	16	gh	0.5	i	2.6	jk	2.85	b-d
Propiconazole	2.4	a-c	0.8	a-c	20	d-h	3.0	fg	6.9	f	2.53	d-g
Proviso® 250EC	2.3	a-d	0.8	3	18	e-h	5.5	c	8.4	cd	2.36	fg
Prosaro®	2.1	a-d	0.6	c-f	21	d-h	1.0	hi	3.3	i-k	3.07	a-c
[c]Mirador® 625 (azoxystrobin)	2.3	a-d	0.6	c-f	12	h	2.8	g	5.4	g	2.57	d-g
Veritas Opti®	1.8	b-e	0.5	d-g	24	c-h	1.0	hi	3.4	h-j	2.67	d-g
Amistar Xtra®	1.5	c-e	0.5	d-g	20	d-h	1.5	h	3.9	hi	3.23	a
Tazer Xpert®	1.4	d-f	0.4	f-h	12	h	1.3	hi	2.6	k	3.19	ab
Maxentis®	1.6	c-e	0.4	f-i	31	b-g	4.0	de	6.9	f	2.74	c-e
Aviator Xpro®	1.8	b-e	0.7	b-e	10	h	4.8	cd	7.1	ef	2.41	e-g
Telbek® Adavelt®	1.1	ef	0.4	f-h	20	d-h	6.5	b	8.9	bc	1.65	h
[d]Legend®	0.5	fg	0.0	j	34	b-d	9.0	a	9.9	a	1.04	i
Telbek® Adavel® + TC EXP 01	0.1	g	0.1	hij	32	b-f	6.8	b	9.2	a-c	1.54	h
Telbek® Adavelt® + TC EXP 01 + Proviso® 250EC	0.0	g	0.1	ij	29	b-g	4.8	cd	7.7	de	2.31	g
TC EXP 01	0.0	g	0.5	efg	32	b-f	9.0	a	9.9	a	0.98	ij
TC EXP 02	0.5	fg	0.3	f-i	40	ab	6.8	b	9.1	bc	1.57	h
TC EXP 04	0.0	g	0.2	g-j	54	a	9.0	a	9.6	ab	1.06	i
Pr (>F)	<0.001			<0.001	<0.001		<0.001		<0.001		<0.001	
LSD (0.05)	0.875			0.3	15		0.9		0.8		0.36	

[a] data has been transformed to log10(1 + pustule count)

[b] blotch score is the leaf area percent of the flag minus 1, 2 and 3 affected by necrosis caused by Wirrega blotch and Septoria tritici combined.

[c] 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.

[d] Legend is available for use under PER93917.

When QoI group 11 fungicides are rendered ineffective due to resistance, and control from SDHI group 7 fungicides is typically low, the DMI group 3 fungicides have been the remaining fungicidal control option, albeit at reduced levels due to reduced sensitivity. A trial at Bute investigated the effect of applying DMI actives at full label rates, standalone or in two-way and three-way mixes, to try and optimise control. Active ingredients included tebuconazole, epoxiconazole and prothioconazole. Results indicate that increasing the load of DMI by applying active ingredients in combination provided better control than applying the actives as standalone treatments (Figure 3).

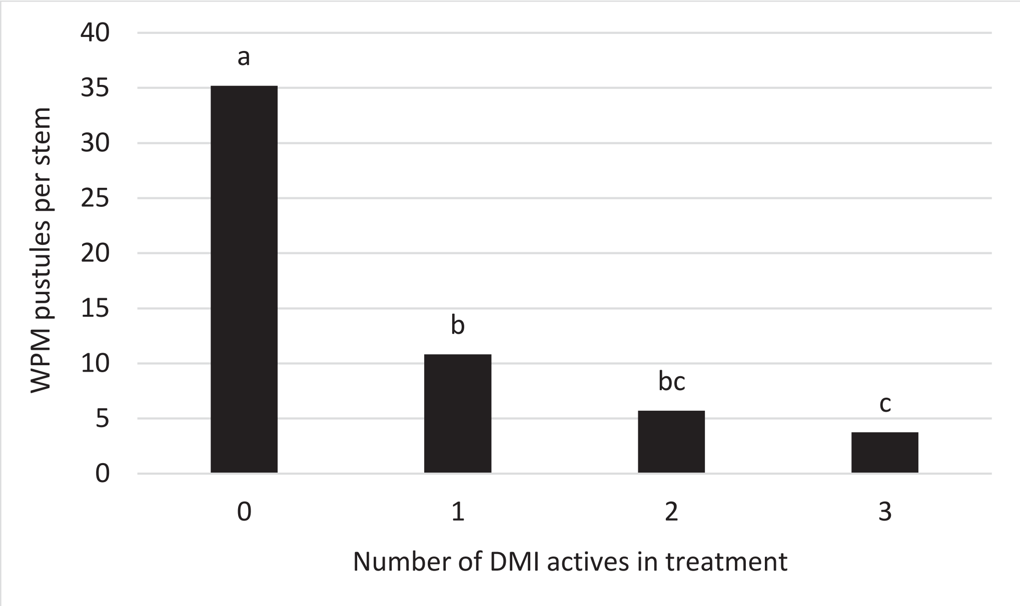

Figure 3: Total WPM pustule number assessed on the Flag minus 1, 2 and 3 and the lower stem on 29/9/2022 for Chief CL treated with group 3 DMI fungicide combinations.

Fungicide applied at head emergence at Port Neill resulted in different levels of WPM head infection, with treatment scores ranging from 2.4 to 5.2 in the untreated (Figure 4). The relationship between WPM head infection and grain yield indicates when the head score was less than 4 there was little difference in grain yield but declined when the head score exceeded 4, where the untreated control yielded 3.2t/ha. A head score of 4 indicates approx. 40% of the head has mildew growth.

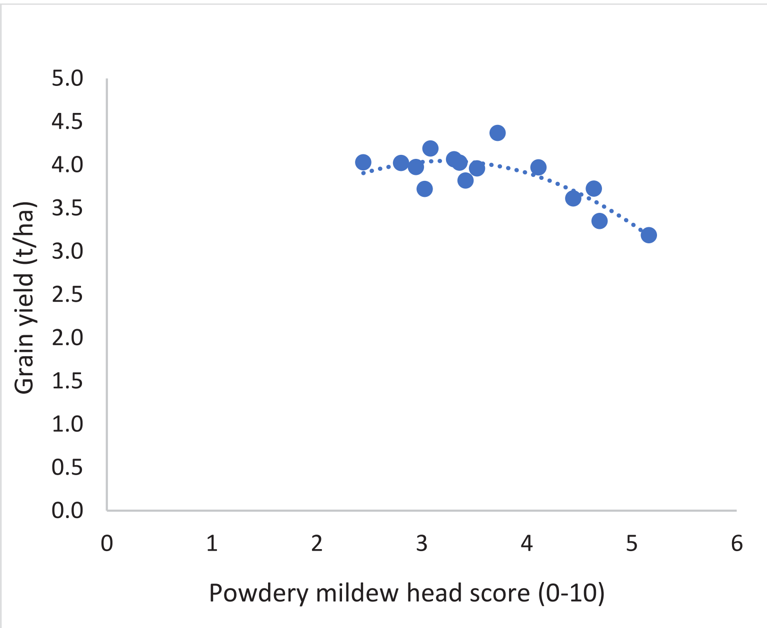

Figure 4: WPM head score in Vixen wheat at Port Neill on Nov 3rd and grain yield response ($Y = -0.232x^2 + 1.494x + 1.637$, $R^2 = 0.689$).

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

Notes

A systems approach to nitrogen management

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GRDC project code:

Keywords

- crop yield, nitrogen management, soil fertility.

Take home messages

- Crops typically get 60–80% of their N requirements from soil and only 20–40% from fertiliser in year of application. Think of fertiliser more as an input to maintain soil fertility and fill seasonal shortfalls, rather than the major source of N for crops.
- Aim to maintain soil fertility and maximise profits by using N fertiliser to achieve a neutral or small positive N balance. N Banks, Yield Prophet® and variable rate N fertiliser application based on protein maps are effective ways of achieving this aim.
- Don't be overly concerned about poor NUE and response to fertiliser N in the year of application, manage to minimise losses (4Rs) and unused N will make an important contribution to soil fertility.

Background

Nitrogen (N) deficiency is the single biggest cause of the gap between water limited potential yield and farm yield in non-legume grain crops in Australia (Hochman and Horan 2018). Recent shifts to continuous cropping with low legume intensity means crops are highly reliant on fertiliser N to achieve water limited yields. Due to Australia's variable rainfall and thus variable water limited potential yields, it is difficult to match fertiliser N to anticipated crop yields, and many crops are under-fertilised and nitrogen deficient. Wheat or barley grain protein less than 11.5% is a good indication of N deficiency. Under-fertilising not only reduces crop yield, but also causes crops to mine soil organic nitrogen, which runs-down soil organic matter, emitting carbon dioxide to the atmosphere and increasing reliance on fertiliser N for future production.

In 2022, urea tripled in price compared to previous years. Grain prices also increased meaning that optimal N rates haven't changed all that much, but the total cost of N fertiliser inputs and value at risk has increased markedly. It is now more important than ever to make sure that N fertiliser is being used effectively and environmental losses are avoided as much as possible.

In the past, much research and extension emphasis has been placed on maximising nitrogen fertiliser use efficiency in the year of application. This overlooks the fact that in continuous cropping systems, fertiliser not used in the year of application contributes to maintaining soil organic matter and thus, soil fertility. We argue that to effectively close yield gaps, a longer-term systems approach to N fertiliser management is needed where losses are minimised, but it is recognised that applications of N fertiliser are as much about maintaining soil N fertility, as they are about meeting the N requirement of the crop in the year of application.

Nitrogen in cropping systems

Most N in cropping systems is stored in soil organic matter that cannot easily be taken up by plants or lost to the environment. There are usually tonnes per hectare of soil organic N in most cropping soils, and this forms the basis of soil fertility. N becomes readily available to plants when it is mineralised by microbes from organic matter into mineral form (Figure 1). Mineral and organic N together are referred to as total soil N. Nitrate (NO_3) and ammonium (NH_4) are the most stable forms of mineral N in the soil, and the forms most readily taken up by plants. These are the compounds that are typically measured in deep N soil tests as a measure of instantaneous fertility.

Figure 1. A twin chamber measuring bottle provides a good analogy for soil N – most N in the soil is in organic form (bottom chamber) but crops mainly take up N in mineral form (top chamber). N moves between organic and mineral form via mineralisation and immobilisation. N can be added to or lost from the soil in both organic and mineral form.

Mineral nitrogen moves back into the organic pool when it is immobilised by microbes or taken up by plants. Immobilisation occurs when soil microbes breaking down carbon-rich molecules in plant residues or other dead microbes for energy, take-up N to form proteins in their cellular structures. When these organisms die, their rapid decomposition can be prevented by association with soil mineral particles or aggregates, and this forms the basis of soil organic matter. Very fine particles of decomposed plant material protected from rapid decomposition by soil aggregates are the other important component of soil organic matter. Nitrogen is also present mostly in organic form in living plants, and in plant residues on the soil surface which form the feedstock for soil organic matter production.

The major inputs (tens to hundreds of kg/ha) of N into cropping systems are from legume fixation of atmospheric N and addition of synthetic N fertiliser or organic wastes, for example, manures, composts, biosolids (Figure 2). There are smaller amounts (ones to tens of kg/ha) provided through rainwater and dust deposition, and fixation of atmospheric N by free-living (non-rhizobial) bacteria.

The major outputs of N from cropping systems are through export of grain and hay, burning or removal of crop residues and environmental losses due to denitrification, volatilisation, leaching, run off and erosion.

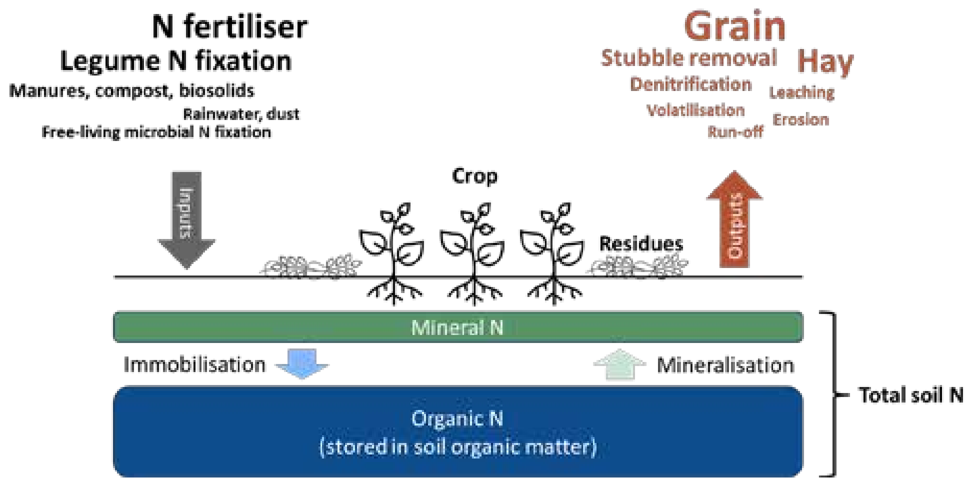

Figure 2. Nitrogen pools, inputs and outputs in grain cropping systems.

Soil is the most important source of N to crops

On average, grain crops derive only 20–40% of their N requirement from fertiliser applied during their life cycle, with the remainder being taken up from the soil (Gardner and Drinkwater 2009, Wallace et al. 2022). Soil sources of N are thus the most important source of N to a crop, and include:

- mineral N accumulated prior to sowing, which comes from various sources, including
  - N that mineralises out of soil organic matter or plant residues during the summer fallow
  - mineral N from various sources not used by previous crops ('spared' N)
- N that mineralises from soil organic matter or plant residues while the crop is growing (in-crop mineralisation).

Rates of net mineralisation (mineralisation minus immobilisation) are determined by soil temperature and water availability, amount of soil organic matter, and amount and C:N ratio of plant residues. Decomposition of plant residues with C:N ratio of 25:1 or less will usually result in net mineralisation, but at C:N ratios above this, net immobilisation is likely (cereal straw typically has a C:N ratio of 80:1).

In any given year, it is difficult to compensate for poor soil N fertility (low mineral N and soil organic matter) with high rates of N fertiliser because it is difficult to get more than 20–40% of total crop N uptake from fertiliser N. To support high yields, it is essential that soil N fertility is maintained.

How can N fertility be maintained

Over the long term, N fertility in cropping systems is maintained by ensuring that N inputs either equal or exceed N outputs in grain and losses. That is, the cropping system needs to have a neutral or positive N balance. When outputs exceed inputs, N balance of the system is negative, and plant and microbial growth become strongly N limited. As N mineralises out of the organic pool to be taken up by crops and exported in grain, it is not replaced, and soil organic N declines over time. This is referred to as 'mining' of soil organic N, and long fallowing is one of the most effective ways for this to be achieved. Because of the fixed ratio of C:N in soil organic matter, soil organic carbon also declines during periods of N mining as C is respired into the atmosphere as CO_2. Eventually, soil organic matter will reach an equilibrium of low fertility where the ability of the soil to provide mineral N to crops (and support yield) is greatly diminished, forcing greater reliance on fertiliser N inputs to support yield.

In continuous cropping systems, N fertility can only be maintained by inclusion of grain or forage legumes in the crop rotation and/or addition of sufficient N fertiliser or manure to compensate for N exported in grain or lost to the environment. Only 30–50% of applied fertiliser (and less of manure) is used by crops in the year of application, and the remainder is either carried over in the soil as 'spared' mineral N, immobilised into soil organic matter or lost to the environment through stubble burning, volatilisation, run-off, leaching or denitrification.

Cropping systems with an overly positive N balance are at risk of accumulating mineral N and suffering higher N losses but running a positive N balance may be necessary to build fertility in paddocks in which soil organic matter is depleted. Building fertility is likely to be more cost effective and less prone to losses if it is achieved by adding organic sources of N, for example, by growing legume pastures or brown manures, or applying manures or other organic wastes, rather than adding excessive amounts of synthetic N fertiliser.

Use of decision support tools such as Yield Prophet®, Nitrogen Banks and variable rate application of N fertiliser based on protein or N removal maps are both effective and can all guide N fertiliser management to ensure that crop N balance is neutral.

Five years of data from the BCG and University of Melbourne long term N management experiment at Curyo in NW Victoria (Hunt et al. 2022) has shown that fertiliser N management strategies which run a neutral to slightly positive N balance (N Bank 125kg N/h, Yield Prophet 50%) are also the most profitable (Figure 3) and that profit begins to decline at an N balance of ±50kg N/ha from neutral. Profitability also declines above a marginal nitrogen use efficiency (NUE) of ~20kg/kg (Figure 4), illustrating that NUE is not the best indicator of overall system performance.

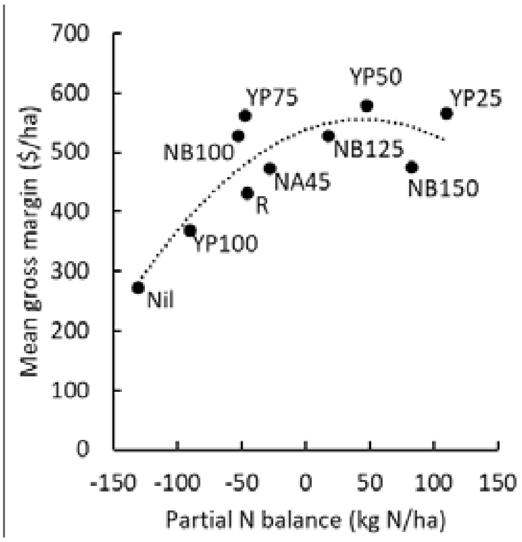

Figure 3. The relationship between partial N balance (N applied as fertiliser – N exported in grain) and mean gross margin (R^2=0.74). Results are averaged from 2018–2022, but costs and prices from 2022 were used to calculate gross margin, including urea at $1 400/t. YP=Yield Prophet at different probabilities indicated by following number, NB = N Banks at different target levels indicated by following number, R= replacement and NA45 = national average application 45kg N/ha.

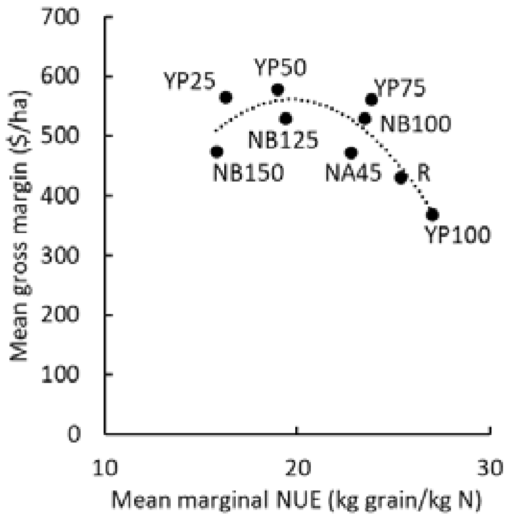

Figure 4. The relationship between mean marginal NUE (kg grain produced per kg of fertiliser N applied relative to Nil control) and gross margin (R^2=0.69). Results are averaged from 2018–2022, but costs and prices from 2022 were used to calculate gross margin, including urea at $1 400/t. YP=Yield Prophet at different probabilities indicated by following number, NB = N Banks at different target levels indicated by following number, R= replacement and NA45 = national average application 45kg N/ha.

Avoiding nitrogen losses

While the benefits of minimising loss of N to the environment are clear, implementing reliable management strategies to achieve this under conditions of uncertainty (seasons and yield potential, input prices, commodity prices) is more complicated. Nonetheless, understanding the risk factors that contribute to N loss can help to inform management for maintaining soil N reserves.

Previous studies across a range of grain crops grown in Australia indicate that, on average, 22% of fertiliser N applied is lost from the farming system by harvest (Angus and Grace, 2017). However, this value can vary greatly, typically ranging from 5–50%. Rates of N loss are highly correlated with soil water supply – either too much or not enough can influence N cycling, availability to the crop and the processes that lead to loss. Measurements of NUE across a range of environments in Victoria have shown that highest losses occur under wet conditions in either high rainfall (7–93%) or irrigated conditions (31–54%). Conversely, measurements from lower rainfall (<450mm annually) environments show typical losses of 5–42% (Wallace et al. 2022).

Under wet soil conditions, potential loss processes include denitrification (where nitrate is reduced to di-nitrogen, nitrous oxide and nitrogen oxide under waterlogged conditions) and leaching or runoff (where soluble nitrate moves through or across the soil with the flow of water).

These processes attract substantial research and policy interest due to their relevance as a potent greenhouse gas (nitrous oxide), potential pollutant of waterways (nitrate leaching or runoff) and a cause of soil acidification (nitrate leaching). Under dryland conditions in most Australian grain growing regions, major leaching events are rare. However, the potential for extended periods of waterlogging, leading to anaerobic soil conditions causing denitrification may result in large rates of N loss. Unfortunately, field-based assessments of total denitrification are currently limited as accurate measurements are difficult. However, research supported by GRDC and their partners continues in this area to help close the nitrogen cycle (Barton et al. 2022).

Where soil conditions following N fertiliser surface application are relatively dry, the risk of losing N to ammonia volatilisation increases. Volatilisation occurs where water supply is sufficient to cause dissolution of fertilisers such as urea (a heavy dew can begin this process) but is insufficient to wash the N into the soil profile. Where N is maintained near the soil surface as ammonium, it can be subject to loss as ammonia gas. High soil pH, surface application of fertiliser, high temperatures, windy conditions and minimal ground cover are some of the key factors influencing the amount of N lost through this pathway. There is a large range of measured losses due to volatilisation in Australian cropping systems, with analysis by Schwenke (2021) suggesting a median of 8.1%, ranging from 0–29% for in-crop, surface application of urea.

Minimising loss of applied N centres around controlling levels of excess mineral N in the soil, particularly at times when conditions are conducive to loss (see above). Ideally, this means more fertiliser N being taken up by the crop. If this can't be achieved, then maintaining this N in the soil, ideally in tied-up/organic forms for future cropping cycles, is preferred. To achieve this, fertiliser decision making can be guided by the 4Rs principle: right rate, right time, right product, right place.

Under Australian conditions, determining the 'right rate' of application is a first order priority. Variable seasons, fertiliser and input prices and uncertainty relating to response make for a difficult decision. While year to year variables often dominate thinking about rate, consideration should be given to a broad balance over multiple years. If removal of N exceeds total inputs, soil fertility is in decline and this needs to be replaced in one form or another. Achieving the 'right time' for application relates to understanding crop demand patterns and their relationship with N availability. Previous studies show that crop uptake of applied N is directly related to crop growth rate at the time of application (Limaux et al. 1999). As a result, delaying application until stem elongation in cereals can help to increase crop uptake of applied N and reduce loss (Figure 5), although this is dependent on conditions following application. In Figure 5 below, results from years with wet winters and modest springs (2012 and 2013) lead to reduced loss where N application was delayed. However, in a dry year (2014), these differences were limited.

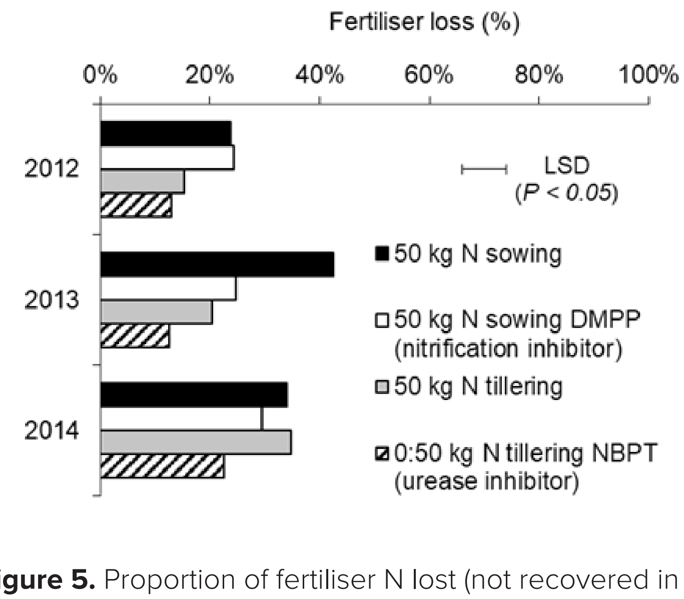

Figure 5. Proportion of fertiliser N lost (not recovered in either plant material or soil) between the time of application and harvest for urea applied to wheat in the Victorian Wimmera (2012–2014). All treatments applied at 50kg N/ha, with sowing treatments banded below the seed and tillering treatments top-dressed. Treatments include inhibitor treated urea at each application time. Seasonal conditions were characterised by wet winters and modest spring rainfall in 2012 and 2013 and dry conditions throughout in 2014 (Wallace et al. 2020).

Where N application during high-risk periods is unavoidable, the use of enhanced efficiency fertilisers (EEFs) offers an opportunity to mitigate this risk. EEFs cover a wide range of fertiliser products that are designed to control the cycling of applied N. Nitrification inhibitors such as DMPP slow the conversion of ammonium to nitrate, helping to control N loss associated with denitrification, leaching or runoff where conditions are conducive (see data from 2013, Figure 4). Conversely, if N is applied during dry conditions, urease inhibitor treated urea can slow the conversion of urea to ammonium, reducing the risk of volatilisation (2014, Figure 4). Of course, the use of EEFs is contingent on an economic response to offset their associated price premium through either increased yield or grain quality, increased retention of N for future seasons, or reduced rate of application.

Achieving the 'right placement' of applied N can also help to reduce loss and retain more N in the crop or soil. Similar to the timing of fertiliser application, if the product is placed into areas of the soil where conditions are conducive to a particular process, it can be prone to loss. Incorporation or sub-surface banding of urea to reduce the risk of ammonia volatilisation during dry conditions is one example of how improvements can be achieved. Trials conducted in Victoria have shown that mid-row banding of urea during the growing season rather than topdressing, can increase crop uptake of applied N from an average of 40% (23–65%) to 56% (31–79%) and reduce loss from an average of 41% (25–50%) to 26% (13–43%) of applied N. However, yield and grain quality responses to fertiliser banding were variable and not consistently sufficient to immediately offset the increased cost of application. Similar to the use of EEFs, increased retention of N for future seasons or reduced rate of application may be required to justify this strategy.

While 2022 was an exceptionally wet year for most grain growing regions in south-eastern Australia, a common question arising after drier seasons relates to potential for carry-over of un-used fertiliser between years. Results from the Victorian studies listed above indicate that, particularly in medium and low rainfall regions, there is potential for substantial amounts of unused fertiliser N to remain in the topsoil following dry seasons (26–92% of applied N). These results are typically associated with poor crop uptake in the year of application, often where N was top-dressed and limited rainfall following meant that crop access to this N was hindered. While this N may be subject to loss mechanisms and tie-up, it nonetheless highlights the potential to gain a return on fertiliser investments in the years following application. Studies investigating N recovery over multiple years under dry seasonal conditions are currently limited. However, this issue is also the subject of ongoing investigation.

Acknowledgements

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Understanding crop potential and calculating nitrogen to improve crop biomass workshop recording (including spreadsheet for calculating N balances) (https://www.bcg.org.au/understanding-crop-potential-and-calculating-nitrogen-to-improve-crop-biomass-workshop-recording/)

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Notes

The agronomics of pulses, implications of new varieties and herbicide tolerance

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GRDC project codes: PROC: DJP2105-006RTX

Keywords

- disease management, herbicide tolerance, pulses, soil constraints.

Take home messages

- New varieties – two new 'IMI' tolerant lentil varieties will offer growers improved grain yield and yield stability across a range of environments.
- Herbicide tolerance - the first lentil to combine the IMI and metribuzin (MET) tolerances, GIA MetroP, has been released. Whilst it is lower yielding than other varieties, agronomic herbicide tolerance trials have shown its metribuzin tolerance will allow alternative weed control strategies, particularly on sandy soils where metribuzin and other Group 5 products can cause crop damage risk even when applied post sowing pre emergent.
- Disease management – newer fungicide products provided profitable improvements in disease control under extreme conditions in 2022, particularly when combined with higher levels of varietal resistance.
- Soil constraints – deep ripping in combination with soil amendments provided yield gains of up to 180% in non-traditional areas for pulse production. Combining the agronomic response with new varieties with improved tolerance to soil toxicities, acidity, salinity, herbicides will contribute to expand areas for pulse production and improve yield stability.

Seasonal comments

From a research perspective, 2022 was the most challenging season I have experienced since the start of my career in pulses in 2000. 'It was the year that just kept giving…and keeps giving into 2023…'. Almost all trial sites experienced good opening rainfall events, which resulted in even establishment and vigorous early growth for all pulses. The months of June and July were generally slightly below average and slight drought stress symptoms were noted in faba beans at drier locations. Then it all changed, at most sites more than 300mm of rain fell throughout August to October, followed by another 100mm or more during November at some sites. This meant that:

- several trials were abandoned due to waterlogging, particularly lentils
- disease management was incredibly difficult due to the high pressure and inability to apply timely fungicides due to trafficability
- maturity and harvest were delayed by at least 2–4 weeks compared to a 'normal' season. For example, this will be the first time lentil harvesting commenced at our Wimmera trial site in January (it's normally finished by Christmas).

Due to the late season finish and delayed harvest, this report highlights some of the new pulse varieties and agronomic research completed in 2022, with more detailed results and grain yield available in the presentation.

Agronomic research highlights

Novel herbicide traits, weed management and new herbicides

The new lentil varieties combining IMI tolerance with metribuzin (GIA Metro⌽) or residual clopyralid (GIA Sire⌽) will improve weed control options in lentil, particularly in tight rotations. Trials in 2021 demonstrated improved vetch control when these traits were used with suitable herbicide packages. In 2022, trials at Ultima (central Mallee), with a background of the weed fumitory, and Kalkee (Wimmera), with a background of medic, investigated various options for control. Below, we focus on the metribuzin trait with GIA Metro⌽.

Metribuzin tolerance

Similar to previous research, at Ultima in 2022, GIA Metro⌽ showed good visual tolerance to all metribuzin treatments, while PBA Hallmark XT⌽ showed significant crop damage in all post-emergent treatments (Table 1 and 2). Similarly, there was no difference observed in biomass or grain yield of GIA Metro⌽ from the herbicide treatments shown below. In contrast, PBA Hallmark showed a significant reduction in biomass and grain yield with post-emergent metribuzin treatments compared with no post-emergent application (Table 2) demonstrating the tolerance of the new variety Metro⌽. Yield loss in PBA Hallmark⌽ was less than in other seasons which was reflective of the seasonal conditions where very high rainfall recorded from August to November, along with mild temperatures, meant there was adequate time to partially recover from the initial crop damage. In seasons with lower rainfall and less time for recovery, grain yield losses for PBA Hallmark XT⌽ from post-emergent metribuzin application can be much higher and result in complete failure, hence post emergent application of metribuzin to non-tolerant varieties is not permitted. It is important to note that, the population of fumitory in this trial was not high enough to create substantial crop competition and enable any meaningful observations on efficacy of control by metribuzin.

In the trial at Kalkee, similar trends in crop damage were observed (data not shown), however at the time of writing, grain yield was yet to be analysed.

Table 1: Application details of selected herbicide treatments applied in a trial near Ultima (central Mallee, Vic) to assess varietal tolerance and control fumitory in 2022. Application dates indicated in brackets.

Herbicide treatment	Incorporated by sowing (28 Apr)	Post-sowing, pre-emergence (28 Apr)	5 node (9 Jun)
Control	Nil	Nil	Nil
Conv			Diflufenican @ 75g ai/ha
Imi			Imazamox @ 24.75g ai/ha + Imazapyr @ 11.25g ai/ha[1]
Met PSPE		Metribuzin @ 210g ai/ha	
Met Post			Metribuzin[2] @ 210g ai/ha
Met PSPE then Met Post		Metribuzin @ 105g ai/ha	Metribuzin @ 180g ai/ha
Reflex® IBS then Met Post	Fomesafen @ 180 gai/ha		Metribuzin @ 210g ai/ha

1. Intercept® is the product registered for use in lentils
2. Metribuzin is registered for use in metribuzin tolerant lentils under permit 'PER92810'

Table 2: Herbicide damage scores (26 July), biomass recorded (15 Nov) and grain yield (20 Dec) of GIA Metro⌽ and PBA Hallmark XT⌽ in response to selected herbicide treatments applied at Ultima (central Mallee, Vic) in 2022. Post-emergent treatments of metribuzin are highlighted.

Herbicide treatment	Herbicide damage score (0–100)		Biomass @ maturity (t/ha)		Grain yield (t/ha)	
	GIA Metro⌽	PBA Hallmark XT⌽	GIA Metro⌽	PBA Hallmark XT⌽	GIA Metro⌽	PBA Hallmark XT⌽
Control	0	0	9.96	12.20	1.40	2.65
Conv	4	6	9.56	12.62	1.64	2.63
Imi	9	15	10.11	11.94	1.48	2.74
Met PSPE	0	11	9.60	12.54	1.54	2.69
Met Post	0	48	9.25	*	1.51	*
Met PSPE then Met Post	0	63	10.16	*	1.49	*
Reflex IBS then Met Post	0	35	9.56	*	1.63	*
Lsd (P<0.05)	4	15	ns	ns	ns	ns

**Denotes off label treatment – significant yield and biomass penalties were incurred*

These trials continue to highlight the potential benefits that metribuzin tolerance could provide to lentils in the farming system, particularly in combination with IMI tolerance and as new varieties are developed with higher grain yields. The technology will have a fit on sandy soils, where the use of group 5(c) products applied post sowing pre-emergent can cause substantial crop damage, even at sub optimal application rates, and where there are specific weed problems that can be controlled with applications of metribuzin around sowing and/or in crop.

Sowing date and yield stability – faba bean and lentil

Several new faba bean varieties have been released or are due to be released with changes in agronomic traits such as flowering time and reproductive duration, disease resistance, and herbicide tolerance. Faba beans currently have limited uptake in drier Mallee regions. Early sowing, with early flowering varieties, combined with herbicide tolerance and agronomic practices, such as deep ripping, have the potential to open new opportunities. Similarly in lentil, varieties have been released, or are due to be released, with changes in agronomic traits such as plant architecture, biomass production, reproductive duration and timing, disease resistance, herbicide tolerance and pod retention. Changes in sowing date have the potential to maximise the benefits of these traits from a crop production and farming system perspective. There is interest in understanding the implications of later flowering with a reduced reproductive window, combined with lower vigour. In addition, the two new varieties GIA Sire$^{\Phi}$ and GIA Metro$^{\Phi}$ have unique growth habits that may require different planting densities to optimise grain yield.

Trials at Warne (central Mallee) and Kalkee (Wimmera in 2022) investigated phenological and yield responses to a range of sowing dates in faba bean and lentil. of the impact of plant densities on yield were also interrogated in lentils at Warne. All trials at both sites were severely impacted by waterlogging due to the very high rainfall in 2022. The Warne lentil trial was abandoned, with much of the trial waterlogged for around 6 weeks. Faba beans showed excellent tolerance to waterlogging with unanalysed grain yields ranging between 3.5t/ha and 5t/ha when sown 3 May, which was approximately 60% higher than the 2 June sown treatments (1.3t/ha and 2.5t/ha). Similar to 2021, AF14092 showed the highest grain yields of 5.06t/ha sown 3 May. At Kalkee, trials were more variable than Warne due to the combination of disease and waterlogging. Unanalysed faba bean grain yields ranged between 5.6t/ha and 8.0t/ha sown 14 April, 5.4t/ha and 7.6t/ha sown 23 May and 3.7t/ha and 5.3t/ha sown 28 June or 8 Aug with wide ranges between varieties demonstrating the importance of selecting phenology adapted to the right sowing opportunity. More information will be provided on varietal differences at the presentation. At both sites, disease was managed with a complete fungicide strategy (eight applications at Kalkee and three applications at Warne), aiming to minimise disease, as the aim of trials was to determine yield responses in the absence of disease. Despite the extreme disease (Botrytis grey mould) pressure, grain yield loss was minimised, which was highlighted at Kalkee where grain yields of 4–5t/ha were achieved with the susceptible variety PBA Bendoc$^{\Phi}$. In contrast, many crops of this variety in the region close by struggled to achieve 2t/ha, with some crop failures.

In lentils at Kalkee, individual plot grain yields ranged from 0 to >6t/ha, highlighting the extreme variation due to waterlogging, disease and weed pressure. Generally, grain yields were highest when sown 23 May, with an average across all varieties sown of 3.3t/ha. When sown 14 April and 28 June, yields were 2.6t/ha and 2.7t/ha respectively, with yields from the late sown treatment (4 August) at 1.0t/ha. Detailed varietal responses will be discussed in the presentation following further analysis accounting for variation observed.

Disease management

In 2022, the importance of varietal resistance and a robust fungicide package (along with a little bit of luck) was highlighted.

Faba beans

Several trials in previous seasons have highlighted the benefits of newer fungicide products combined with using resistant varieties adapted to the cropping region (i.e., PBA Amberley$^{\Phi}$ in the high rainfall zone and PBA Samira$^{\Phi}$ in the medium to low rainfall zone). In 2022, trials in the high rainfall zone focused again on new chemistry and timing of application. Some key observations in the initial data were:

- waterlogging compounded disease severity, an observation which was corroborated by many growers, and resulted in considerable difficulties in timing of application for fungicides
- a spray strategy involving SDHI fungicides required fewer applications to provide similar or better level of disease control compared to conventional strategies with older chemistry. It also provided a longer window of coverage between applications, which is critical in high rainfall seasons where there are often limited opportunities for application.

Vetch

Botrytis grey mould has been a major issue in vetch, particularly in early sown crops and higher rainfall conditions, causing reduction in biomass production and hay quality. In addition, there are no varieties with high levels of resistance. In 2022, a small disease management trial was sown early (14 April) to compare the impact of canopy closure applications of carbendazim and Miravis® Star on disease development, biomass production and hay quality in four varieties (Studenica$^{\phi}$, Timok$^{\phi}$, Morava and Benetas) differing in growth patterns. In short, Miravis Star showed reduced disease intensity at 7 weeks after application compared with carbendazim (Table 3 and Figure 2) and resulted in improved biomass at the flat pod stage. This was particularly notable in the earlier variety, Studenica$^{\phi}$, where cuts were taken in early September and disease was just beginning to spread again in the Miravis Star treatment.

Due to the high rainfall, the disease epidemic progressed so that visual scores in the carbendazim treatments were similar to the 'Nil' on 2 September, while Miravis Star were about 40% lower than the 'Nil'. At the end of September, all treatments had similar disease scores (data not shown). The progression of disease potentially explains why the relative biomass increase in other varieties was lower than observed in Studenica$^{\phi}$.

Figure 2. Botrytis grey mould symptoms in Studenica$^{\phi}$ vetch 17 August 2022 following canopy closure fungicide sprays of carbendazim (applied 23 June 2022).

Table 3: Botrytis grey mould score (recorded 19 August) and biomass at early flat pod of vetch varieties in response to canopy closure fungicide application of carbendazim or Miravis Star compared with nil and complete control fungicide strategies at Kalkee in 2022.

Fungicide1	Studenica$^{\phi}$	Timok$^{\phi}$	Morava$^{\phi}$	Benetas$^{\phi}$
Botrytis grey mould score (0, No Disease – 100, Plot dead)				
Nil	53	29	29	6
Carbendazim	19	13	14	3
Miravis Star®	4	3	3	0
Complete	1	1	1	0
Lsd (P<0.05) = 6				
Biomass (t/ha)				
Harvest Date	*5 Sept*	*20 Sept*	*10 Oct*	*29 Nov*
Nil	4.39	6.46	6.45	8.65
Carbendazim	4.74	6.21	7.35	8.50
Miravis Star®	6.00	6.58	7.98	9.52
Complete	6.44	7.95	12.40	14.10
Lsd (P<0.05) = 2.00				

1. Carbendazim (500mL/ha) and Miravis Star® (750mL/ha) were applied at canopy closure for each variety (23 June for Studenica$^{\phi}$, Timok$^{\phi}$ and Morava$^{\phi}$, 29 June for Benetas$^{\phi}$). The nil treatment was unsprayed and the complete treatment had fungicides applied regularly to eliminate disease starting 10 June.

Soil constraints

Surface acidity, heavy alkaline clay subsoils and sandy soils are all constraints to pulse production in the newer pulse production area north of Nhill in the west Wimmera. Following work in 2021, it was identified that there is an opportunity to ameliorate these soils, particularly with deep ripping and the addition of an organic ameliorant to help overcome these constraints. A trial comparing lentil, chickpea and faba bean was sown near Yanac on a sandy soil with a heavy clay at 40cm. Ripping treatments (to 40cm) with and without the addition of composted cow manure (10t/ha) were applied. Similarly, in the expanding North Central area where sodic, acidic and saline soils constrain pulse growth, a trial was implemented at Mitiamo to investigate the effect of deep ripping, in combination with gypsum and other novel amendments applied at depth, on growth and yield of chickpea, lentil, vetch and field pea.

At Yanac, similar to previous observations on sandy soils, deep ripping prior to sowing lentil (cv. GIA Thunder⁽ᴰ⁾) increased grain yield by 80% from 1.22t/ha in the unripped treatment to 2.20t/ha. The addition of cow manure as an amendment at depth, resulted in a further increase in yield, to 2.46t/ha. In faba bean (cv. PBA Samira⁽ᴰ⁾), grain yield was increased by 44% from 3.33t/ha to 4.84t/ha by deep ripping, and to 5.27t/ha with the addition of cow manure. Ripping and amendment with the cow manure also resulted in a increase in nodulation and biomass (data not shown).

Unfortunately, the trial at Mitiamo was severely waterlogged and could not be harvested, however some key in season observations indicate potential for further investigation. Notably, biomass appeared to be improved with ripping and the addition of gypsum. Additionally, following the flooding event, the same treatments were observed to have survived longer before dying highlighting potential for the ripping plus gypsum to aid recovery in years of short duration temporal waterlogging stress.

Both these trials highlight further opportunities to expand pulse production as we overcome major soil constraints. In addition to the ripping and amendment research, the agronomy program is also working closely with breeding groups on identifying new varieties with improvements in tolerance to boron, soil acidity and adaptation to sandy soils. Combining these new traits with the improved agronomic management should continue to increase yield and yield stability of pulses.

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Useful resources

Brand J, Mawalagedera S, Manson J, Moodie M, Farquason L (2022) Agronomy best practices with pulses – Victoria. 2022 GRDC Updates, Bendigo. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/02/agronomy-best-practices-with-pulses-victoria

2023 Victorian and Tasmanian Crop Sowing Guide (https://grdc.com.au/resources-and-publications/all-publications/nvt-crop-sowing-guides/vic-tas-crop-sowing-guide)

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Notes

Crop growth stages refresher

Dale Grey

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Keywords

- canola, cereals, growth stages, pulses.

Take home messages

- Correct growth stage identification is critical for chemical application to work effectively.
- Crop growth stage development can tell you if a plant is growing abnormally in time to make corrective action.
- Grazing crops at the wrong growth stage can be very detrimental to yield.

Cereal identification

At the seedling stage, all cereal crops can look the same, but small differences for alert eyes can easily tell them apart.

Looking at the auricles (the clasping structures at the base of the leaves where they join the stem), wheat and triticale are small and hairy, cereal rye has a very small non-hairy auricle, barley is big and bare and paler in colour, and oats have none. The ligule (the see-through membrane surrounding the unrolling leaves at the base of a leaf) is small on wheat, notched and small on rye, medium size on barley and quite large on oats. When plants are very small, it can be quicker to dig up the plant and observe the remnants of the seed. This is the only way to tell triticale from wheat, where triticale seed is twice the length of wheat and darker in colour. In the early stages of growth, oat and wild oat leaves twist in an anti-clockwise way (when viewed from above), where the other cereals all twist clockwise.

Cereal growth stages

Leaves (Z11-19)

For consistency, just the number of leaves growing on the main stem are counted for a growth stage. Easier said than done. Up until leaf three, it's easy as there will only be three leaves on a plant. The first leaf is easy to find (if not eaten) and characterised by a short leaf and a blunted tip (even when dead), all other leaves will have a pointed tip. Once you get four leaves, the presence of tillers can confuse the count. To find the main stem on any size plant, hang it upside down, clasp your hand around all the leaves and tillers and run your hand down, the main stem will be attached to the last leaf that you feel. Monitoring leaf emergence allows you to assess if the plant is growing normally and when a plant has six leaves on the main stem, you know it's close to getting to the start of stem elongation and then the first node stage. A new leaf forms every 100 accumulated degree days (called the phyllochron) and this practically means about one every fortnight in winter and a leaf a week in spring. A hundred degree days is not set in stone, as counterintuitively, earlier sown crops have more degree days between leaves, while crops sown later than June, have less degree days between leaves. Estimating leaf emergence rates based on temperature forecasts can be quite handy for planning fungicide protection of upper leaves. The number of potential leaves a plant can grow on the main stem is determined by the variety and the sowing date. It can vary from just five for a spring wheat sown in summer to 14 in a winter wheat sown in March. The total number of leaves on the main stem is set very early after germination. Many herbicides have a minimum number of leaves required for earliest application and this can be two, three or four leaves on the main stem. Some herbicides have a maximum number of leaves required for application, as crop damage can occur if the plants are older when sprayed.

The emergence of the last leaf, the flag leaf, signifies no more leaf production and the start of booting where the head rapidly starts growing in size. Many herbicides have a cut-off for application at this time.

Tillering (Z21-29)

The first primary tiller should be easily visible forming at the base of the fourth leaf when the plant is around four true leaves. The second tiller will form at the base of the second leaf and the third tiller will form at the base of the third leaf. The fourth tiller is likely to form at the leaf sheath of the first tiller and is called a secondary tiller. The fifth tiller is likely to form at the leaf sheath of the second tiller. Further secondary tillers can form at the base of the first leaves of the tillers. Early planted winter habit cereal crops and some spring feed barleys can sometimes develop tertiary tillers, where tillers start developing in the leaf sheaths of the secondary tillers. Knowing this timing and behaviour allows you to notice when tillering is not happening and potentially make remedial N applications to boost mid-tillering. The third tiller will usually be appearing at about the six-leaf stage and close to the start of stem elongation in normal sowing time spring wheats.

Sometimes you can see a tiller forming below the first leaf and these are called coleoptile tillers, more common on winter habit types and with deeper sowing. This will appear to be growing from the seed. Counting of total tillers (mainstem plus tillers per m^2) can be used to assess nitrogen response likelihood.

There are primordia for tillers formed at the bases of many other leaves and these are suppressed by the dominance of the first formed tillers. When the mainstem and tiller heads are killed off by mowing, grazing, frost or hail we get 'regrowth' (technically new growth) of those little undeveloped tillers (moisture permitting), once the first formed tillers are removed.

The main stem is attached to the fine primary root system, which is the first developed and grows to the greatest depth from the seed. Each tiller formed has to grow its own root system and these are the stouter secondary roots which anchor the plant and do much of the surface nutrient scavenging. The last tiller formed will therefore have the weakest secondary root system. This is why, when you see tiller death due to moisture or nutrient availability, the smallest tiller is the first to die. Later sown crops are prone to easier tiller loss due to a less developed secondary root system. Some herbicides can only be applied during the tillering phase. Early tillering would be described if one to two tillers are present, nominally a four-leaf plant. Mid-tillering when two tillers are present, a five-leaf plant. Late tillering would be when there are three or more, but a node is not visible, around a six-leaf plant. You need to be careful with this identification, as missing tillers (due to early nitrogen stress or waterlogging) can mean the plant is actually older and at a more advanced growth stage than what it appears.

Nodes (Z30-34)

The visual and tactile appearance of the first node indicates the start of stem elongation has occurred and in theory, this marks the end of tillering. In practice, small tillers that have formed, that are barely visible, can still grow and form heads. The small head has already been formed and from this stage on, will start setting the number of spikelets high and the number of florets wide that will be available for flowering. Practically, in normal sowing time varieties, the start of first node on the main stem is somewhere around the presence of the sixth to seventh leaf on the main stem. The presence of nodes is best found by splitting the stem in half with a sharp knife. The node first starts at crown level and will then start to be moved up by subsequent expansion between the node growth plates. The first node is not counted until the gap below it is greater than 1cm and the second node is not counted until the gap between it and node one is greater than 2cm. In practical terms, when the node is a few centimetres above the ground, it's prone to being grazed by sheep and when it's 5cm off the ground, it's edible by cattle. The timing of stock removal in grazed crops to prevent severe yield loss is predicated on the first node growth stage not being eaten. If it's removed, this necessitates firing up of the baby tillers to reshoot, which are rarely as large or capable of yielding as high, but are capable of a salvage situation.

Some herbicides can only be applied during the stem elongation stage and some must be stopped being applied once the crop reaches first node.

The second to third node stages are critical when considering timing of fungicides. At the second node stage, the flag -2 leaf is fully out but flag -1 and the flag leaf are still inside and get no coverage, in fact, the flag leaf is only a few millimetres long. At the three-node stage, flag -1 is fully unfurled and the flag leaf is still hidden and about one week out from unfurling.

Booting (Z41-49)

Once the flag leaf is fully emerged and until the first awns appear is called booting. The head is progressively pushed upwards by expanding internodes. The head increases in size and final floret number and spikelet height is being determined. Awn peep is the final application timing for a few herbicides. Severe frost at early booting can lead to complete head sterilisation in cereals. In barley, flowering occurs inside the boot before the head has emerged and frost damage at late booting can cause floral abortion.

Ear emergence (Z50-59) and flowering (Z60-69)

In wheat, about a week to ten days after awn peep, the ear will be fully out and start flowering. This is the critical time for flowering frost in wheat.

A wheat crop flowers in the middle third first, then the bottom third and then the top third. Frost at this stage can often take out different thirds of the head depending on its severity. The appearance of the anthers hanging outside the florets indicates that the crop has actually pollinated some days earlier.

Canola growth stages

Leaves

Counting canola leaves is one of the easier jobs in crop growth stages. When a leaf is fully unfurled to the sun, it is counted. The heart shaped cotyledon leaves that arise as the first things out of the seed are not true leaves. If the plant is cut/eaten off below the cotyledons, the plant can't regrow new leaves or shoots and dies. Normal spring varieties might produce 10 to 15 leaves before the start of stem elongation, while winter varieties might produce up to 30. At higher leaf numbers, some of the older leaves have been shaded, senesced, died and fallen off. Some herbicides are able to be applied up until the six true leaf stage. Like wheat, leaf emergence rates in canola are driven by accumulated temperature and a new leaf in a normal sowing time crop takes 80°days. This can be useful in estimating the time to herbicide application windows opening or closing.

Stem elongation

The stem will start elongating by pushing the flower buds up by expanding internodal joints. There will be a leaf at the start of each node. The flower bud will be hidden at the early stages and the leaves need to be pulled back to see it. Eventually the developing flower buds will be visible but surrounded by leaves and this is called the green bud stage. Some fungicides use this stage as a cut-off. Subsequent node expansions will push the flower head above and eventually the green buds will turn yellow, indicating they are close to flowering at the yellow bud stage.

Flowering

Canola is an indeterminate plant and will continue to flower if temperature and moisture conditions are suitable. This makes the start of flowering easy, with the first visible flower opened. Some herbicides cannot be applied after this stage. The end of flowering will be when no more open flowers remain on the plant. 'Flowering' can be a short or long process, depending on variety and season. Generally, the longer the plant flowers for, the more it might yield. Canola can branch from the leaf axils joining the stem but when assessing flowering stages, only the main stem is considered. Usually, the branches are behind in their development.

The number of open flowers on a plant can be an important determinant of fungicide timing. The following flowering stages are when 50% of the plants in the paddock are exhibiting the following flowering amounts: 10% bloom is when the plant has around 10 main stem flowers open; 20% bloom is when there are 14–16 main stem flowers open; 30% bloom is when around 20 main stem flowers are open; and 50% bloom is when greater than 20 main stem flowers are open. Some fungicides can't be applied past the 50% bloom stage.

Pulse growth stages

Leaves

Lupins (and navy, adzuki, mung, soy bean) start life differently to the other pulses, as they push their cotyledons above ground. Lupins are very vulnerable if the young plants are removed below the cotyledons as they can't regrow. Lupins, where the stem is removed above the cotyledons, can regrow from the cotyledons but always at a decreased yield potential. In the early growth stages, the number of fully emerged true leaves attached to stem petioles are counted to determine the growth stage. Only count a leaf if it's fully unfolded. Eventually, the main stem growing point reaches the reproductive stage and a green collection of flower buds sits at the top, called the big bud stage. Many herbicides have growth stage restrictions for application of two, four, six, and eight true leaves, and some finish at the big bud stage pre-flowering.

All other pulse crops (lentil, chickpea, pea, faba bean) send their first leaves up and leave the cotyledons in the ground. Leaves are attached to the stem and appear alternately on each side of a node. Only count a leaf if it's fully unfolded. The growing point of new nodes and leaves is constantly being pushed up by elongating nodes. Many herbicides have requirements for starting or stopping application at the two to eight leaf, branch or node stage. These pulse crops also have small leaf like growths called scale leaves above ground level and before the first node. These are not counted as leaves or nodes. One to two branches can form from these scale leaves and are a point of regrowth if the main shoot is removed. Branches can also form at the nodes.

Useful resources

Identifying cereal seedlings (https://agriculture.vic.gov.au/crops-and-horticulture/grains-pulses-and-cereals/crop-production/general-agronomy/identifying-cereal-seedlings)

Using the growth stages of cereal crops to time herbicide applications (https://www.weedsmart.org.au/app/uploads/2020/05/Timing-applications-cereals-1.pdf)

Fungicide management and timing - keeping crops greener for longer in the high rainfall zone (https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2014/08/fungicide-management-and-timing-keeping-crops-greener-for-longer-in-the-high-rainfall-zone)

GRDC GrowNotes™ Canola section 4 plant growth and physiology (https://grdc.com.au/resources-and-publications/grownotes/crop-agronomy/canola-west/GrowNote-Canola-West-4-Physiology.pdf)

A visual guide to key stages in the growth and maturity of field pea (https://www.agric.wa.gov.au/field-peas/visual-guide-key-stages-growth-and-maturity-field-pea)

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Notes

Emerging blackleg challenges this season

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Keywords

- blackleg, canola, seed treatment, stubble management.

Take home messages

- Normal blackleg in 2022 was not severe, this was because the season prior to spring was very conducive for excellent plant growth.
- Crown canker was low due to good blackleg resistant cultivars, highly effective SDHI fungicides and most crops being sown early prior to cold winter conditions.
- Crown canker was more severe where waterlogging occurred, this was due to root tissue death which was easily colonised by fungi.
- Upper Canopy Infection (UCI) was not severe as most crops flowered in a normal flowering window. The cool wet spring also meant that crops didn't mature under stress and therefore plants could tolerate partial blocked vascular tissue in their stems and branches. Fungicide application at the early bloom stage was also widely adopted and highly effective.
- Pod infection was in some circumstances very severe. Rainfall post-flowering caused both blackleg and Alternaria infection. Mature pods were colonised by saprophytic fungi.
- Disease on pods, wind, hail, and delayed harvest resulted in pod shatter which was probably the cause of most yield loss in 2022.
- Blackleg management in 2023 will not be changed from the wet conditions in 2022. That is, high levels of infection in 2022 will not change the disease risk in 2023.

Learnings from 2022

The year 2022 was, up until October, the perfect canola growing season in Victoria. An early break meant crops were established early in the growing season. Early sown crops grew quickly and became established prior to cold conditions in June.

Blackleg

Crops avoided early seedling infection as they were already past the 3-leaf growth stage at the onset of winter. (Blackleg is most severe between late May and mid August.) In addition, new cultivars generally have excellent blackleg resistance (blackleg ratings MR or above), most seed was treated with a highly effective SDHI seed treatment and/or flutriafol on the fertiliser. The result was seedling blackleg infection in 2022 was generally low. However, where waterlogging occurred, crown canker was much more severe. Waterlogging causes root tissue death which is easily colonised by blackleg.

Downy mildew

Downy mildew is most severe when it kills the cotyledons and 1^{st} true leaves, robbing your crop of vital seedling vigour, crops can be set back and then are more reliant on the spring growing conditions. In 2022, similar to blackleg, crops were established prior to conditions being conducive for downy mildew, therefore although downy was commonly present, it was not generally severe and unlikely to cause yield losses.

White leaf spot

White leaf spot is a very common disease, it causes loss of leaf photosynthetic area. In 2022, in cooler areas and with higher winter rainfall, it did cause leaf area reduction. Miravis® Star is registered for WLS control and was probably warranted in some southern Victoria crops.

Spring 2022 was obviously an extreme event – given the very high rainfall, it could be assumed that crops would be severely infected with Upper Canopy Infection (UCI) blackleg. However, July, which is the key infection month for early flowering crops, was not overly wet. In addition, data from CSIRO shows that UCI is expressed when crops mature under warm dry conditions. UCI causes partial blockage of the vascular tissue in the stem and branches, therefore if late spring conditions are cool and moist resulting in low stress on plants, then UCI is typically less expressed and causes less yield loss. By 2022, most growers had previous experience with UCI and therefore applied fungicides given the very favourable canola outlook at the time. The result of cool moist spring and fungicide protection meant UCI was not a big issue in 2022.

Pod stage, late spring is when the season turned pear-shaped. A lot of rain fell on crops post-flowering and this resulted in pod infection. Pods were infected with blackleg, Alternaria and other saprophytic fungi. Blackleg and Alternaria were expected and caused substantial yield loss to many crops. Yield loss is a result of infection of the seed (causing the seed to die and shrivel) and premature pod shattering. This was exacerbated as many (most) crops could not be windrowed and harvested at ideal timing as machinery could not get onto the paddock. In 2022, we also observed pods maturing (50% seed colour change), but the plants supporting the pods were still completely green. Some plants even had mature pods but were still producing new leaves. Wind and hail then arrived at the party.

In 2022, pods were also impacted by unusual symptoms (Figure 1). As stated previously, mature pods remained on unharvested plants in some circumstances for a considerable time period. Due to constant rainfall, these mature pods were infected with opportunistic saprophytic fungi, causing discolouration on the pods. This was exacerbated in crops where plants had prematurely died due to waterlogging. Many dead plants were a very grey colour as they were colonised by saprophytic fungi. When harvest then did occur, high levels of mould were reported on seed. Kurt Lindbeck (NSW DPI) grew cultures from many infected seed lots, and interestingly, all cultures were either the blackleg fungus or *Alternaria* species. The saprophytic fungi were only present on the pod and did not penetrate onto the seed. The other issue in 2022 was how blackleg infected the pods – it caused normal lesions but also caused pods to turn white, starting at the peduncle and working towards the tip. Pycnidial fruiting bodies then occurred across the entire pod, rather than within a round lesion as normally occurs.

			
Disease and shattered waterlogged plants	Waterlogged crown infection	Entire pod blackleg infection	Pods being colonised by various fungi as they mature

Figure 1. Various disease symptoms on canola in the 2022 season.

Management decisions for 2023

Canola intensity continues to increase. Canola intensity is a driving factor for blackleg due to this disease being stubble borne. Therefore, understanding your risk of blackleg is essential and is driven by the following factors:

- region – high canola intensity and high rainfall = high risk. One in 4-year rotations and 500m isolation between this year's crop and last year's stubble reduces risk. Monitor crops for both UCI and crown canker so that you know if you need to retain or change practices
- distance to canola stubble – crops sown adjacent to one-year-old stubble will have the highest amount of disease, so maintain a 500m buffer if possible
- cultivar resistance – cultivars rated R–MR or above have very low risk of developing crown cankers. MR will develop cankers but only if grown under high disease severity, for example canola/wheat/canola in high rainfall. See www.grdc.com.au/resources-and-publications/all-publications/publications/2020/blackleg-management-guide
- pathogen population – if you've grown the same cultivar for a number of years and disease severity is increasing, and you sow a cultivar from the same resistance group, then you will be at a higher risk of crown cankers
- seasonal risk based on sowing/germination timing – are you managing for crown canker or UCI? See later sections for additional information and Figure 2.

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

In recent times, new fungicide actives and new timing recommendations have resulted in large yield responses. Many agronomists have reported 20% returns, but many others have also reported no yield returns. In our trials, we've achieved up to 49% return but also zero. So how do you know where your crop will sit in 2022?

Obviously, predicting a yield return will be very accurate if you know exactly how much disease will occur, but unfortunately, the level of crop damage caused by disease is determined by a number of interconnected factors and to complicate it even further, other diseases such as Sclerotinia, white leaf spot, powdery mildew and Alternaria, can also influence economic returns.

The key is to identify the risk for an individual crop and then determine the cost of application compared to the cost of potential yield loss. In most years, this is relatively easy, for example, low rainfall year is low risk, whereas with a high rainfall year and high yield potential, it is very easy to gain an economic advantage from fungicide application. But it is the decile 4 to 7 years where there is lots to be gained or lost from fungicide decisions.

Blackleg crown canker

Do I need to protect seedlings

Risk factors

- Canola growing region – high canola intensity and high rainfall = high risk. One in 4-year rotations and 500m isolation between this year's crop and last year's stubble reduces risk.
- Cultivar resistance – cultivars rated R-MR or above have very low risk of developing crown cankers. MR will develop cankers but only if grown under high disease severity, for example canola/wheat/canola in high rainfall.
- Pathogen population – if you've grown the same cultivar for a number of years and disease severity is increasing, and you sow a cultivar from the same resistance group, then you will be at a higher risk of crown cankers.
- Crop germination timing – severe crown canker is most likely to develop when plants are infected during the early seedling stage (cotyledon to 4th leaf). The driving factor for seedling infection is the length of time that the plant is exposed to blackleg infection while in the seedling stage (Figure 2). Therefore, the risk of seedling infection, which leads to crown cankers, is very variable from season to season. For infection to occur, blackleg fruiting bodies on the canola stubble must be ripe and ready to release spores. Fruiting bodies typically become ripe approximately three weeks after the break of the season, when the stubble has stayed consistently moist. Spores are then released with each rainfall event. Temperature also has a large influence, as it will determine the length of time that the plant remains in the vulnerable seedling stage. Once plants progress to the 4th leaf stage, they are much less vulnerable to crown canker.

- Older plants will still get leaf lesions, but the pathogen is less likely to cause damaging crown cankers as the fungus cannot grow fast enough to get into the crown. Typically, plants sown early in the growing season (April) will develop quickly under warmer conditions and progress rapidly past the vulnerable seedling stage, whereas plants sown later (mid-May) will progress slowly and remain in the vulnerable seedling stage for an extended period.

Blackleg upper canopy infection fungicide application

Blackleg upper canopy infection (UCI) refers to infection of the upper stem, branches and flowers and, whilst we are constantly improving our understanding regarding these new symptoms, there is still a very large knowledge gap of how individual cultivars react to UCI. Furthermore, our research shows that similar symptoms of UCI can cause very severe economic impact in one season and have no economic impact in another. As such, our recommendations for managing blackleg UCI are constantly evolving. However, we now know that early sowing, which leads to early flowering, is a major trigger for UCI (Figure 2).

What are the steps to determine a UCI spray decision

- Leaf lesions – presence of leaf lesions indicates that blackleg is present and that your cultivar does not have effective major gene resistance. No leaf lesions = no reason to spray. However, if you have applied a seedling foliar fungicide, lack of lesions may be due to the fungicide and your crops may still become susceptible to UCI at the early bloom stage.
- New leaf lesions on upper leaves as the plants are elongating – this observation is not critical but does give an indication that blackleg is active as the crop is coming into the susceptible window. However, a number of wet days at early flower will still mean high risk even if there were no lesions on new leaves up to that point. Remember, it will take at least 14 days after rainfall to observe the lesions. More lesions = higher blackleg severity.
- Date of 1st flower and targeted date of harvest – the earlier in the season flowering occurs, the higher the risk. This date will vary for different regions. Generally, shorter season regions can more safely commence flowering at an earlier date compared to longer season regions. Earlier harvest date results in less time for the fungus to invade the vascular tissue and cause yield loss. Consequently, if you're in a long growing season rainfall region, your crop flowers in early August and is harvested in December, you are in a very high risk situation.
- Genetic resistance – this is a knowledge gap for many growers, if your crops are susceptible, it is much more likely to gain a yield response to a fungicide. At present, no cultivars have a UCI blackleg rating. In 2022, the GRDC investment screened all commercial cultivars for UCI resistance. It is hoped that a UCI blackleg rating system can be developed in conjunction with seed companies.
- Yield potential – yield potential is simply an economic driver. A 1% return on a 3t/ha crop is worth more money than a 1% return on a 1t/ha crop.

How can I determine if I should have sprayed for UCI

- Check for external lesions.
- Cut branches and stems to check for blackened pith, which is indicative of vascular damage and likely yield loss.
- Observe darkened branches, these branches go dark after vascular damage and are indicative of yield loss.
- Pod infection will cause yield loss, unfortunately there is nothing that can be done to prevent pod infection.
- Leave unsprayed strips to check for yield returns.

Acknowledgements

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

Useful resources

BlacklegCM App for iPad and android tablets

Blackleg management guide (http://www.grdc.com.au/resources-and-publications/all-publications/publications/2020/blackleg-management-guide)

Marcroft Grains Pathology (https://marcroftgrainspathology.com)

Australian Fungicide Extension Network (https://afren.com.au/)

NVT Australia (https://www.nvt.com.au)

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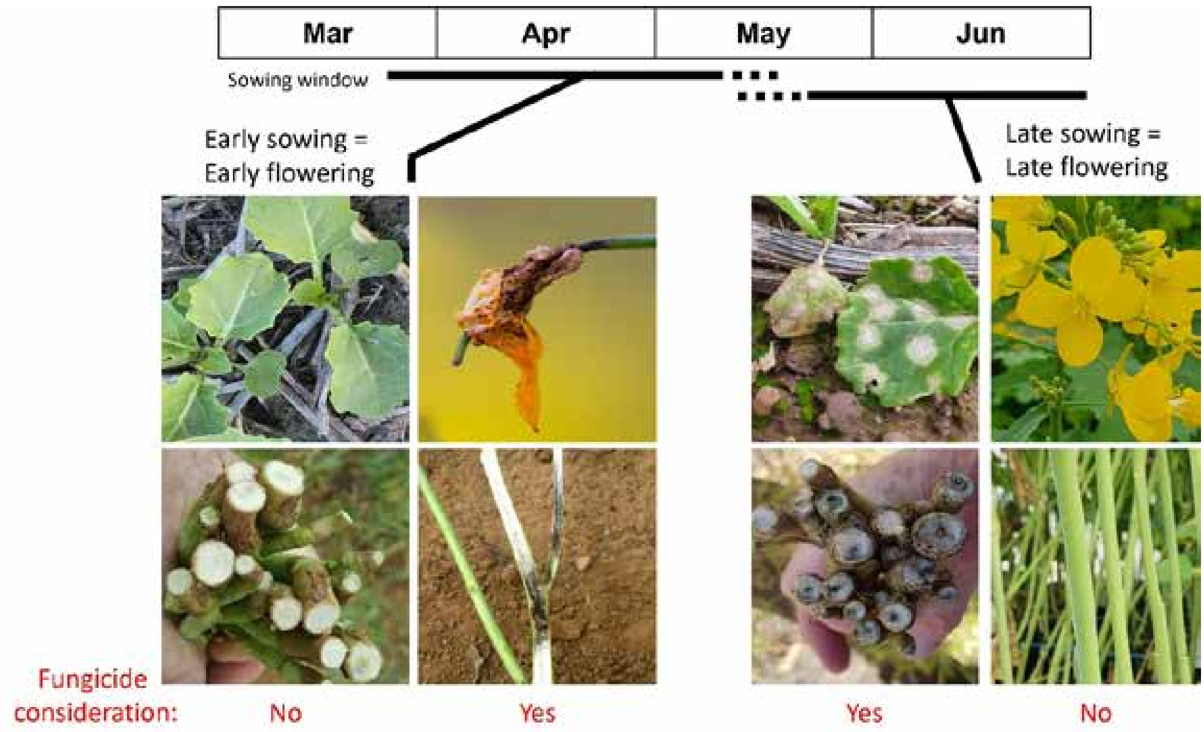

Figure 2. Sowing time, and therefore flowering time, determines whether you will be needing to control crown canker blackleg or upper canopy infection blackleg.

Notes

Managing sclerotinia stem rot of canola in 2023

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GRDC code

DPI2206-023RTX - Managing sclerotinia in oilseed and pulse crops in Northern and Southern farming systems

Key words

- sclerotinia stem rot, canola, foliar fungicides

Take home messages

- Outbreaks of sclerotinia stem rot are sporadic and dependent on the growing season conditions. Saturated canopy conditions for more than 48 hours during flowering favour the development of the disease
- Outbreaks of sclerotinia stem rot were widespread in spring 2022 due to highly favourable conditions for the disease
- The frequency of canola or lupin in a paddock is very important in determining the risk of a sclerotinia outbreak, as these crops are very good hosts for the disease and can quickly build up levels of soil borne sclerotia
- Foliar fungicides for management of the disease are best applied at 20 – 30% bloom (15-20 flowers on the main stem) for main stem protection
- A bad Sclerotinia year will have a legacy effect for following broadleaf crops as the sclerotia can survive in soil for many years.

Where did Sclerotinia stem rot develop in 2022

The extraordinary rainfall conditions across southern NSW and Victoria in spring 2022 favoured the development of sclerotinia stem rot for an extended period. Ordinarily the conditions that favour development of the disease tend to cease in the second half of September as the air becomes warmer and drier. In 2022, wet conditions and saturated crop canopies continued well into November extending the disease pressure across many regions. The pre-emptive use of foliar fungicides by producers had the significant effect of reducing disease levels in commercial crops. The widespread wet conditions across the region resulted in sclerotinia stem rot developing in districts where the disease isn't normally seen, and epidemics of the disease were able to develop from very low background pathogen levels.

How does the disease develop?

Sclerotinia stem rot is a complex disease with sporadic outbreaks due to the synchronisation and completion of various key development stages necessary for plant infection to occur. The pathogen responsible for this disease requires favourable weather conditions at every stage in its disease cycle. The stages of development include:

1. Softening and germination of soil borne sclerotia
2. Apothecia development and release of ascospores
3. Infection of petals by air-borne ascospores
4. Senescence of infected petals in the presence of moisture and subsequent stem infection.

Weather conditions during flowering play a major role in determining the development of the disease. The presence of moisture during flowering and petal fall will determine if sclerotinia stem rot develops. Dry conditions during this time can prevent development of the disease, hence even if flower petals are infected, dry conditions during petal fall will prevent stem infection development.

What are the factors that drive the development of sclerotinia stem rot?

- **Frequency of sclerotinia outbreaks.** The past frequency of sclerotinia stem rot outbreaks in the district can be used as a guide to the likelihood of sclerotinia developing this season. Paddocks with a recent history (last 5 years) of sclerotinia outbreaks are an indicator of potential risk, as well as those paddocks that are adjacent. The frequency of canola and lupin in the paddock can also increase disease risk. Canola and lupin are very effective hosts for the disease and can quickly build up levels of soil-borne sclerotia.
- **Commencement of flowering.** The timing of commencement of flowering can determine the severity of a sclerotinia outbreak. Spore release, petal infection and stem infection have a better chance of occurring when conditions are wet for extended periods, especially for more than 48 hours. **Canola crops which flower earlier in winter (late June - July) are more prone to disease development and exposure to multiple infection events.**
- **Spring rainfall**. Epidemics of sclerotinia stem rot occur in districts with reliable late winter and spring rainfall with long flowering periods for canola. These provide long periods of canopy wetness necessary for the disease to develop, at least 48 hours or more. Overnight dews generally won't trigger epidemics of the disease.

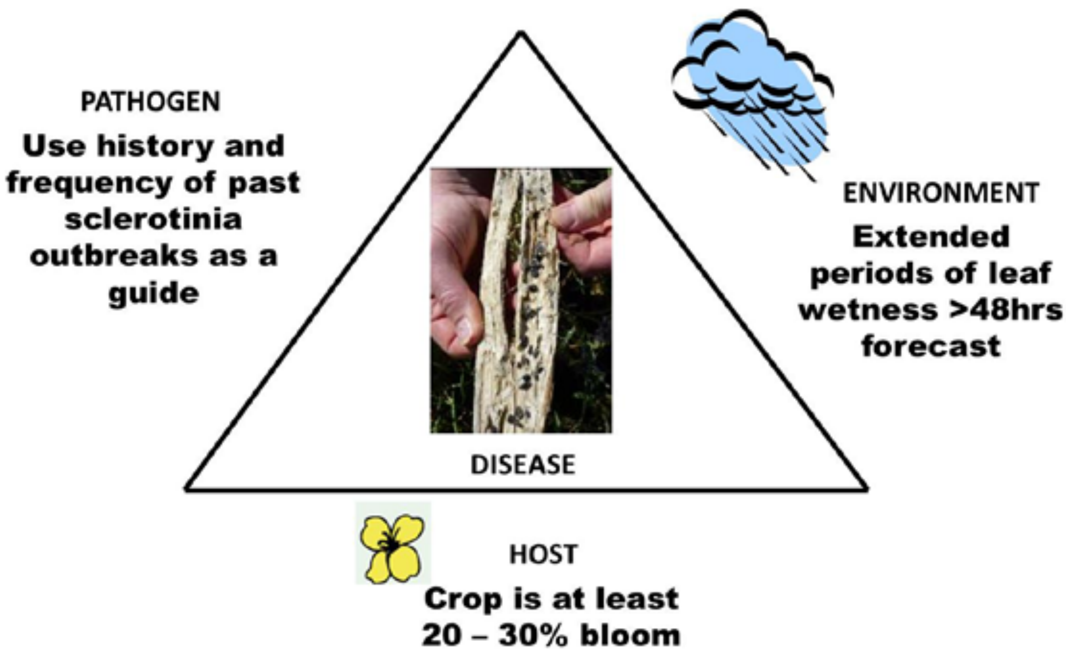

Figure 1. Factors that drive the development of sclerotinia stem rot

Pre-sowing sclerotinia management

Crop rotation

- Grow canola only once in every 4 to 5 years to reduce build-up of sclerotia
- Incorporate lower-risk crops into the crop rotation e.g., cereals, field pea and faba bean
- Separate last year's canola stubble and new seasons' crops by at least 500m
- Ascospores of Sclerotinia spread within 100m to 400m of the apothecia.

Clean seed

- Always use seed free of sclerotia where possible
- Grade retained seed for sowing to remove sclerotia if in doubt
- Grain receival standards allow a maximum of 0.5 per cent sclerotes in the sample.

Variety selection

- There are no Australian canola varieties with known resistance to sclerotinia. Some differences may be observed in the level of stem rot in some seasons. This is likely to be related to the variety maturity, and timing of flowering with infection events.

Crop management

- Always follow the recommended sowing time and seeding rate for your region
- Early maturing varieties sown early can be prone to developing stem infection due to the earlier commencement of flowering when conditions are wet for prolonged periods
- Once flowering starts the crop becomes susceptible to infection and prolonged exposure to infested senescent petals means greater chance of stem infection
- Bulky crop canopies can retain more moisture and are conducive for the development of stem infections
- Wider row spacing or reduced seeding rates can increase air-flow through the canopy, reducing moisture retention and potential for infection.

Burning

- Burning stubble and windrows will kill some sclerotia, but will not significantly reduce the risk of disease

Use SclerotiniaCM app (see useful resources) to determine the most appropriate management strategies for your district.

Post-sowing sclerotinia management – fungicide application

- Use foliar fungicides to prevent early stem infection via infested petals
- Always use fungicide products that are currently registered in your state
- Timing of foliar fungicide application is more important than choice of fungicide product in reducing potential levels of stem infection
- Foliar fungicide application is most effective before an infection event
- Application of fungicide at 20-30% bloom is essential to reduce main stem infection and the majority of yield loss. Application at this stage protects early petals from infection and enables the fungicide to penetrate the canopy and protect potential infection sites where petals fall
- Multiple foliar fungicide applications may be needed in high disease-risk districts with high yield potential. Applications at both 10-20% and 50% bloom provide critical early and follow up protection from multiple infection events. Fungicide applications made during full bloom have limited penetration into the crop canopy and will not protect main stems from infection
- Use high water rates (at least 100 litres per hectare) to achieve adequate coverage and penetration into the crop canopy
- Foliar fungicides generally have an active life of two to three weeks. The protection provided may wear off during the critical infection period or where crops have an extended flowering period. A single fungicide application early may not be effective at preventing later infections
- Foliar fungicides have no effect on managing basal infections, as this occurs below the soil surface and beyond the activity of foliar fungicides. Foliar fungicides do not travel down the vascular tissue in plants.

ALWAYS

- Determine disease risk as your crop enters the flowering period
- Assess bloom stage, seasonal conditions and weather forecasts to identify the potential risk periods to your crop
- Identify how many consecutive wet days are forecast as the crop commences flowering and the week ahead, especially consecutive wet days of 48 hours or more

- Monitor crops for disease development and identify the types of infection. Basal and main stem infections cause the most yield loss.

Useful resources

- NSW DPI winter crop variety sowing guide (disease updates, fungicide products). https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide
- SclerotiniaCM App for iPad and android tablets

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Final session
Day 1

The impact of soil water on soil constraints and crop growth

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Keywords

- physiochemical, subsoil amelioration, summer recharge.

Take home messages

- The amount and distribution of rainfall will alter the impact of subsoil constraints on different crop species.
- Wheat yield is likely to be reduced where stored subsoil water is coupled with a dry start to the growing season rainfall where subsoil constraints are present.
- Lentil will unlikely be affected if the subsoil constraints are below 60cm.
- Canola was unaffected by subsoil constraints but was affected by soil water distribution.

Background

The Wimmera produces a range of grain crops including wheat, barley, oat, canola and pulse species, including, faba bean, field pea, chickpea and lentil. Although classified as a semi-arid environment, the amount and pattern of rainfall can vary markedly (Agriculture Victoria 2019; Bureau of Meteorology). Seasonal rainfall variability affects the water limited yield potential of crops and this is exacerbated by the shorter flowering windows of modern cultivars, meaning crop productivity can be more severely impacted if rainfall/soil water is limiting around flowering and during grain filling (Armstrong et al. 2015; Rodriguez and Sadras 2007). The Wimmera is also home to large areas of Sodosols (Isbell and National Committee on Soil and Terrain 2021) which, with their strong texture contrasts and dispersive, high clay content subsoils, result in both chemical and physical constraints to water holding capacity, crop root growth and subsequent productivity (Armstrong et al. 2015; Bronick and Lal 2005) Crop tolerance to soil constraints varies and is in part due to the variation in root architecture between species and cultivars (tap-rooted, that is, ***Brassica napus,*** canola or ***Lens culinaris***, lentil; or fibrous, that is, ***Triticum aestivum***, wheat) and their differing potential rooting depth (Armstrong et al. 2009; Kirkegaard et al. 2007). Studies have investigated individual chemical constraints and rainfall distribution on root growth in isolation (Kirkegaard et al. 2007; Lilley and Kirkegaard 2007) however there are multiple factors that make up a constrained soil. This experiment investigated how seasonal rainfall distribution affects the impact of subsoil constraints on root distribution and grain yield of different crop species.

Methods

An artificial sodic subsoil was created using a mixed salt (calcium sulphate, sodium chloride, potassium chloride and magnesium sulphate) (EC_e 9.38) and boron (24.6mg/kg) solution applied to a soil with no chemical or physical constraints (benign clay/sand mix), which was packed into large PVC columns (1100mm x 150mm) to a bulk density of 1.1g/cm^3. Four different seasonal rainfall scenarios were imposed (adapted from Dunbabin et al. 2009including: nutrient mobility, soil type and soil physicochemical and biological factors, season (including rainfall amount and distribution); dry start/dry finish, dry start/wet finish, wet start/dry finish and a wet start/wet finish. Wet and dry soil depths were wet up to 95% and 50% of PAW, respectively either in the top or bottom 50cm of soil in the columns (Figure 1) and initial soil water contents maintained weekly by weighing columns and replacing water lost to evapotranspiration. Soil volumetric water throughout the soil profile (0–110cm) was measured weekly using a PR2 profile probe reader (capacitance) and HH2 moisture meter. Columns were sown to wheat (cv. LRPB Trojan⚅), lentil (cv. PBA Greenfield⚅) and canola (cv. OP – ATR-Wahoo⚅) at three plants per core and grown in a naturally lit controlled temperature glasshouse at Grains Innovation Park, Horsham for 17–22 weeks, depending on crop type and water treatment. Plants were grown to maturity and biomass and yield components measured. Soil samples were taken after harvest to assess the chemically imposed constraints and gravimetric water content. Roots were extracted from each depth of the soil profile by washing over a 5-mm sieve before root length, diameter, and biomass assessment.

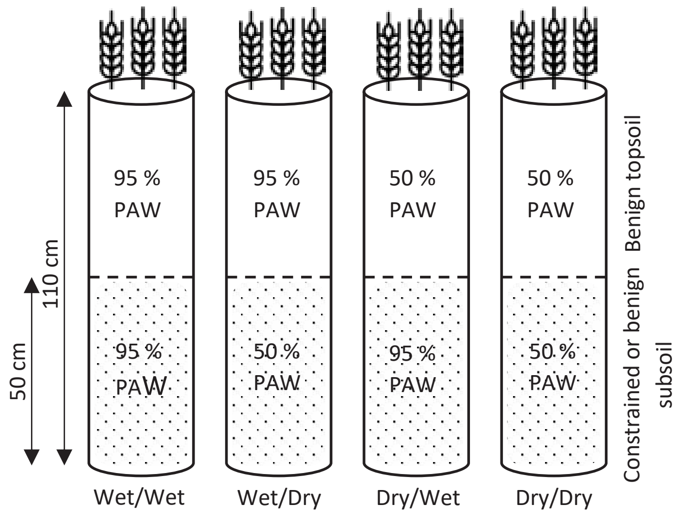

Figure 1. PVC columns (1100mm H x 150mm W) filled with a benign clay/sand soil mix. Columns were either treated or untreated with a salt and boron solution in the bottom 50cm of the core (patterned region). Four seasonal rainfall events were simulated by pre-wetting different layers of the soil to 95% or 50% of the soil's plant available water capacity (PAW) and maintained by weekly weighing. Wet/dry and dry/wet water treatments were achieved by recalculating the PAW to represent 50% and 90% PAW for a dry or wet finish at GS50 (pre-ear emergence).

Results and discussion

In this study, we imposed a chemically constrained subsoil using a mixed salt and boron solution, but it is unlikely that soil physical constraints were limiting. We found no significant effect of subsoil chemical constraints on crop yield, except for wheat. The relative effect of soil constraints was greater for wheat compared to lentil and canola, particularly where subsoil water was present (Figure 2b). The decrease in grain yield under a dry/wet scenario can be attributed to a decrease in grain number (Figure 2c). Preliminary root distribution data (not shown) indicate the dry/wet scenario caused wheat roots to grow deeper to access subsoil water, encountering subsoil constraints which impacted grain set either through the osmotic effect, high exchangeable salts or high available boron (Adcock et al. 2007; Nuttall et al. 2003). Overall, the seasonal rainfall scenario that experienced a dry finish (wet/dry) exhibited the greatest overall impact on yield across all three crops (Figure 2b, f, j). The simulated seasonal rainfall scenarios, dry/wet and wet/wet, saw significant increases in shoot biomass of wheat, lentil, and canola above a dry season (dry/dry) and wet start, dry finish (wet/dry), indicating subsoil water is important in the production of biomass (Figure 2a, e, i). The increase in biomass with subsoil water translated to increased grain yield in all crop types.

Canola was not significantly affected by the type and magnitude of subsoil constraint present in this experiment and was most responsive to water availability and location, seemingly able to overcome constraints as long as there was sufficient soil water available (Figure 2i, j, k, l). Similarly, lentil was not significantly impacted by subsoil constraints but exhibited higher biomass, grain yield and grain number where subsoil water was present (dry/wet and wet/wet simulated rainfall scenarios, Figure 2e, f, g).

Plant available soil water remaining at harvest may have indicated an effect of subsoil constraints on lentil roots between 60cm and 80cm soil depth, as seen by less stored subsoil water (60cm and below) in a benign subsoil under dry/wet conditions (Figure 3b). However, the level of stored soil water below 70cm was similar to that recorded in the constrained wet/wet and dry/wet and benign wet/wet soil conditions. We can therefore theorise that the potential maximum rooting depth of lentil roots is limited to 60–70 cm, so are unaffected by any soil constraints below those depths.

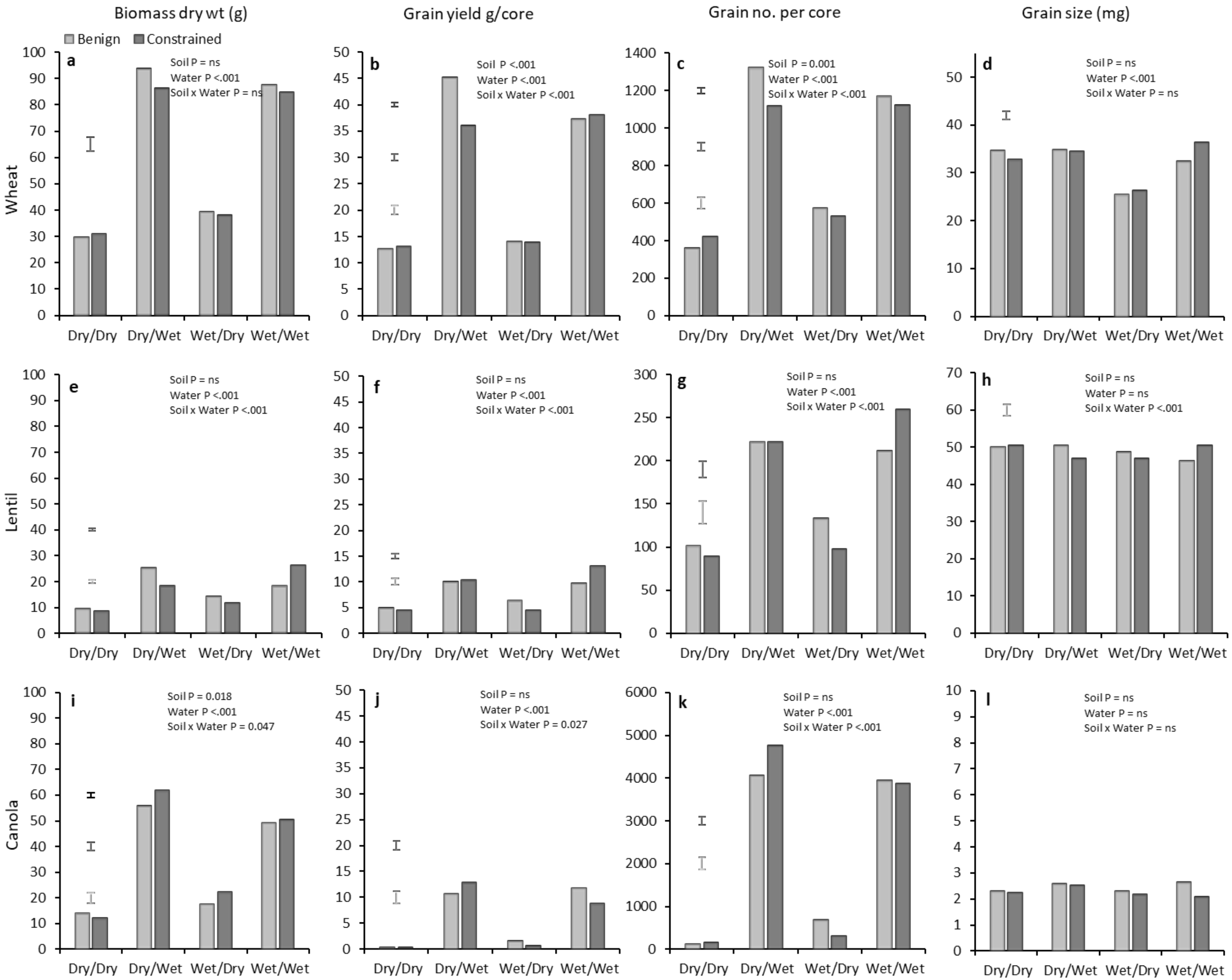

Figure 2. Biomass dry weight (g/core), grain yield/core, grain number/core, grain size (mg) of wheat (a, b, c, d), lentil (e, f, g, h) and canola (i, j, k, l), respectively. Lsd bars (5%) (top to bottom) black vertical bar = soil treatment, mid grey vertical bar = water treatment, light grey vertical bar = soil/water interaction. If ns, vertical bar not presented.

These findings are in line with a field study conducted by Armstrong et al. (2009) that also examined/quantified rooting depth of lentil under various subsoil constraints. Greater stored soil water below 80cm in a constrained wet/wet and dry/wet scenario compared to equivalent benign soils, indicated wheat and canola roots were unable to utilise subsoil water.

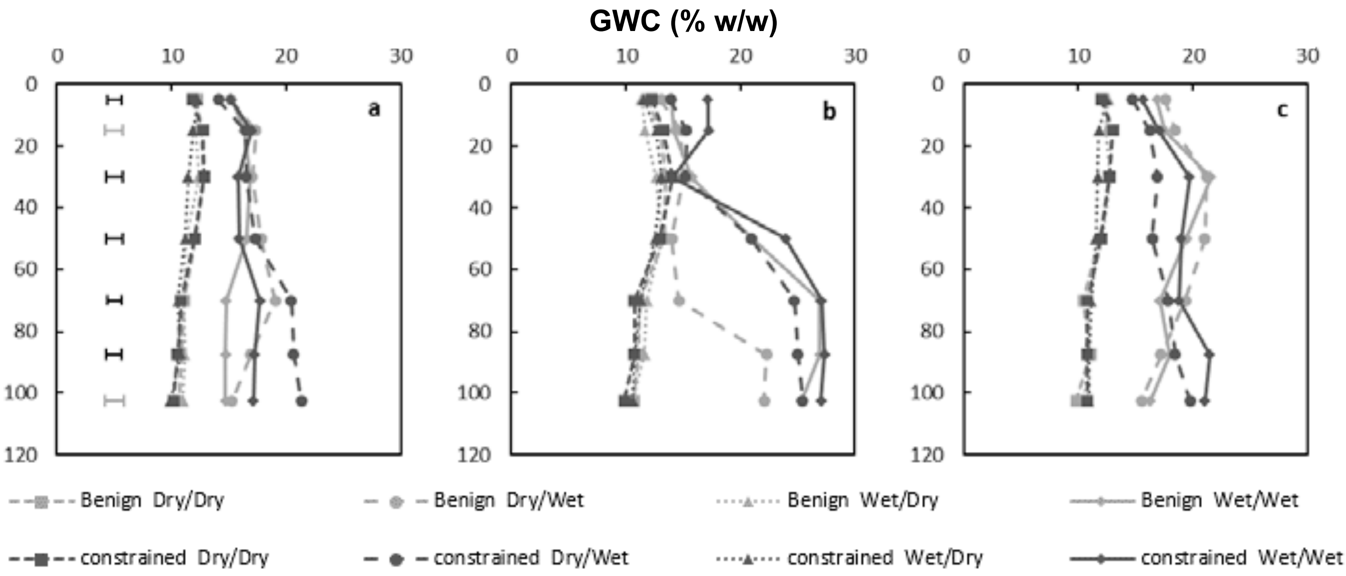

Figure 3. Gravametric water content (GWC % w/w) measured at harvest, of seven depths (0–10cm, 10–20cm, 20–40cm, 40–60cm, 60–80cm, 80–95cm, 95–110cm) of wheat (a), lentil (b) and canola (c). Black Lsd = 5% three-way interactions, grey Lsd = 5% two-way interactions only.

Conclusion

Different seasonal rainfall scenarios affect the impact of subsoil constraints on crop production and different species are affected to varying degrees. Where subsoil water is present from summer/autumn fallow rainfall, subsoil constraints will have a greater impact on crop production, however the degree of impact varies with crop type and severity will be less where adequate soil water is available during early growth stages. Soil tests are needed to determine the depth where the constraint becomes substantial, and in medium to high rainfall zones, it is recommended to select more tolerant crop species and cultivars accordingly.

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Notes

Genotypic variability in architectural development of *Pisum sativum* root systems and its relationship with topsoil foraging

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Keywords

- field pea, root system architecture, rooting depth, topsoil moisture.

Take home messages

- Rainfed cropping systems within low and medium rainfall environments of south-eastern Australia are primarily constrained by low and unreliable water availability.
- Selection of root system architectures (RSA) that are better adapted to these agroecosystems may be able to utilise soil moisture in topsoils by legume crops, such as the field pea.
- 154 field pea genotypes were screened to identify root phenes responsible for topsoil foraging.
- Tap root exit points during the seedling stage influenced the distribution of root length density at maturity.
- Genotypes which had fewer tap root exit points had a greater proportion of their total root mass in the upper 0–60cm.
- Selected genotypes K3419, CGN3105, Improved Harbinger, WT107, laVioletta and CGN3332 displayed contrasting soil foraging strategies.
- The diversity present within tap root exit points suggests the potential opportunity to pyramid with other phenes to create synergistic interactions and so, markedly improve topsoil nutrient acquisition in existing field pea cultivars.

Background

Cultivation of field peas within south-eastern Australia predominately occurs in the northern Wimmera and Mallee, which is categorised as medium-low rainfall zones. Akin to Mediterranean type environments, annual rainfall within these agroecosystems is typically below 400mm, with the majority occurring during the growing season. The dominant soil types in this region have either uniform clay throughout the profile (vertosols) or clay subsoils (sodosols and calcarosols). With the move towards continuous cropping and a lack of long fallows since the turn of the century, and the predominance of frequent but relatively small rainfall events of <5mm (Sadras and Rodriguez 2007), there is generally insufficient rainfall to fully recharge subsoils, particularly for clay soils, for example 191mm/m depth for a Murtoa vertosol, especially after accounting for evaporative losses and transpiration. Furthermore, the merit of accruing water at greater depths within these soil types is questionable, as water acquisition and root growth is restricted due to the widespread occurrence of subsoil physicochemical constraints, such as high boron and sodicity (Hobson et al. 2006; Nuttall et al. 2003). To date, most breeding programs internationally have focused on selecting for deep rooting (Li et al. 2019, Singh and Bell 2021, Wasson et al. 2012). However, roots are 'expensive' to grow in terms of plant assimilates, so the possession of deep rooting traits may result in a potential yield penalty in scenarios where there is no clear benefit in attempting to access subsoil resources (water and nutrients). As a result, the project aims to test the hypothesis that selection for germplasm, in this case field peas, that preferentially focus root architecture on the utilisation of soil water in topsoils rather than deep subsoils, may result in better adaptation (higher yields) in LRZ and MRZ environments with clay soils compared to germplasm with deep rooting architecture. This project focuses on the first component of this research which aims to identify field pea germplasm that has either 'shallow' or 'deep' rooting architecture that can be subsequently used in glasshouse and field trials to assess whether these differing root architectural traits confer any growth/yield advantage under differing soil water scenarios.

Method

Controlled environment seedling assay

A field pea seedling assay was conducted within a controlled environment to ensure there was sufficient genetic diversity available for root phenes of interest (Figure 1). A greater proportion of genotypes screened originated from the primary centre of diversity (that is, the Middle East) and important secondary centres (such as Ethiopia and Asiatic regions) because greater *Pisum* diversity resides in non-cultivar accessions (Figure 2). Other genotypes selected were based on recommendations after consultations with field pea breeders and Australian Grains Genebank (AGG) staff. One hundred and fifty field pea genotypes were screened using a cigar roll system (Watt et al. 2013)and are targets for crop improvement. Here we assess a controlled-environment wheat seedling screen to determine speed, repeatability and relatedness to performance of young and adult plants in the field.MethodsRecombinant inbred lines (RILs, whereby imbibed seeds were wrapped in brown germination paper and grown in cores measuring 15cm (diameter) × 43cm (height).

Root system characterisation at maturity

A polytunnel experiment using long PVC cores (10cm diameter × 150cm deep) was undertaken to characterise field pea root systems when grown to maturity (Figure 1). Forty promising field pea genotypes selected from the prior seedling assay were grown in long cores measuring 10cm (diameter) × 150cm (height). Linear regression modelling indicates there was an association between seedling root phene (taproot exit point) and final root expression at maturity (Figure 5). Genotypes with shallow and deeper soil foraging strategies were identified (Figures 4).

Rooting depth phene characterisation

Six field pea genotypes selected from the polytunnel experiment were grown in rhizoboxes for detailed phene classification (Figure 1). Selection was based on a ranking of the percentage of root length (RL%) within the 0–60cm depth; genotypes selected had contrasting RL % within the upper layers and possesed similar agronomic chracteristics (Figure 5). A single plant of each genotype was grown in a rhizobox chamber 59cm × 40cm × 4cm containing 13kg of air-dried Grey Vertosol for 30 days, when various root properties were assessed.

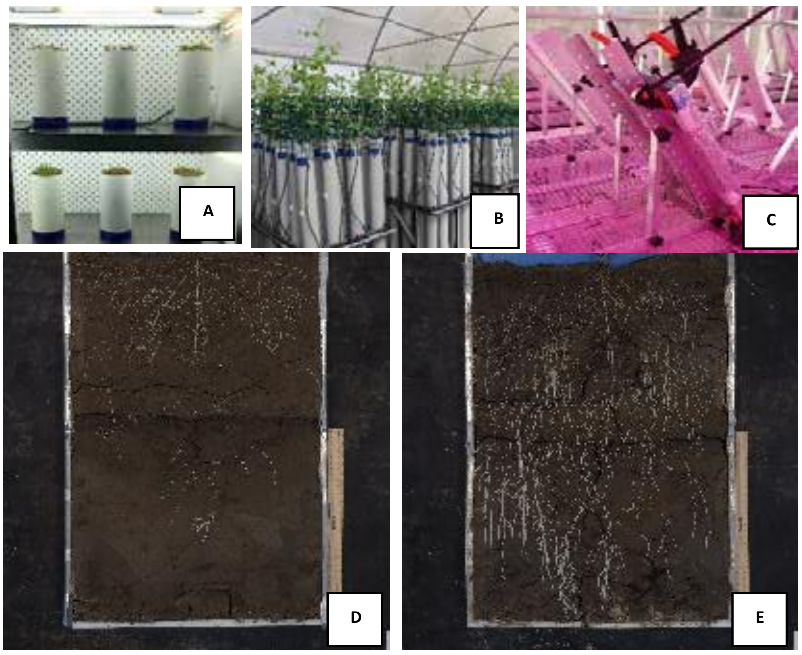

Figure 1. Controlled glasshouse experiments – a seedling assay screen (A), maturity characterisation experiment (B), rhizobox experiment (C), a deeper root system (D) and a shallow root system (E).

Results and discussion

A controlled seedling screen was utilised to investigate the genetic diversity of rooting depth. Analysis of variance suggested that there was a strong genetic diversity in seedling rooting depth which can be utilised in future breeding programs (Figure 2). The data indicated that Middle Eastern/ Mediterranean countries, for example Jordan and Israel, exhibited shallower rooting depth characteristics in comparison to more temperate environments, for example Germany and New Zealand. The potential advantage associated with a root system adapted for topsoil foraging also occurs in Western Australian (Mediterranean climate) native vegetation. In contrast, germplasm originating from Germany and New Zealand are adapted to agroecosystems where soil water is comparatively less limiting for crop production.

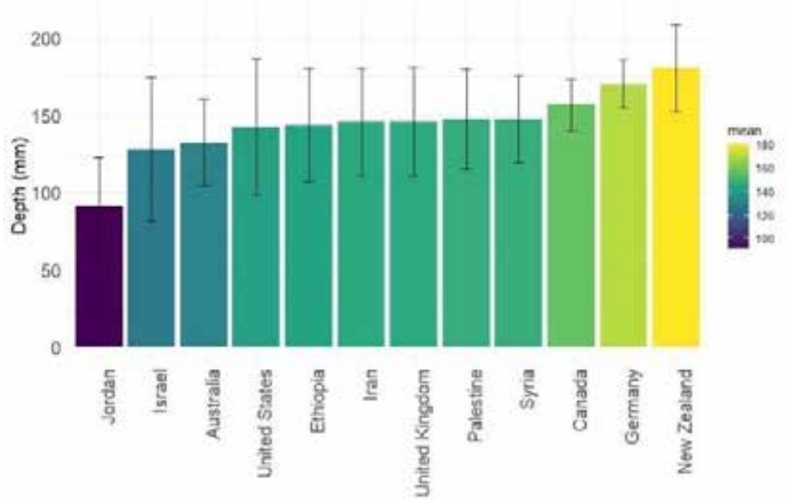

Figure 2. Rooting depth of field pea genotypes from various countries in a seedling assay at Agriculture Victoria's Grains Innovation Park 2021 ($P<0.05$).

Subsequent characterisation of the 40 promising field pea genotypes at maturity confirmed that there is substantial genetic diversity in root system architecture. Analysis of variance suggested that genotype had a significant influence on the expression of root length at depth 0–60 cm (RLD60) (Figure 3). Amongst the germplasm assessed, the genotypes CGN3332, laVioletta, WT107 and Improved Harbringer possessed significantly higher RLD60 values than K3419 and CGN3105 (Figure 3).

Whilst genotypes with a 'shallow root architecture' have been identified, we still are unsure of the various phenes (phene is to phenotype as gene is to genotype) (York et al. 2013)or traits, that interact. Phenes are the units of the plant phenotype, and phene states represent the variation in form and function a particular phene may take. Root phenes can be classified as affecting resource acquisition or utilization, influencing acquisition through exploration or exploitation, and in being metabolically influential or neutral. These classifications determine how one phene will interact with another phene, whether through foraging mechanisms or metabolic economics. Phenes that influence one another through foraging mechanisms are likely to operate within a phene module, a group of interacting phenes, that may be co-selected. Examples of root phene interactions discussed are: (1 controlling their overall root system architecture. Further investigation regarding the various phenes controlling shallower rooting for genotypes CGN3332, laVioletta, WT107 and Improved Harbinger must be identified for this trait to become selectable for breeders. Literature has indicated that an array of phenes, such as basal root angle, basal root number, basal root whorls, tap root diameter, lateral root orientation and more can all influence rooting depth. These genotypes may consequently possess only one or few of these necessary phenes. Developing a truly shallow rooted system that benefits industry would require a genotype that possessed all the necessary phenes. Literature has indicated that phene stacking can result in synergistic interactions that outperform the individual phenes. For example, the summation of wider basal root angles and thicker root hairs resulted in greater topsoil phosphate acquisition in comparison to the single phenes alone (Miguel et al. 2015). This suggests that synergistic interactions between root phenes that increase topsoil moisture acquisition is also possible.

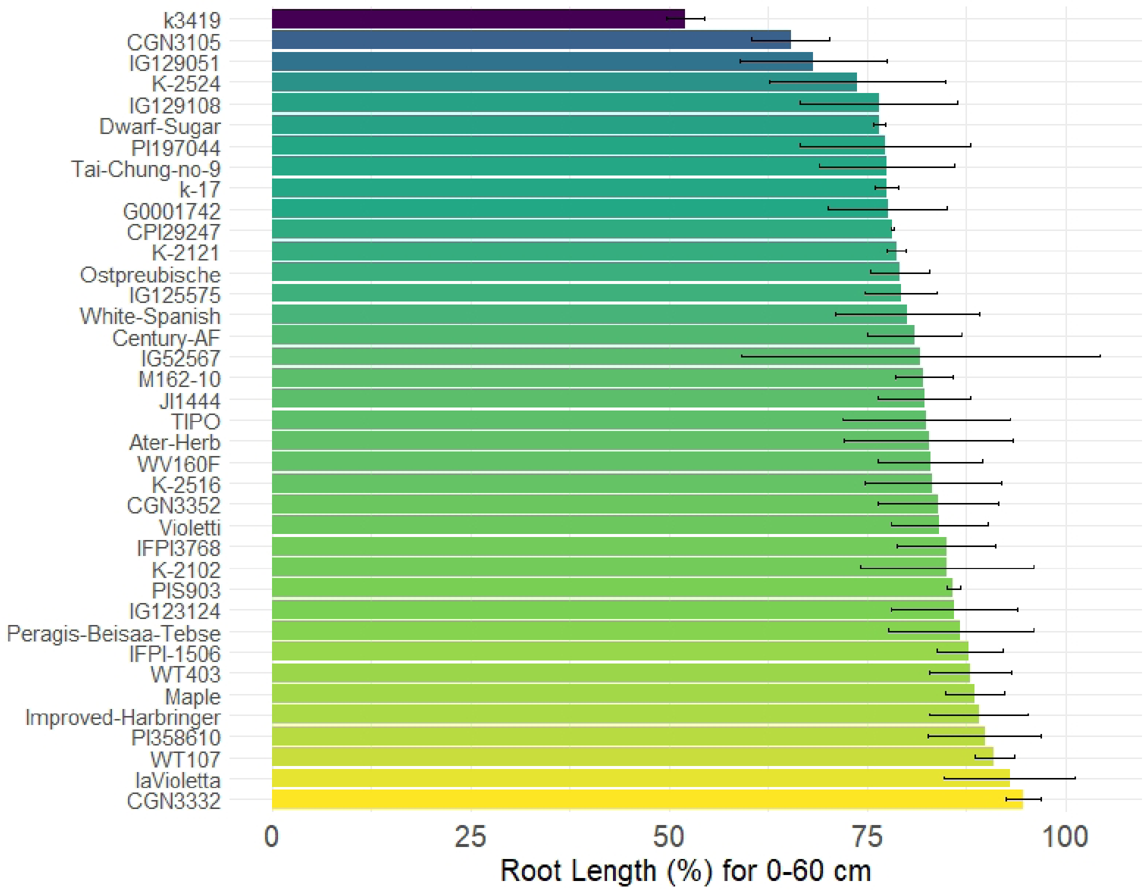

Figure 3. Percentage of root length captured between 0–60cm depth (RLD60) for field pea genotypes at Agriculture Victoria's Grains Innovation Park Agriculture 2021 (P<0.01).

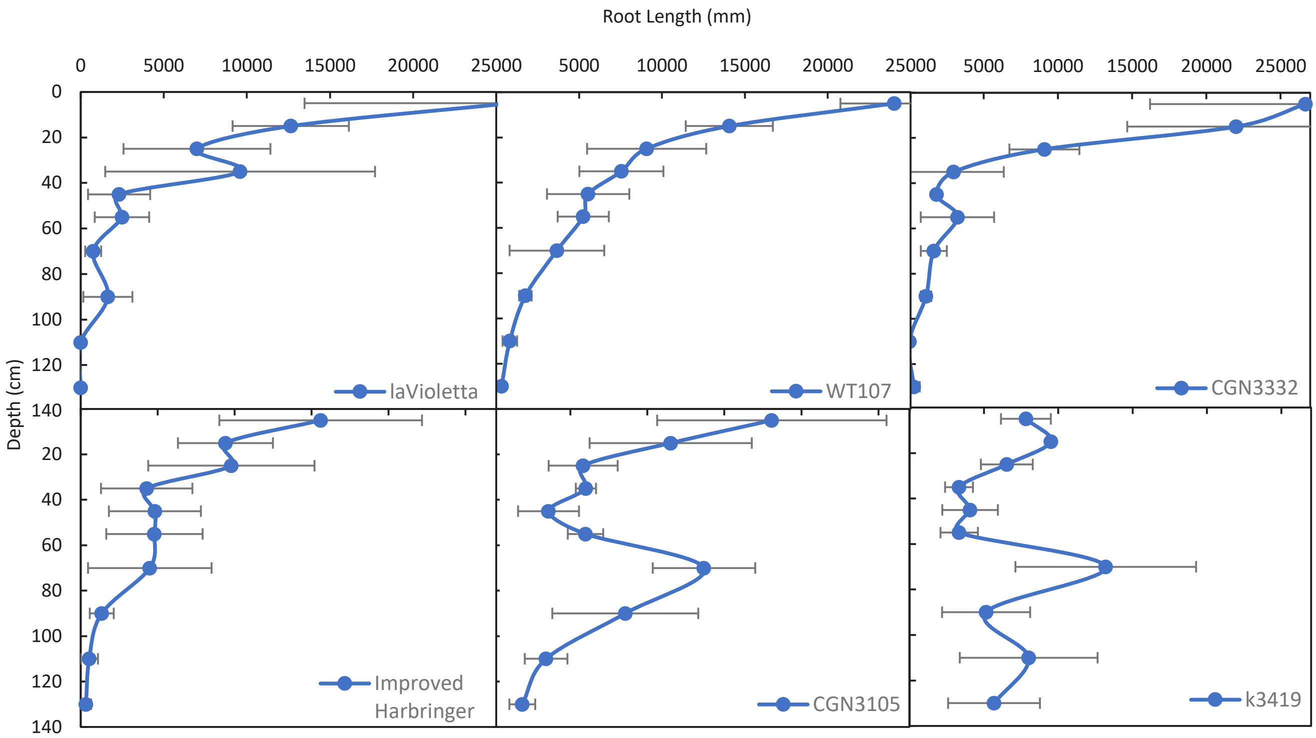

Figure 4. Root length (mm) of selected field pea germplasm from depths 0–140 (cm) grown at Agriculture Victoria's Grains Innovation Park Agriculture 2021.

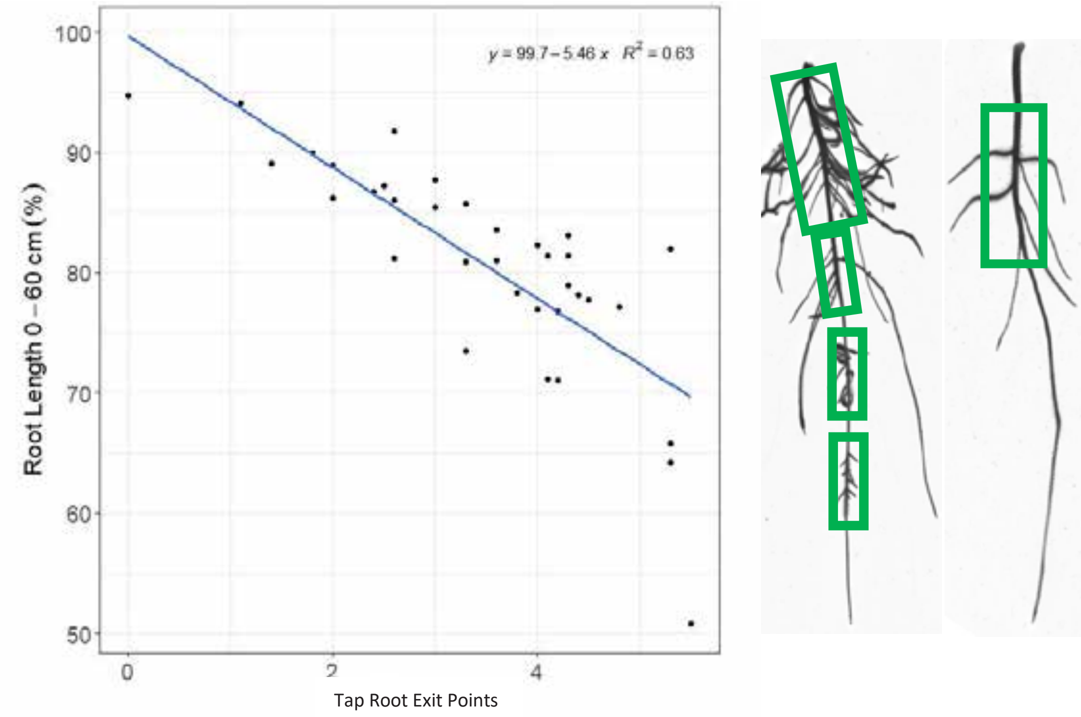

Figure 5. (Left) Comparison of seedling taproot exit points and root length proportion at 0–60 (cm) depth of Pisum sativum germplasm at maturity (P<0.01). (Right) Seedlings showing differing tap root exit points. Data sets from the controlled seedling screen and root system characterisation at maturity were correlated to identify seedling root phenes which influenced overall rooting depth at maturity. It was identified that lower tap root exit points significantly correlated with higher RLD60 values (P<0.01). Linear regression modelling revealed the association was moderate (R2=0.63) and negative. The identification of stable seedling root phenes that influence root system architecture at maturity could greatly reduce the time required to develop deeper or shallower rooted genotypes. Considering how resource intensive root studies are, the identification of stable root phenes that can be utilised in high throughput seedling assays could be the only way to improve root systems within a commercial setting.

Germplasm identified with contrasting soil foraging strategies will be further investigated to determine if certain roots phenes confer higher water acquisition efficiency in the topsoil. Experimentation will identify if there is an interaction between genotype and location of soil moisture on yield. Differences in yield attributed to variation in soil foraging strategy can elucidate which phenes breeders must select for under varying rainfall regimes.

Conclusion

Adjusting the rooting depth of pulses such as field pea can be achieved if the various constituent phenes responsible for this trait are identified and selected for in breeding programs. The benefit of a shallow or deeper legume root system is ultimately dependent on the dominating soil water (and nutrient) dynamics within a particular agroecosystem. Specialised root systems, in contrast to generalists, proliferate in soil domains where limiting soil resources are most abundant, resulting in greater resource uptake efficiency and so, greater biomass accumulation and overall yield. Findings from this study identified that tap root exit points during the seedling stage influenced root length distribution at maturity. The identification of this root phene could prove useful in future breeding programs. Selected genotypes for further studies included K3419, CGN3105, Improved Harbinger, WT107, laVioletta and CGN3332 which displayed contrasting soil foraging strategies.

Acknowledgements

I would like to thank the Centre of Agricultural Innovation (CAI) and GRDC for funding this research. I also acknowledge the continued support from my supervisors, the University of Melbourne and Australian Grains Genebank (AGG) throughout this project.

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PennState Department of Plant Science(https://plantscience.psu.edu/research/labs/roots/about)

Root painter (https://github.com/Abe404/root_painter)

PennState Extension(https://www.youtube.com/@PennStateExtension)

CF Strock (https://www.youtube.com/@CFStrock)

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Maintaining a health mindset under pressure

Kim Huckerby.

The Wellbeing Affect

Maintaining a healthy mindset under pressure is something that Growers and Advisors have felt extremely challenged to uphold over the last 12 months (on top of an already impactful period throughout Covid-19). It has been a confronting time in the industry, with constant, unexpected disruption, with various factors and conditions triggering stress and anxiety about the ultimate performance and fate of crops and livelihoods.

The result? Rural farming communities are at greater risk of mental health issues and therefore there is a critical need to nurture and support these individuals, families, and communities. Kim Huckerby has a career spanning over 20 years in the mental health space and will talk about the unique industry pressures that are impacting the wellbeing of so many. The issues and concerns that result in anxiety, stress, and burn out will be explored with sensitivity and compassion and Kim will ensure that people walk away feeling equipped with strategies and a better understanding of how to handle these challenges.

Key take aways:

- Mental health continuum – identifying when stress, burn out, anxiety and other mental health issues become a concern.
- Unpacking the pressures and their impact on wellbeing/mindset e.g. navigating the difficulties of professional/personal boundaries, isolation, rising costs of farming inputs and subsequent impact on the bottom line etc.
- Strategies and scripts to support difficult situations and conversations.
- Creating sustainable strategies to prevent burn out – the significance of self-care.

Overall, it is essential that we recognise the vital role that mental health plays in the lives of Growers and Advisors. By doing so, we are ensuring the sustainability and productivity of the agricultural sector, its people and their communities.

Looking after your mental health and maintaining a healthy mindset means:

(healthdirect.gov.au)

- recognising when things are getting too much/overwhelming.
- talking to a GP or other Mental Health Professional about what is going on/how you are feeling.
- sharing your experiences and problems with someone you trust, family, friends, a healthcare professional or via a helpline, such as MensLine / Lifeline
- accessing resources, information and supports that are available online

Support services:

Managing the pressures of farming - MPF Booklet Cover (sydney.edu.au)

National Centre for farmer health - Support | National Centre for Farmer Health

Beyond Blue - https://www.beyondblue.org.au/ or 1300 22 4436

Blackdog Institute – blackdoginstitute.org.au

Lifeline - 131 114

NSW Mental Health Line 1800 011 511

Suicide call back service - 1300 659 467

Headspace (ages 12-25) - 1800 650 890

ReachOut.com - Reachout.com

The Worry Tree!

The Carpenter I hired to help me restore an old farmhouse had just finished a rough first day on the job. A flat tire made him lose an hour of work, his electric saw didn't start, and now his ancient pickup truck refused to start. While I drove him home, he sat in stony silence.

On arriving, he invited me in to meet his family. As we walked toward the front door, he paused briefly at a small tree, touching the tips of the branches with both hands.

When opening the door, he underwent an amazing transformation. His tanned face was all smiles, and he hugged his two small children and gave his wife a kiss.

Afterward he walked me to the car. We passed the tree, and my curiosity got the better of me. I asked him about what I had seen him do earlier.

"Oh, that's my trouble tree", he replied. "I know I can't help having troubles on the job, but one thing's for sure, troubles don't belong in the house with my wife and the children. So, I just hang them on the tree every night when I come home. Then in the morning I pick them up again."

"Funny thing is", he smiled, "when I come out in the morning to pick 'em up, there ain't nearly as many as I remember hanging up the night before." Author unknown

Notes

GRDC

GRAINS RESEARCH
& DEVELOPMENT
CORPORATION

Concurrent session Day 2

Novel seed traits – An update on recent R & D

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[1]CSIRO Agriculture and Food; [2]SLR Agriculture; [3]EPAG Research; [4]Charles Sturt University; [5]Australian Grain Technologies; [6]Intergrain; [7]Longreach Plant Breeders; [8]S&W Seeds; [9]NSWDPI; [10]AgGrow Agronomy; [11]QDAF.

GRDC project codes: CSP00182, SLR2103-001RTX, DAQ2104-005RTX, CSP1907-001RTX

Keywords

- breeding, climate resilience, seedling establishment and growth, weed competitiveness.

Take home messages

- The long-term climate trend is for increasing summer rain and later autumn sowing breaks throughout the Australian wheatbelt. Long coleoptiles and hypocotyls will permit deeper sowing of winter crops into summer-stored subsoil moisture allowing timely, earlier germination, and crop growth to occur under conditions optimal for maximising water productivity.
- Breeding improved establishment, which together with greater early vigour, should increase weed competitiveness to aid in weed and herbicide management, and increase nutrient uptake/nutrient-use efficiency. Greater biomass with higher vigour should also facilitate the breeding of crop varieties for later sowing in frost-prone regions or where dry sowing and double-knock weed control strategies are commonplace.
- Methods developed in assessment of seedling vigour in wheat are being translated into canola and other crops to hasten the identification of new genetics and speed the delivery of improved crop varieties for changing climates.

Aims

To identify and validate traits contributing to timely and reliable seedling emergence and greater seedling root and shoot growth.

Translate learnings in genetic improvement of seedling establishment and growth in wheat to other crops in order speed delivery of new crop varieties with improved adaptation to changing climates.

Background

The seed contains all the necessary nutrients, sugars, and primordia for the first 3–4 weeks of seedling growth. All components are necessary in optimising coleoptile (or hypocotyl) and shoot and root growth, highlighting that seed quality sets the potential for establishment and early growth of the crop. Environmental challenges including competition by weeds, reduced soil moisture and high temperature, chemical and physical soil constraints, and sowing depth can act to limit this potential to reduce plant numbers and, where extreme, result in crop failure. Genetic variation is available to meet these challenges, and tools are being developed to assist breeders in the release of new crop varieties that, together with improved systems knowledge, will improve early crop growth, particularly with increasing climate variability.

This update paper highlights current research in genetic understanding to improve seedling growth and particularly increased emergence and establishment, and early leaf and root development. Presented examples are focused on wheat and include translation of learnings from wheat to adoption in other crops.

Improved wheat establishment

Timely and successful plant establishment is critical to crop productivity in rainfed farming systems. Early emergence combined with optimal phenology increases yield potential due to a longer duration for root, tiller and crop growth while ensuring conditions are suitable for growth and flowering, and during grain-filling. Well-established crops also provide ground cover to protect soils, reduce water loss through soil evaporation, and increase crop competition with weeds.

Changing weather patterns are associated with proportionally greater summer rainfall and increasingly later sowing breaks (Flohr et al. 2021; Scanlon and Doncon 2020). There is increasing interest in deep sowing into subsoil moisture (at depths up to and exceeding 10cm) to better utilise sowing opportunities after summer and early autumn rainfall and ensure earlier germination and establishment (Rich et al. 2021; Flohr et al. 2022). However, the shorter coleoptiles and hypocotyls of many current crop varieties limit sowing depths to less than 10cm and commonly as shallow as 3–5cm. High-throughput phenotyping methods have been developed and fine-tuned to screen global germplasm and identify genetic sources for use in breeding. At the same time, recognition of the critical importance of characteristics in the seed in improving seedling establishment and early growth has focused efforts in assessment of global germplasm in breeding greater shoot and root vigour.

The long coleoptile Mace$^{\phi}$ experimental line ('Mace18'), containing a new Rht18 dwarfing gene, established well at sowing depths of 120–140mm (up to 80% of 40mm control depth) across southern, eastern and western Australia in 2020, 2021 and 2022 (for example, see Figure 1). Establishment with deep sowing of the experimental line Mace18 was as good as the older tall, long coleoptile wheat variety Halberd. Coleoptile lengths were measured at lengths of 120mm+. By contrast, the shorter coleoptile of commercially available Mace$^{\phi}$ reduced establishment with deep sowing (30–40%). The new AGT variety Calibre$^{\phi}$ also emerged well with deep sowing compared to Mace$^{\phi}$ and Scepter$^{\phi}$ (Figure 1). Grain yields were significantly ($P<0.01$) greater for deep-sown Mace18 in 2020 and 2021, and we are awaiting yield data in 2022 at up to 10 sites throughout Australia. Crop modelling analysis of previous research and grower data suggests an 18-20% increase in wheat productivity with improved establishment when deep-sowing particularly when targeting early-to mid-April sowing dates (Zhao et al. 2022).

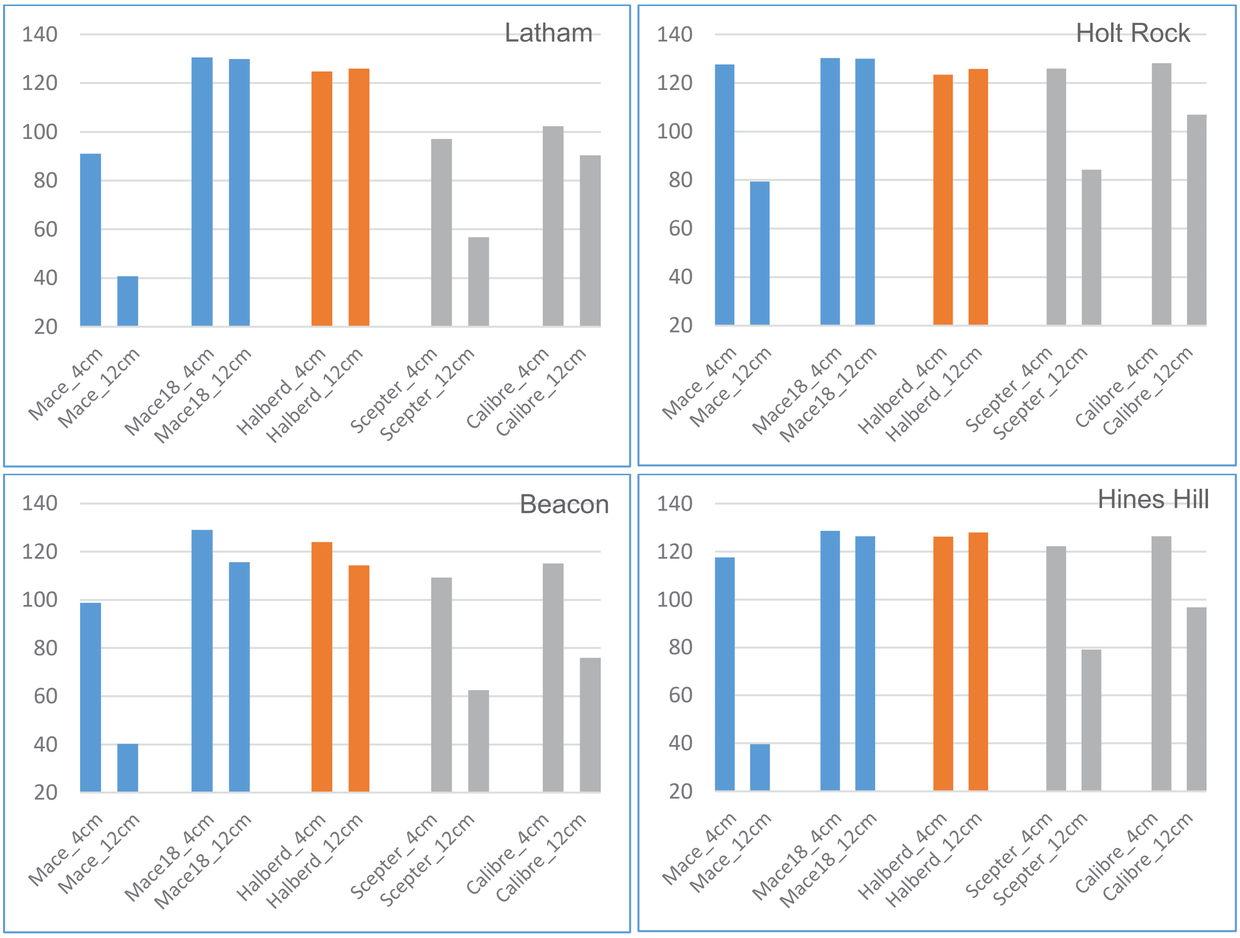

Figure 1. Mean number of plants/m^2 (at 200ºCd) at four WA sites in 2021 for shallow-sown (4cm) and deep-sown (12cm) Mace$^{\phi}$ *Rht2* and *Rht18* NILs ■, tall, long coleoptile variety Halberd ■, and commercial *Rht2* dwarfing gene varieties Scepter$^{\phi}$ and Calibre$^{\phi}$ ■. Lsds were 8, 16, 6 and 6 plants per m^2 for Latham, Holt Rock, Beacon and Hines Hill, respectively.

Improved canola establishment

Poor establishment of canola (*Brassica napus L.*) is a widespread problem in Australia and globally with an average 50% or less of germinable seeds successfully establishing (McMaster et al. 2019). New laboratory-based, screening methods were adapted from wheat for high-throughput assessment of hypocotyl length. Figure 2(a) shows significantly ($p<0.05$) longer hypocotyls in three overseas canola varieties compared with representative Australian varieties. As in wheat, validation of laboratory conditions was needed to confirm performance with deep sowing in the field. Figure 2(b) summarises emergence data for Boorowa (one of four sites) in 2021 for the best Australian and overseas canola varieties under laboratory conditions. At the 50mm sowing depth, the three longest hypocotyl overseas varieties had significantly ($p<0.05$) higher emergence rates than the best Australian variety. As in wheat, rapid laboratory-based screening methods appear effective in identifying varieties with improved establishment potential. Experimental data from 2022 confirm these field-based results are repeatable.

Similarly, preliminary results indicate genetic variation for greater mesocotyl length among oat gene breeding germplasm (Tanu et al. 2023). As for wheat and canola, the potential exists in breeding oats with improved establishment when deep-sowing. As oats are the only winter cereal possessing a mesocotyl, sowing deeper than wheat maybe possible but requires validation.

(a) (b)

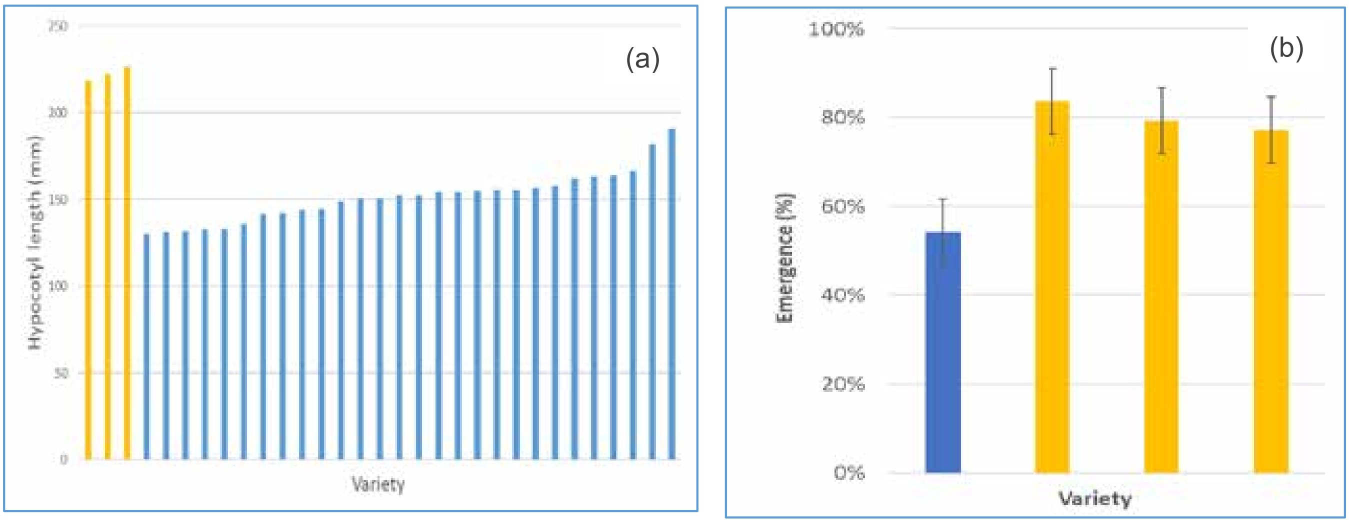

Figure 2. (a) Laboratory-based hypocotyl length for three selected overseas canola accessions (yellow) and 28 Australian varieties (blue) (Lsd = 25mm); and (b) percentage seedling emergence with deep-sowing (5cm) in the field for the best overseas long hypocotyl accessions (yellow) and best Australian canola variety (blue).

The laboratory-based methods and physiological understanding developed over three decades in wheat are being translated and modified accordingly to fast-track breeding in other crops. It is predicted that crop varieties with potential for deep-sowing will be available across most crops in the next decade to aid in de-risking poor establishment with predicted changes in the amount and timing of Australian rainfall and increasing soil temperatures.

High early vigour for improving performance with late sowing

Reductions in April–May rainfall have been mirrored by a shift in increasing rainfall later in the season (Cai et al. 2012). Growers are therefore faced with the decision to sow dry and risk poor germination. Additionally, double-knock herbicide strategies, soil amelioration, double-cropping, and pest and disease control all take considerable time to complete at the beginning of the season. The option to sow later in the season would provide more time to remediate soils and implement necessary weed control strategies. However, later sowing is tightly linked to growth under cooler temperatures, in turn reducing crop biomass and grain number to reduce yield.

New high early vigour genetics bred over 30 years at CSIRO has shown promise in rapid growth after emergence, even when sown later in the season. Figure 3 summarises grain yields at Wagga Wagga in 2021 for experimental high vigour breeding lines (CW17#66-35, CW18#58-B11 and LCH9396) and commercial varieties at two sowing dates. Later sowing reduced time to flowering from an average 133 to 107 days (p<0.001), and reduced grain yields (yet still exceeded 5t/ha). The experimental high vigour lines ('CW_') achieved the same higher yields as the more vigorous commercial varieties Condo^Φ^ and Vixen^Φ^ despite not being selected for grain yield. Of the different plant traits measured, the strongest association with grain yield in the later sowing was with increased plant height, greater early biomass and ground cover (Green et al. 2023). These high vigour genetics have been delivered and are being used in commercial breeding programs.

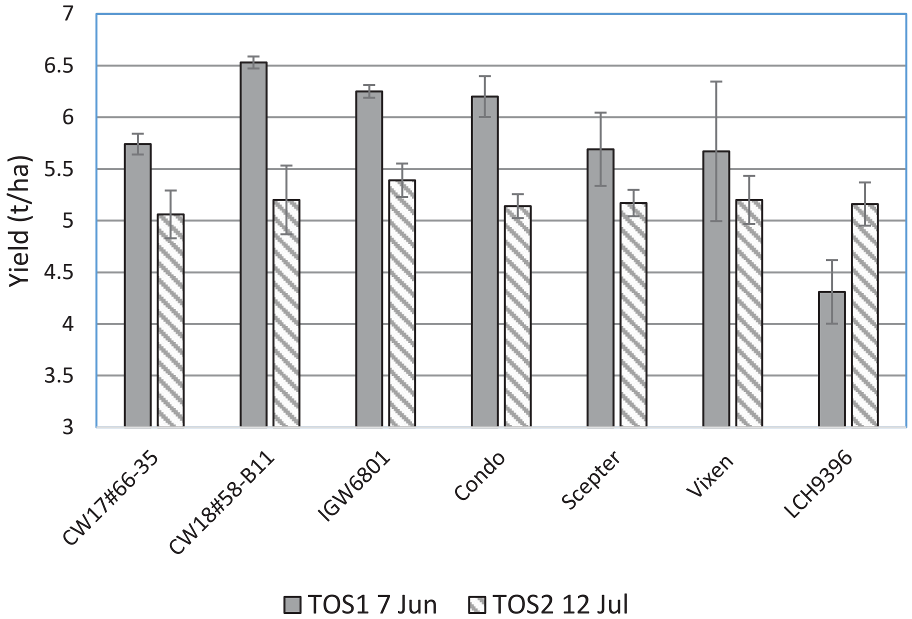

Figure 3. Grain yields of selected wheat lines sown on two sowing dates (TOS) at Wagga Wagga in 2021. Closed horizontal bars represent standard errors. Lsd (Genotype) = 0.75t/ha, Lsd (TOS) = 0.11t/ha, Lsd (Genotype × TOS) = 1.07t/ha.

Greater seedling vigour to increase crop competitiveness

Herbicide resistance, together with the high cost of pre-emergent herbicides, represent a substantial cost to Australian growers. Yield losses of up to 25% are sometimes reported where weed control is inadequate, while carryover of weed seed can present a major cost in subsequent crops while increasing risk with herbicide resistance with already limited chemical control options. Older crop varieties were very effective in competing with weeds. They were taller and produced greater leaf area early in the season to compete with weeds for light, while there was indication of their awwbility to also compete effectively below-ground (Hendriks et al. 2022).

Figure 4 summarises the significant (p<0.05) reduction in ryegrass biomass in high early vigour (HV) selected Wyalkatchem^Φ^ and Yitpi^Φ^ derivatives carefully assessed in seedling pouches. The influence on wheat vigour in reducing ryegrass growth was consistent at moderate (635 plants/m^2) and high (1270 plants/m^2) ryegrass densities, and whether growth of the ryegrass was competing above- or below-ground with the wheat. The suppression of ryegrass growth by the high vigour lines was more than two-fold the suppression of ryegrass growth by the low vigour parents. The results in this controlled laboratory assessment are consistent with field observations currently being analysed (P. Hendriks unpublished data).

Conclusions

The seed contains all the necessary machinery to assure the first 3–4 weeks of seedling growth. The potential for excellent establishment and early growth can be massively enhanced with the right genetics and high quality seed. Seed quality is determined by conditions through seed growth, harvest and storage, and can be readily assessed with germination and vigour testing.

Current research into genetic control of coleoptile and hypocotyl growth, and seedling shoot and root vigour are highlighting the potential for new crop varieties to be more resilient with changes in climate. Together with improved climate modelling and agronomy, new genetics will support opportunities in breeding for system resilience to climate change while reducing risk in weed and nutrient management. Learnings from wheat are being translated into other crops, thereby fast-tracking the breeding and farming systems requirements with the new genetics.

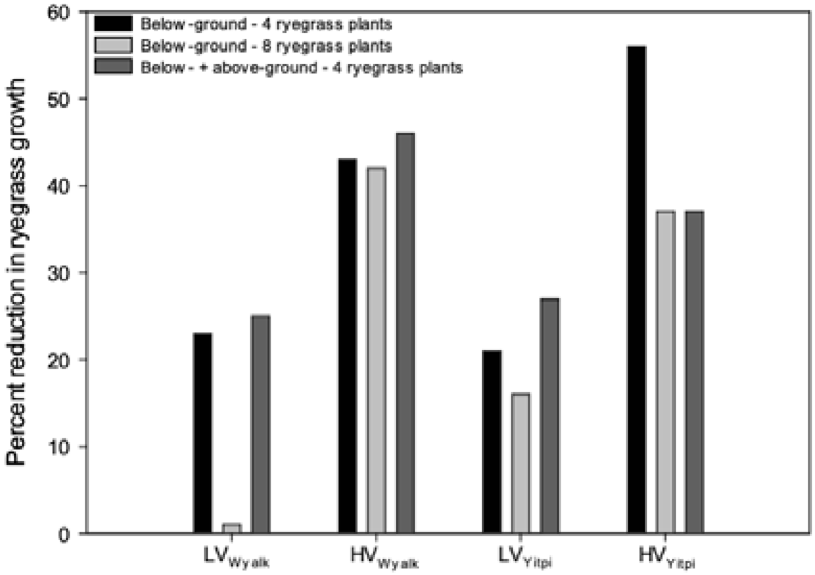

Figure 4. Reduction in ryegrass growth (biomass) for low vigour (LV) wheat varieties Wyalkatchem$^{\Phi}$ and Yitpi$^{\Phi}$ and their high vigour (HV) bred derivatives when assessed for below-ground competition in seedling pouches containing four or eight ryegrass seedlings and with above- and below-ground competition with four ryegrass seedlings. The four and eight plants correspond to 635 and 1270 ryegrass plants/m^2. Differences between high and low vigour varieties for ryegrass biomass was statistically significant ($p<0.05$) for all treatments.

Acknowledgements

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Notes

A resistance update on broadleaf weeds in South Australia and Victoria.

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GRDC project codes: UCS00020, UCS2008-001RTX

Keywords

- broadleaf weeds, herbicides, random weed survey, resistance.

Take home messages

- Herbicide resistance is most prevalent in wild radish, Indian hedge mustard (IHM), sowthistle (milk thistle), prickly lettuce (whip thistle) and fleabane.
- The most common resistance is to Group 2 herbicides.
- The highest incidence of resistance is in sowthistle and prickly lettuce.
- Integrate herbicides with alternative modes of action such as Group 13, 14 and 27 in cropping programs.

Broadleaf weed species in broadacre cropping across southern Australia

Herbicide resistance has been detected in several broadleaf weed species across southern Australian cropping paddocks (Table 1). Wild radish, indian hedge mustard, sowthistle (milk thistle), prickly lettuce (whip thistle), wild turnip and fleabane are the most prevalent broadleaf weeds with resistance. Herbicide resistance also has been confirmed in another six broadleaf weed species (Table 1).

Table 1: Occurrence of broadleaf weed species confirmed herbicide resistant from southern Australia. Source of data: CropLife Australia.

MAJOR WEED SPECIES			MINOR WEED SPECIES		
Species	**MoA**	**Sites**	**Species**	**MoA**	**Sites**
Sowthistle	2	>10 000	Bedstraw	2	<10
“	4	>50	Calomba daisy	2	<10
“	9	>50	Charlock	2	<10
Fleabane	2	>100	Iceplant	2	<10
“	9	>1 000	Turnip weed	2	5
“	22	<10		2	20
Prickly lettuce	2	<2 000			
“	9	1	**MODE OF ACTION**		
Indian hedge mustard	2	>1 000	2 = B (Ally®)		
“	4	>50	4 = I (2,4-D)		
“	5	<20	5 = C (atrazine)		
“	12	>50	9 = M (glyphosate)		
Wild turnip	2	>100	12 = F (diflufenican)		
Wild Radish	2	>5 000	22= (paraquat)		
“	4	>1 000			
“	5	>20			
“	9	3			
“	12	>1 000			

https://croplife.org.au/resources/programs/resistance-management/herbicide-resistant-weeds-list-draft-3/ Content last updated: July 16, 2020

Resistance has been quantified via random weed surveys (funded by GRDC) involving the collection of weed seeds from plants present in randomly chosen paddocks at harvest (Figure 1, Table 2).

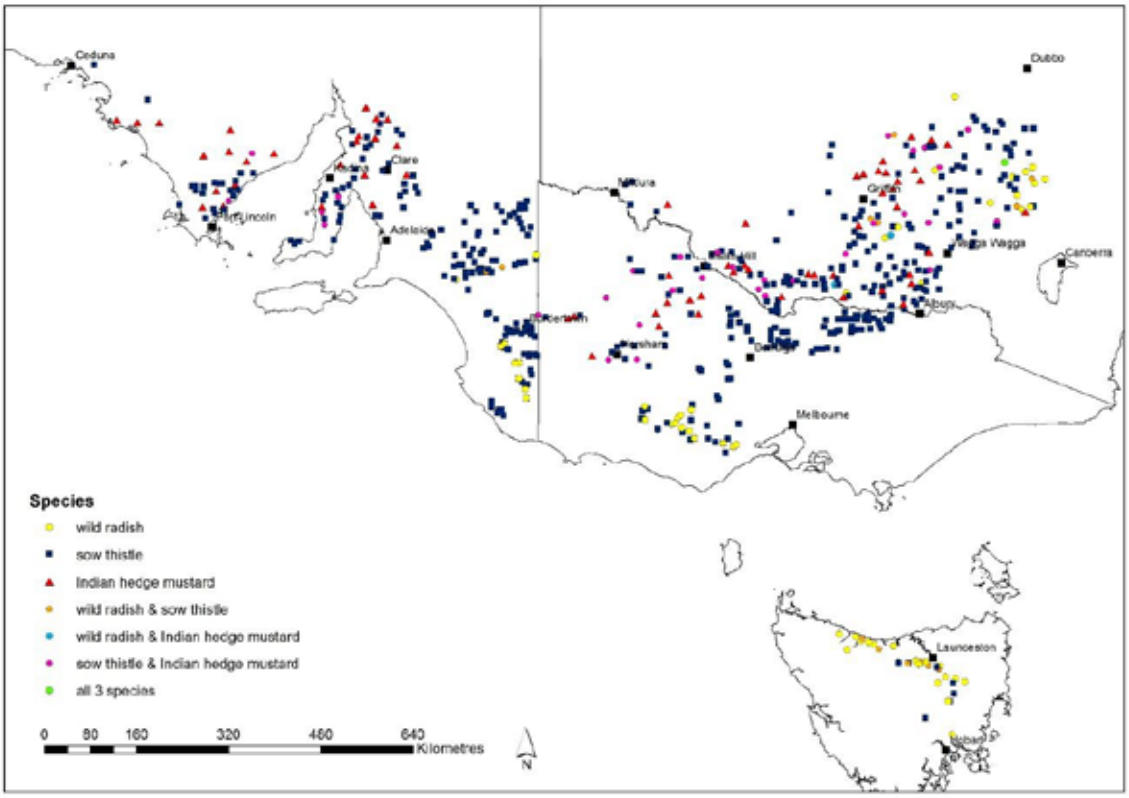

Figure 1. Survey area across south-eastern Australia for 2013-2017. Each point represents a field where one or more of the three broadleaf weed species were collected. The different symbols and colours represent different weed species present: wild radish (yellow circles); IHM (red triangles); sowthistle (blue squares); turnip weed and IHM (blue circles); wild radish and sowthistle (orange circles); IHM and sowthistle (pink circles); and all three species (green circles). Figure courtesy of John Broster.

Wild radish

In wild radish, Group 2 herbicides sulfonylurea resistance was more prevalent than resistance to imidazolinone (IMI) herbicides. A significant percentage of samples from SA exhibited resistance to 2,4-D (39%), with fewer from Victoria (7%). Almost all of the samples in SA were collected from the south-east and in Victoria from the south-west. No resistance to atrazine or diflufenican was detected.

Indian hedge mustard (IHM)

Similar to wild radish, greater resistance was detected to sulfonylureas than IMI herbicides. One third of the samples from Victoria also exhibited resistance to 2,4-D compared to only 3% from SA. In contrast to wild radish, resistance to atrazine and diflufenican was also detected in both states.

Sowthistle

Over three quarters of the samples from both states exhibited resistance to sulfonylurea herbicides. Although IMI herbicides were not tested, other trials have indicated that there is a strong correlation between sulfonylurea and IMI herbicide resistance in sowthistle. A recent survey identified 78% of populations resistant to sulfonylureas and 68% resistant to IMI herbicides (Merriam et al. 2018). A low percentage of samples from SA (6%) and Victoria (3%) exhibited resistance to 2,4-D. No resistance to glyphosate was detected.

Table 2: Extent of resistance to various herbicides in three broadleaf weed species from surveys conducted 2013–2017. The number of samples for each species is in brackets ( ) next to the species name. Samples were considered to be resistant if >20% of individuals within that population survived application of the herbicide in a pot trial.

State (& nr of samples)	Herbicide					
	Chlorsulfuron	Intervix®	Atrazine	Diflufenican	2,4-D	Glyphosate
	Resistance (% samples)					
South Australia	39	23	0	0	39	-
wild radish (13)	43	13	3	20	3	0
IHM (30)	80	-	-	-	6	0
Sowthistle (190)						
Victoria	29	0	0	0	7	0
wild radish (14)	42	5	21	47	32	0
IHM (19)	78	-	-	-	3	0
Sowthistle (119)						

A dash indicates herbicide was not used on this species.

Prickly lettuce

Prickly lettuce is not collected in the pre-harvest surveys as it has not set seed. Directed surveys were conducted in SA in 1999 and 2004 that showed sulfonylurea resistance in prickly lettuce was already high with 66% of populations from 1999 and 82% of populations from 2004 resistant to sulfonylureas (Lu et al. 2007). In 2018, 30 populations were collected from four regions in South Australia. Every population exhibited resistance to both sulfonylureas and IMI herbicides, showing a continued increase in Group 2 herbicide resistance.

Fleabane

Seeds of fleabane from a survey of 89 agricultural locations in 2014 across north-east Victoria were collected (Aves et al. 2020). Of these, 40% exhibited resistance to glyphosate, 100% resistant to sulfonylureas, but there was no resistance to Group 4 herbicides or paraquat. Testing of suspect samples sent by agronomists to commercial testing services have identified resistance to paraquat (Table 1).

Wild turnip

This species was only included in earlier surveys. Wild turnip was collected from 31 paddocks in the 2012 SA Mallee survey, with 23% and 16% of samples exhibiting resistance to sulfonylureas and IMI herbicides, respectively. No resistance to atrazine, Brodal® or 2,4-D was detected.

Resistance in broadleaf weeds:

Resistance to the Group 2 sulfonylurea (for example, metsulfuron), imidazolinone (for example, Intervix) and triazolopyrimidine (for example, Eclipse®, Crusader®) is common. Resistance in broadleaf weeds is almost exclusively due to target-site resistance. The target site of Group 2 herbicides is the enzyme, acetolactate synthase (ALS). A number of point mutations at eight different sites on the ALS gene have been recorded in resistant individuals of various species (Tranel et al. 2022). The most common site for mutations is Proline-197, with eleven different amino acid substitutions reported at this site across 40 different weed species. Different amino acid substitutions at each of the sites can provide different cross resistance patterns across the chemical families within Group 2 herbicides and the resistance phenotype for a substitution can vary between species (Tranel et al. 2022). Resistance can vary between weak resistance with substantial biomass reduction to no reduction at all, even at rates magnitudes higher than recommended label rates. Cross pollinating species such as wild radish can easily accumulate multiple mutations in the same plant increasing the level of resistance further.

Group 4: In SA and Victoria, resistance to Group 4 herbicides has been detected in wild radish, IHM and to a lesser extent in sowthistle (Tables 1 and 2).

Group 5 and 12: Resistance to atrazine and diflufenican has only been detected in IHM from the random weed surveys and not in wild radish. However, resistance to both atrazine and diflufenican in wild radish from SA and Victoria has been confirmed by commercial testing services.

Group 9: Out of the broadleaf weed species presented here, resistance to glyphosate has only been detected in fleabane in SA and Victoria, more common from horticulture. Glyphosate resistance in other broadleaf weeds has not been detected in SA or Vic, whereas in NSW and Qld, glyphosate resistance in sowthistle has been confirmed for over a decade.

Minor weeds: In a few cases, resistance has been detected in several other weed species, such as bedstraw (Table 2), other than the main weed species discussed here. Factors that are responsible for the low prevalence of resistance in these species includes a narrower distribution resulting in fewer individuals exposed and an inherently lower frequency of resistance in the species.

Combatting herbicide resistance in broadleaf weeds.

Where there are multiple herbicides within a group (such as Group 2 sulfonylureas and IMI's), testing for resistance can help identify those herbicides that are still effective. It is also useful to test for resistance to other mode of action herbicides such as Group 4 (2,4-D), Group 5 (atrazine) and Group 12 (diflufenican), to identify herbicides that still work.

For some herbicide groups where weak resistance is common, such as Group 4, resistant populations may be controlled by products containing more than one mode of action herbicide, such as Group 6 (bromoxynil) or Group 12 (diflufenican, picolinafen). Identifying such mixtures that are still able to control the resistant population is helpful for management.

In the past few years, herbicides with alternative modes of action that control broadleaf weeds have become available such as Group 14 (G) and Group 27 (H). The option to use herbicides pre-emergent at sowing such as Voraxor® (Group 14) and Callisto® (Group 27) can increase the flexibility of broadleaf weed control in cereals. A continuing challenge has been in controlling resistant broadleaf weeds in broadleaf crops where IMI herbicides have been widely used. Herbicide introductions such as Overwatch® (Group 13, selective in canola) and Reflex® (Group 14, selective in pulses) allow a greater range of modes of action for control of some broadleaf weeds. Using these alternative herbicides will also help to extend the life of the more commonly used products.

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Pulse disease research update

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GRDC project codes: DJP1097-001RTX, DAV00150, DJP2103-005RTX, DAW2112-002RTX, DPI2206-023RTX, DJP2007-001RTX

Keywords

- Botrytis, faba bean, Sclerotinia, varietal resistance.

Take home messages

- It is anticipated that disease pressure on crops will be high going into 2023 due to carry over of high disease loads on stubble, seed and in the soil. Growers, therefore, should take a proactive approach to disease management this season.
- Where possible, choosing more resistant varieties will reduce grain yield losses caused by disease and reduce the reliance on fungicides.
- Testing seed and sowing disease-free seed will reduce disease carryover from 2022.
- Timely fungicide applications are essential if conditions are conducive for disease development.
- Following the 'Fungicide Five' strategies will reduce the risk of fungicide resistance development.

Year in review

During 2022, it was shown that proactive management of pulse diseases was essential to maintain profitable production. Planning was critical and when plans were enacted based on the conducive seasonal conditions, there was reduced disease severity and increased profitability.

Adequate soil moisture and warm soil temperatures meant crop establishment during 2022 was early in many cases, with canopy closure earlier than average. Consistent rainfall provided a long season and conducive conditions for disease development throughout Victoria. Increased disease pressure resulted in varieties being at their most susceptible in the 2022 season and proactive disease management plans were the most successful. However, environmental conditions further exacerbated the disease situation in many pulse crops.

Seed testing

In 2023, it is important to sow seed with a minimal amount of disease to ensure desired plant establishment and minimise disease carryover. With multiple diseases present in many pulse paddocks during 2022, it is important to consider the implications for 2023 with retaining seed. Many diseases can carry over with the seed, either as sclerote contamination in grain (Sclerotinia white mould and Botrytis grey mould (BGM)) or infected seed (BGM and Ascochyta blight). Seed can be tested for disease at state laboratories (see Useful resources).

Botrytis disease management

General

Botrytis affects most pulse crops (faba bean, lentil, vetch, chickpea and lupin). The disease is called Chocolate Spot in faba bean and sometimes in vetch. It is caused by two pathogens, Botrytis cinerea and B. fabae which are both found across faba bean, lentil, vetch, and lupin, with chickpea only affected by Botrytis cinerea. Therefore, disease can spread readily between susceptible pulse crops or from previously infected stubbled. The pathogens are necrotrophic fungi, which means they kill plant cells and then feed off those dead cells. This infection process places stress on the plant which make plants more susceptible to further infection. Therefore, it becomes more difficult to control the disease once it is established and can cause greater disease severity.

During 2022, high canopy humidity combined with early canopy closure produced conducive conditions for Botrytis to establish early in the season. Continued conducive conditions contributed to more reproductive lifecycles, increasing disease pressure. Botrytis development can occur at most growing season temperatures, but disease development is quickest when canopy humidity is high (greater than 70%) and temperatures are warm (15–25°C). These environmental conditions can differ between crops, depending on the prevailing weather and canopy density.

Faba bean experiments

With the 2022 season highly conducive to Chocolate spot, the 2020 Hamilton trial results (next to Lake Linlithgow, Vic) are highly relevant to the recent season. This experimental site was comparable to many Medium rainfall zone (MRZ) areas during 2022 and provides data to support the management advice around Chocolate spot.

Newer dual active fungicides including, tebuconazole + azoxystrobin (Veritas®), bixafen + prothioconazole (Aviator® Xpro®**) and fludioxonil + pydiflumetofen (**Miravis Star®) were compared against the single active chemistries carbendazim or procymidone (procymidone is now permitted under the permit PER92791, Table 1). All treatments received a 4-node tebuconazole application to prevent Cercospora leaf spot. Treatments were applied at early flowering as these newer chemistries were expected to have longer efficacy and this timing is the latest permissible application timing for Aviator® Xpro® and Miravis Star®.

It was a very conducive year, hence additional applications of carbendazim and procymidone were applied in addition to the fungicide treatments to be more realistic in a very conducive environment.

These additional fungicides struggled to limit disease progression and highlights the need for proactive disease management, as disease epidemics can develop rapidly.

Table 1: Fungicide treatments and timings in faba bean experiments conducted at Hamilton during 2020.

Treatment[A]	Rate (g ai/ha)	Timing
Untreated (No fungicides)		
Carbendazim	250	Canopy Closure
Procymidone[B]	250	Early Flowering
Tebuconazole + Azoxystrobin	200 120	Early Flowering
Bixafen + Prothioconazole	45 90	Early Flowering
Fludioxonil + Pydiflumetofen	113 75	Early Flowering

[A]These fungicides are additional to all treatments receiving a tebuconazole application at the 4–6 node growth stage. There was high disease pressure later in the season. Therefore, an additional two carbendazim (250g ai/ha) and an extra one procymidone (250g ai/ha), or two extra procymidone applications on the carbendazim treatment were applied alternately every 2–4 weeks to control Chocolate Spot. Carbendazim and Procymidone were applied up to a maximum of 2 consecutive applications.

[B]Procymidone can be applied under PER92791 on faba beans.

PBA Bendoc⍉ and Fiesta consistently showed higher levels of Chocolate spot compared to PBA Samira⍉ and PBA Amberley⍉, with disease symptoms observed and progressing under all treatments (Table 2). These results highlight the requirement for fungicides to be applied to all varieties, to prevent severe disease.

Faba bean grain yield indicated greater fungicide efficacy in the dual active chemistries, with fludioxonil + pydiflumetofen, providing higher yield gains compared to the other fungicide strategies (Table 3). The economic benefit of applying the fludioxonil + pydiflumetofen was similar to the strategy involving carbendazim with the canopy closure application, further highlighting the need to minimise disease early in the season (Table 4).

Table 2: Chocolate spot severity in four varieties with different fungicide strategies applied at Hamilton, assessed on 20 October 2020.					
Treatment[A]	**Chocolate Spot Severity (%)**				
	Fiesta	**PBA Bendoc**⟨D⟩	**PBA Samira**⟨D⟩	**PBA Amberley**⟨D⟩	**Mean**[B]
2022 Disease resistance rating	S	S	MS	MRMS	
Untreated	94	94	85	76	87 c
Carbendazim	76	78	65	63	70 a
Procymidone	83	89	75	71	79 b
Tebuconazole + Azoxystrobin	88	86	79	66	80 bc
Bixafen + Prothioconazole	84	86	79	73	80 bc
Fludioxonil + Pydiflumetofen	81	83	75	63	75 ab
Mean[B]	84 c	86 c	76 b	68 a	
	P	**Lsd**			
Variety	<0.001	2.3			
Treatment	<0.008	7.6			
Variety x treatment interaction	0.473	ns			

[A]Fungicide strategies are described in Table 1.

[B]Different letters indicate significant differences (P<0.05) between means of varieties or treatments.

Table 3: Grain yield of four varieties with seven different fungicide strategies applied at Hamilton during 2020.				
Treatment[A]	**Grain Yield (t/ha)**[B]			
	Fiesta	**PBA BendocA**	**PBA SamiraA**	**PBA AmberleyA**
Untreated	0.72 a	0.62 a	1.27 b	2.75 hijklm
Carbendazim	3.33 kmno	2.68 ghijkl	4.36 qrst	4.89 suv
Procymidone	1.98 bcdefghi	1.68 bcd	2.46 cdefghj	4.21 pqrs
Tebuconazole + Azoxystrobin	1.88 bcdefg	1.78 bcdef	2.65 hijk	3.69 nopq
Bixafen + Prothioconazole	1.76 bcde	1.65 bc	2.50 dfghij	4.04 opqr
Fludioxonil + Pydiflumetofen	3.36 klmo	2.9 jklmn	4.49 qrstu	5.69 v
	P	**Lsd**		
Variety	<0.001	0.164		
Treatment	<0.001	0.749		
Variety x treatment interaction	0.004	0.824		

[A]Fungicide strategies are described in Table 1.

[B]Different letters indicate significant differences (P<0.05) between grain yield means across varieties and treatments.

Table 4: Gross margin ($/ha) of four varieties with seven different fungicide strategies applied at Hamilton during 2020.

Treatment[A]	Gross Margin[B]			
	Fiesta	PBA Bendoc⚲	PBA Samira⚲	PBA Amberley⚲
Carbendazim	$937	$717	$1 130	$751
Procymidone	$407	$327	$380	$487
Tebuconazole + Azoxystrobin	$361	$361	$448	$274
Bixafen + Prothioconazole	$307	$300	$380	$406
Fludioxonil + Pydiflumetofen	$932	$785	$1 164	$1 051

[A]Fungicide strategies are described in Table 1.

[B]Gross margin was calculated as the grain yield gains minus the cost of the fungicide treatments. Chemical prices were an average of three chemical resellers prices provided, grain price was assumed to be $400/t and an application cost of $10/ha.

Sclerotinia white mould

Sclerotinia white mould (SWM) is a damaging disease that can infect many pulse crops including lentil, chickpea, faba bean, vetch, field pea and lupin. It can also affect canola, pasture legumes and many weeds. This disease poses its greatest risk during seasons with prolonged damp conditions. Currently, there is limited knowledge on its control, but several fungicides currently registered or under permit for other diseases in pulses and could be used in Victoria. Sclerotinia was widespread in Victoria during 2022 and sclerotes can last in the soil for over 15 years. Research into management strategies is in the preliminary stages, with a focus on determining whether varietal resistance exists, and research on the incorporation of integrated disease management strategies.

With limited management knowledge, growers are advised to monitor for infected paddocks, consider non-host crops and, where possible, ensure they are sowing clean seed.

Sowing time

Delaying sowing can be an effective disease management tool, as it delays canopy closure and reduces the number of disease cycles that can occur in a season. It is important though to offset this with the potential yield reductions from late sowing. It is a balance and should be based around plant establishment, noting that sowing, germination and establishment times vary. If paddocks are sown early in warmer soils, plants may establish early, thus increasing the disease risk. One example of this is from a chickpea Ascochyta blight experiment in Horsham during 2022 where significant differences ($P<0.005$) in disease severity were observed. The variety Genesis 090 had 42% disease severity when sown in May, compared to 22% disease severity when sown in July. This is only an example and sowing times should be adjusted for different crops and regions.

Fungicide resistance

Resistance to fungicides is becoming an increasing threat to crops across Australia.

Currently, there are no new detections of fungicide resistance in pulses within Australia. Samples have been taken and tested across the Southern region, which suggests that this is not occurring, but the threat is always present.

Pulse production is reliant on fungicides and many crops only have single active fungicides applied at multiple times throughout the season. Therefore, there is a high probability that we may observe fungicide resistance if growers do not take preventative steps now.

There are five strategies that growers can adopt to slow the development of resistance in pathogen populations and therefore extend the longevity of the limited range of fungicides available:

- **Avoid susceptible crop varieties.** Where possible select the most resistant varieties suitable and/or avoid putting susceptible varieties in high-risk paddocks
- **Rotate crops.** Avoid planting crops back into their own stubble or adjacent to their own stubble
- **Use non-chemical control methods to reduce disease pressure**. Delaying sowing and 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.** Use fungicide mixtures formulated with more than one mode of action, 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

Conclusions

With high disease levels during 2022, it's important to sow clean seed during 2023 to ensure desired plant establishment and reduce disease carryover. Plan a disease management strategy early that incorporates varietal resistance, paddock rotations, reliable agronomy practices (sowing time, interrow sowing, nutrition), rotation of fungicide groups, and strategic fungicide applications. Without a solid strategy, grain yield losses of greater than 90% can be experienced if conducive disease conditions occur.

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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. Appreciation is given to the Agriculture Victoria Southern Pulse Agronomy and Field Crops Pathology teams, the Southern Farming Systems research team and the growers and agronomists who have assisted with these experiments.

Useful resources

Pulse disease guide (https://agriculture.vic.gov.au/biosecurity/plant-diseases/grain-pulses-and-cereal-diseases/pulse-disease-guide)

Victorian and Tasmanian crop sowing guide (https://grdc.com.au/resources-and-publications/all-publications/nvt-crop-sowing-guides/vic-tas-crop-sowing-guide)

Crop protection products details including Minor Use Permits, can be viewed at the Australian Pesticides and Veterinary Medicines Authority (APVMA) website www.apvma.gov.au

Seed testing services

Agriculture Victoria, Crop Health Services (Ph: 03 9032 7515), chs.reception@agriculture.vic.gov.au

SARDI (Ph: 08 8429 2214) sue.pederick@sa.gov.au

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Notes

Introducing the Bureau of Meteorology Climate Outlook Tools for forecasting extreme weather

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Agriculture Victoria.

Keywords

- weather, climate, extreme events.

Take home messages

- Add the new Bureau of Meteorology Climate Outlook Tools to your weather/seasonal outlook decision-making process.
- Comparing the 99 model runs allows you to see the spread of possibilities.
- Seasonal outlook information is just one component of your decision-making process.

Background

Between November 2021 and August 2022, the Bureau of Meteorology has released five new Climate Outlook Tools to give greater insight into unusually warmer, cooler, wetter or drier conditions over weeks, fortnights and months across Australia.

Climate Outlook and Forecasting Tools estimate the chance (or probability) of a future climatic condition occurring in a certain location over a certain period. In the past, outlooks described the chance of above or below median rainfall or temperatures. The products released in 2021/22 now provide:

- outlooks for rainfall describing the chance of occurrence of unusually dry, drier, average, wetter or unusually wet conditions
- Outlooks for maximum and minimum temperatures describing the chance of unusually cool, cooler, average, warm or unusually warm conditions.

These forecasts describe the chance of these climatic conditions occurring compared to the average historical occurrence. For these products, 'extreme' has been defined as being the unusually dry, unusually wet, unusually cool or unusually warm 20% of periods (weeks/months/seasons) that have historically occurred.

The Bureau of Meteorology's Climate Outlooks — weeks, months and seasons page is found at: www.bom.gov.au/climate/outlooks/#/overview/summary. The extreme climate prediction products are seamlessly embedded into the existing ACCESS graphical forecasts and have a 'click on' or 'type in' your location feature.

Product #1 Climate Outlook Maps for extreme temperature and rainfall

Climate Maps show the chance of experiencing climatic extremes (unusually wet, dry, warm or cold conditions) for the weeks, months and seasons ahead. These maps are an extension of previously available 'probability of above median' maps.

The example below shows a Climate Outlook Map forecasting unusually wet conditions across Australia between 10 September and 23 September 2022 (Figure 1). This map shows a high chance of having an unusually wet couple of weeks in September 2022 in central and southern Queensland (amongst the top 20% in the climatology period) with three to four times the normal chance.

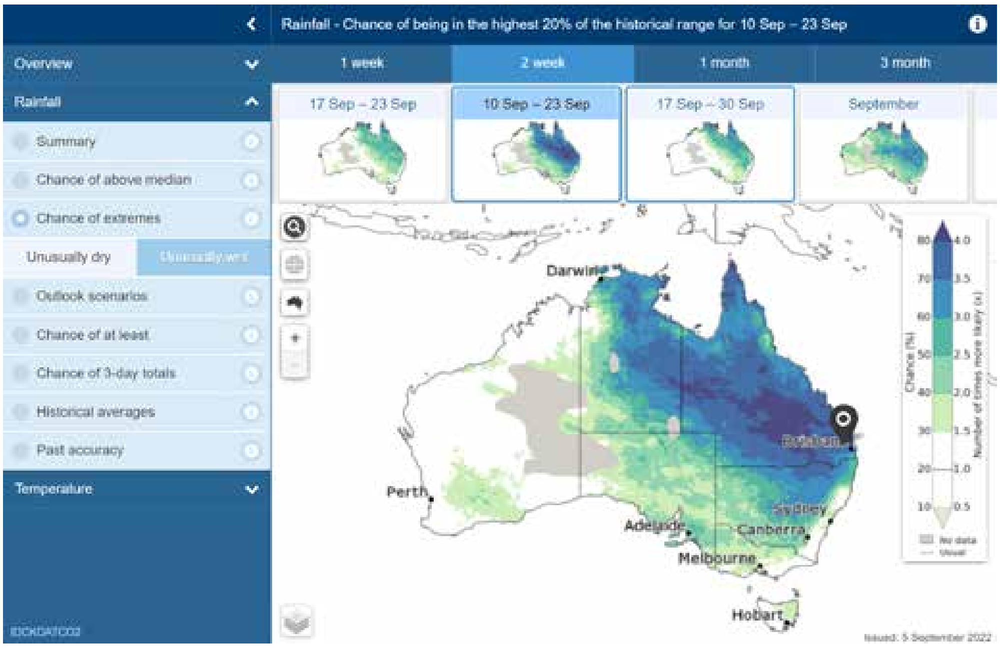

Figure 1. Climate Outlook Map forecasting unusually wet conditions issued in September 2022 for the two weeks between 10 September and 23 September across Australia.

Product #2 Location specific Decile Bars for rainfall and temperature.

Decile Bars are location-specific bar graphs showing the forecast probability of rainfall or temperature being in a particular climatological range at selected locations for the weeks, months and seasons ahead. These bars indicate the shift in the probabilities of climatic extremes compared to historic observations from 99 separate model runs.

The long-term average probability (usual chance) for each category is 20%, shown by the horizontal dashed line. If the coloured bars are above this line, it means there is a stronger than usual chance that category will occur. If they are below the line, there is less chance than normal.

This includes the likelihood of 'extremes', for example, of being in the bottom 20% of historical records (decile 1&2), or the top 20% (decile 9&10). This also includes the three ranges in between (deciles 3&4, deciles 5&6, and deciles 7&8). For the first time ever, this product provides information on the chance of 'average' rainfall for the middle 20% of historical records (decile 5&6). A decile describes how data is split into ten equal subsections. For example, climatic data in decile 1&2 describes the bottom 20% of historic temperature or rainfall observations.

This Decile Bar chart below shows an example of Decile Bars for the three-month rainfall forecast for October to December 2022 at Swan Hill, Victoria (Figure 2). The odds show wet conditions being likely, with more than double the usual risk of having unusually wet conditions (for example, being amongst the top 20% of wettest October–December).

Importantly, every other outcome is still on the table, it is just that the chance of dry or average conditions has halved, and the chance of experiencing unusually dry conditions would be less likely. It is common for forecasts to show 20% chances of each decile range, which is what is termed a neutral forecast or climatology.

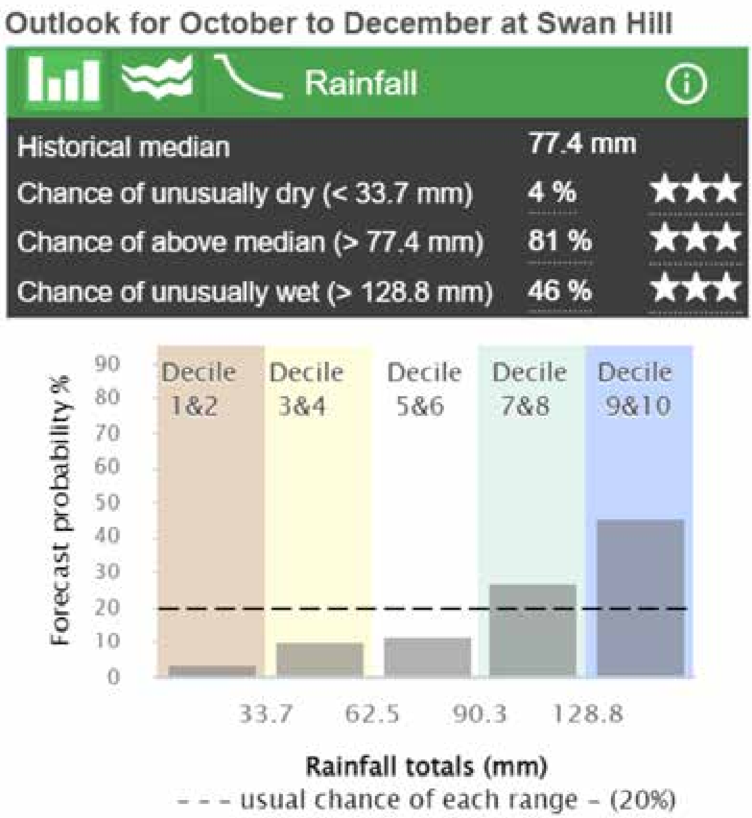

Figure 2. Decile Bar graph showing rainfall forecasts for October–December 2022 in Swan Hill, Victoria (generated on 6 September 2022). The forecasts show the probabilities across five different decile ranges. The long-term average probability (usual chance) for each category is 20% and the forecasts show the shift in the odds compared to usual.

Product #3 Climate Timeline Graphs

The Bureau of Meteorology's Timeline Graphs display a timeline of recent climatic observations from the previous weeks and months, against historic averages, and show what may happen in the future.

They use box and whisker plots to show the range of predictions for dry or wet, warm or cool conditions, for the four weeks or five months ahead. Figure 3 is a Climate Timeline Graph showing historic rainfall and five-month forecast rainfall in Swan Hill, Victoria for a time point in 2022.

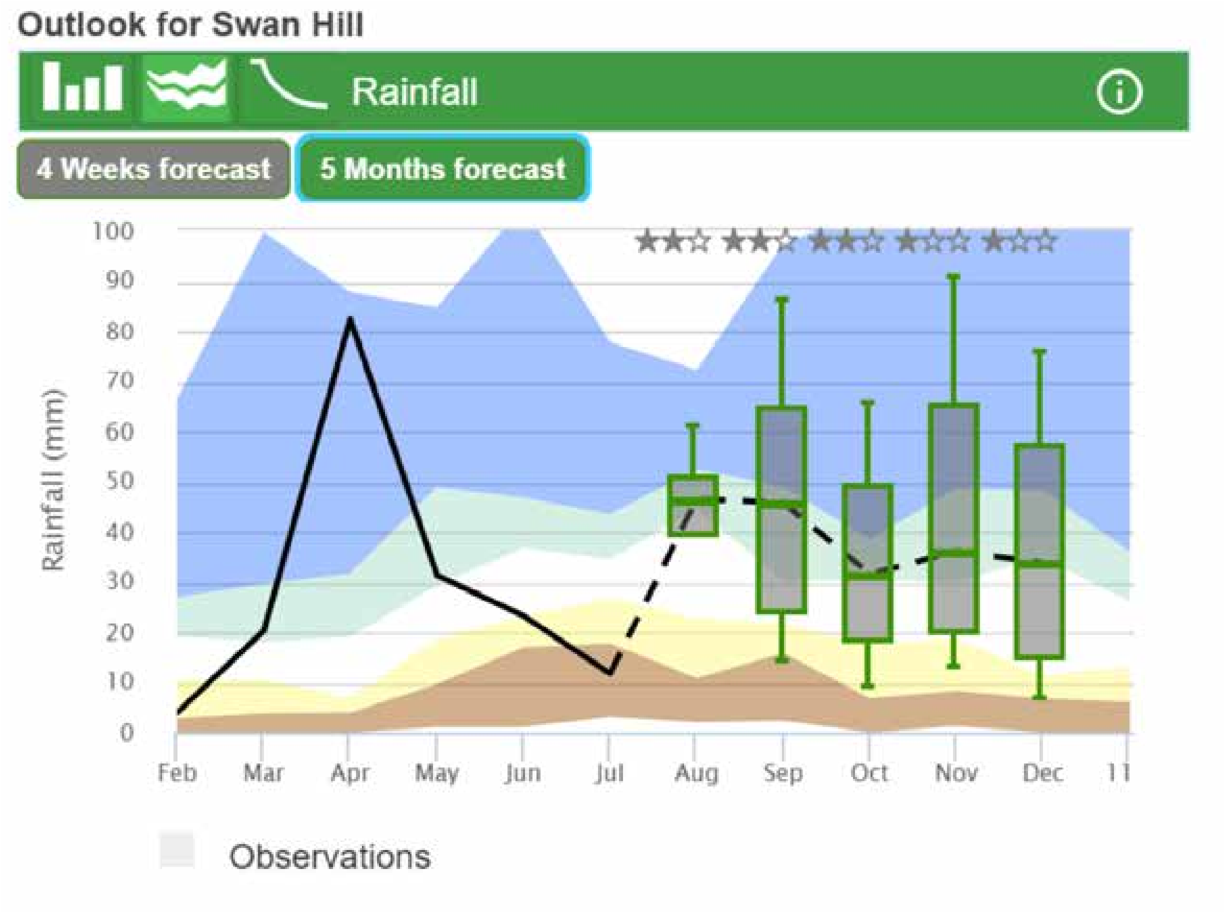

Figure 3. Climate Timeline Graph showing historic rainfall (February–July 2022) and five-month forecast rainfall (August– December 2022) in Swan Hill, Victoria.

The area graph (shading behind) shows historic deciles for unusually dry (brown), dry (yellow), average (white), wetter (green) and unusually wet (blue) conditions. The solid black line graph shows observed average monthly rainfall over the last six months. The dotted line graph shows predicted mean rainfall in the coming five months. The box and whisker graph shows variability in the 99 model runs used to generate the forecast prediction. Boxes show the middle 25–75% of model outputs. Whiskers show the range of 10–25% of lower values and the 75–90% of higher values. The stars on the right-hand side of the top panel refer to the past accuracy of the outlook. If the model has performed well in forecasting for that location/period/time of year in the past, it will be indicated by three solid stars, meaning high past accuracy. If the model has medium past accuracy, it will have two solid stars and low past accuracy will only have one solid star. If the majority of the 99 Bureau of Meteorology forecast runs are within a tight range, this will result in a smaller box, smaller whiskers and gives us greater confidence in the prediction. Often, shorter term predictions (looking out weeks rather than months) have a narrower range of predictions and we can have more confidence in their accuracy. However, we must always remember that any outcome is possible.

Product #4 Probability of Exceedance outlooks (rainfall only)

The Bureau of Meteorology Probability of Exceedance line graphs present the forecast and historical likelihoods (per cent) of receiving a desired amount of rain in a selected period.

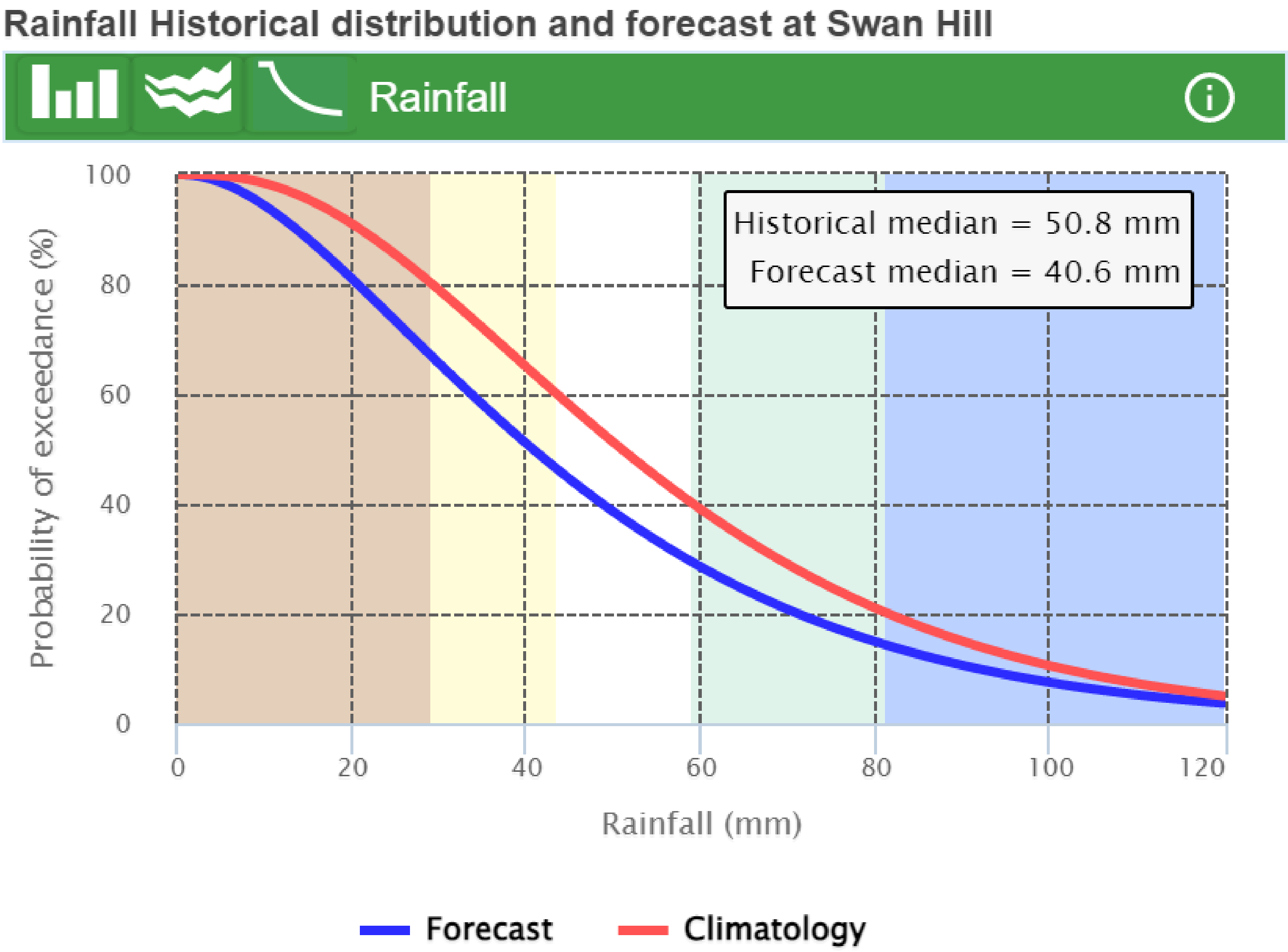

Figure 4. Probability of Exceedance line graphs showing historic and forecast chance of rainfall for February–April 2023 in Swan Hill, Victoria.

There are two lines shown on the graph. The red line shows the historic chance (or climatology) at that location of receiving a particular rainfall total. Low rainfall totals have a high chance of occurring, while higher rainfall totals have a much lower chance. For example, the above graph (Figure 4) shows an outlook for February to April 2023 in Swan Hill, Victoria. Swan Hill typically has a 60% chance of receiving around 43.4mm of rainfall during October, a 40% chance of 58.6mm, and a 20% chance of 81.2mm.

The blue line shows a range of rainfall values and how often the 99 model runs exceeded these values. When the blue line is below the climatological red line, this indicates a drier outlook, while a blue line above it indicates a wetter outlook. The example shows a drier outlook, with a 60% chance of receiving 33.4mm, a 40% chance of 48.6mm, and a 20% chance of 70.4mm.

Tapping/hovering the mouse over the graph brings up the percentage chance for the corresponding rainfall depth in a text box. These outlooks allow users to obtain information for specific rainfall amounts that are of interest for their specific application.

Like the Timeline Graphs, the coloured background of the graph also helps put the outlooks into historical perspective. The shading behind shows historic deciles for unusually dry (brown), dry (yellow), average (white), wetter (green) and unusually wet (blue) conditions. All of the new products use historical values calculated over the period 1981–2019.

Product #5 3-Day Burst outlooks

The Bureau of Meteorology's 3-Day Burst forecast maps show the chance of receiving a particular rainfall total, over three consecutive days in the forecast period across Australia (for example, Figure 5). Forecasts are produced for 15mm, 25mm, 50mm and 75mm of rain in a three-day period. This tool was designed particularly for northern parts of Australia, around the onset and bursts of the wet season. It could also be useful in southern parts of Australia when considering the autumn break or timing of harvest operations. Historic data is also available for the chance of 3-day totals (15mm, 25mm, 50mm or 75mm) (for example, Figure 6).

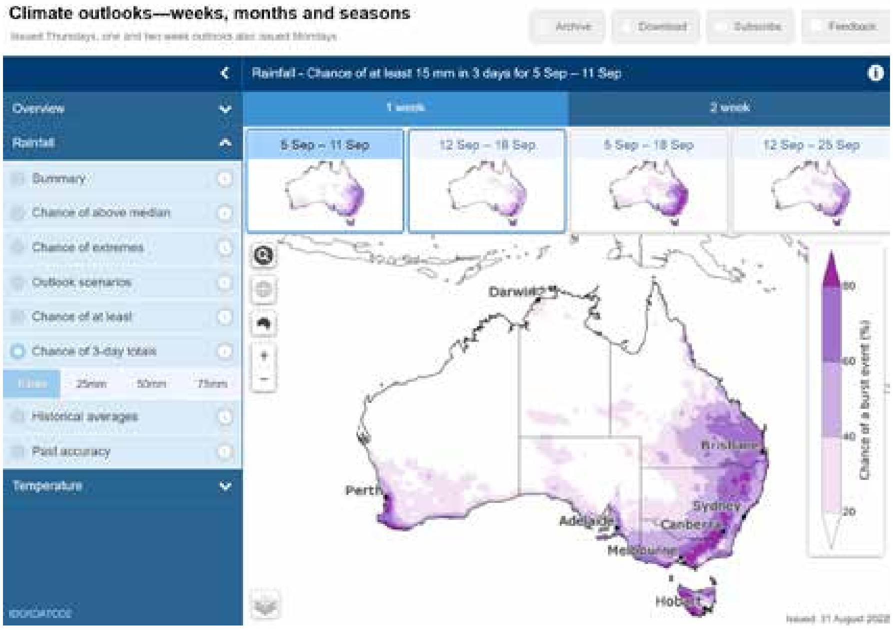

Figure 5. Map showing the chance of receiving a 15mm 3-day total in areas across Australia between 5 September and 11 September 2022.

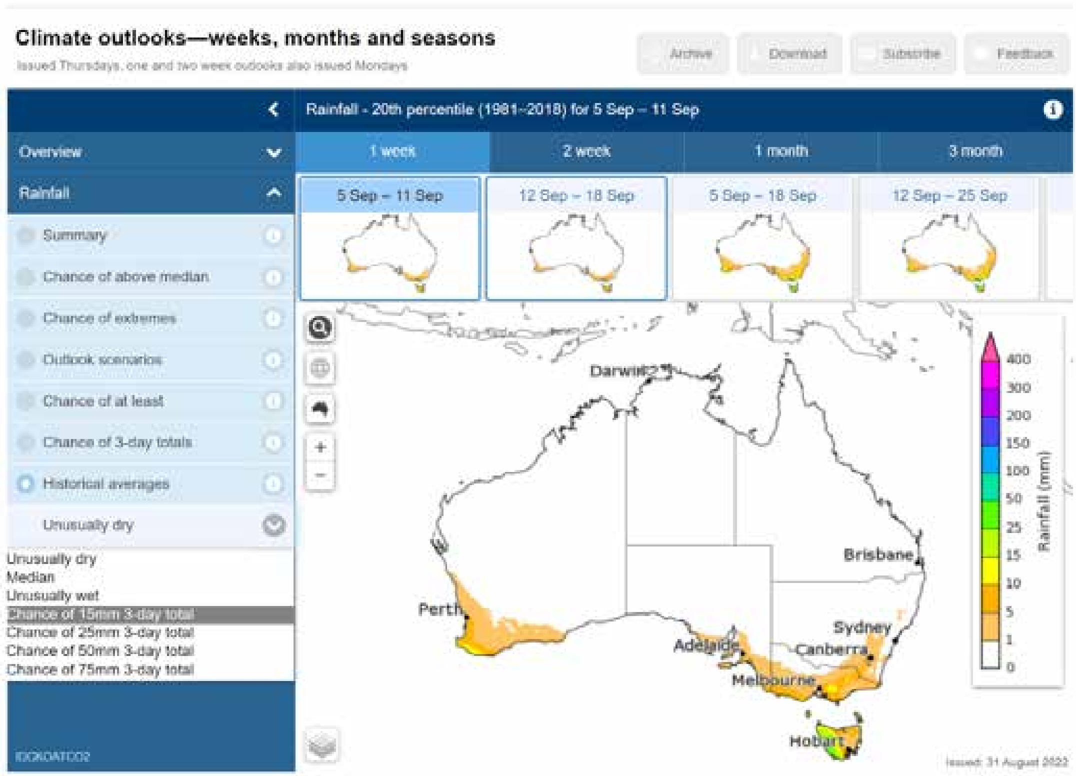

Figure 6. Map showing the historic chance (1981–2021) of receiving a 15mm 3-day total in areas across Australia between 5 September and 11 September. Historic averages for rainfall are accessed using the drop-down tabs on the left of the screen.

Acknowledgements

The Forewarned is Forearmed, Managing Climate Variability project was made possible by support of the GRDC, the authors would like to thank GRDC for their support.

Useful resources

Forewarned is forearmed: outlooks and new features on the Bureau of Meteorology's website 2021 (www.youtube.com/watch?v=lhHmZS9h2LI)

This webinar explores two tools developed and released as part of the Forewarned is Forearmed project, a partnership of government, research and industry sectors funded through the Australian Government's Rural R&D For-Profit Program. The features respond to the growing need for information around unseasonal and extreme weather and climate events to build climate resilience and support better-informed decision making. The tools enable users to drill down to their location to view the chance of unseasonal and extreme temperature and rainfall for the weeks, months, and seasons ahead.

Forewarned is forearmed: outlooks and new features on the Bureau of meteorology's website 2022 (www.youtube.com/watch?v=RL0JrRY61NU)

This webinar explores the final three of five tools developed and released as part of the Forewarned is Forearmed project.

Using seasonal climate prediction tools eLearn (

This eLearn introduces extreme climate and weather forecasting tools developed by the Bureau of Meteorology.

https://agriculture.vic.gov.au/support-and-resources/elearning/climate-and-weather-courses)

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Soil amelioration in medium and high rainfall regions – where will it pay

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GRDC project codes: DAV00149, NLP 4-GKXBV5N/DJP2204-011SAX

Keywords

- physicochemical constraints, simulation modelling, soil water, subsoil.

Take home messages

- Subsoil amelioration has the potential to increase yields and long-term profitability when targeted at appropriate soil conditions and climates.
- The likelihood of achieving favourable yield responses is low on heavy clay topsoils, medium rainfall environments (<420mm annual rainfall) or if soil constraints become severe at depths greater than amelioration (typically >35cm).
- Subsoil amelioration should be approached with knowledge of the location and severity of soil constraints in a paddock, including how deep they are, and following appropriate economic analysis. Following this approach can markedly reduce production and financial risk associated with subsoil amelioration.

Background

Many cropping soils in south-eastern Australia contain a range of subsoil physicochemical constraints including sodicity (dispersion), high electrical conductivity and boron. These can limit root growth and water and nutrient uptake, resulting in crops not achieving their full water limited yield potential. Research over the past three decades has shown the potential to overcome these soil constraints using various ameliorants, a process sometimes termed 'subsoil manuring'. However, the large upfront costs associated with subsoil amelioration (up to $1500/ha; Sale and Malcolm 2015), logistical constraints such as availability of manures, and highly variable yield responses has resulted in few growers adopting this technology.

An analysis of factors that limit the economic and technical viability of subsoil amelioration has identified four key determinants:

- the need for reliable predictions of where soil amelioration will and, just as importantly, will the need to reduce high upfront costs of implementation ($/ha)
- ready access to (relatively) cheap ameliorants, preferably sourced on-farm
- the need for a soil ameliorant to benefit several subsequent crops (residual value) to justify the investment.

This paper reports key findings from a GRDC project that addresses the four determinants of whether subsoil amelioration is a feasible management option for a grower. This project focused on medium and high rainfall cropping systems in south-eastern Australia, with a particular emphasis on clay soils. Another project, known as the 'Sandy Soils Project' (CSP00203; Therese McBeath) focuses on soil amelioration on sandy soils and the low/medium rainfall zone. We propose that the learnings outlined in this paper provide growers with the potential to effectively manage economic risk associated with soil amelioration. To assist growers and advisers in deciding whether to trial ameliorating or not, we have developed a preliminary decision tree.

Method

Results from two components of the DAV00149 project are used. The first involved a series of field trials established at two sites in 2017 and a further six sites in 2018 (Rand and Grogan in southern New South Wales, Condowie and Stansbury in South Australia, Nile in Northern Tasmania, and Kiata, Tatyoon and PBC (Horsham) in western Victoria), with four sites classified as MRZ and four as HRZ. Sites were predominantly classified as Sodosols, but there was also Vertosols (Kiata and PBC) and a Calcarosol (Condowie). All sites had sodic (exchangeable sodium percentage >6%) subsoils, but the severity and depth where sodicity first became substantial in the soil profile varied with site. Each trial assessed a range of amelioration treatments including both animal manure and plant based organic matter (lucerne or field pea), gypsum and fertiliser that were applied to either the topsoil or incorporated into subsoils (typically 25–40cm depth), which were then compared to both a 'deep ripping only' and a non-ameliorated control. Ameliorants were applied once, and soil and crops subsequently monitored for five years. Crop and soil data from these experiments were used to both assess interactions between amelioration (depth and type), soil and seasonal conditions on grain yield, as well as use in subsequent APSIM simulation modelling. The second component comprised a detailed analysis using both generalised linear mixed modelling (GLMM), and generalised additive modelling (GAM) regression procedures of a range of historical data sets and some field trials (n = 30 sites with up to six seasons monitored). These trials were conducted in south-eastern Australia from 1986 to 2020 and examined the effect of applying an ameliorant (manure or plant based) to the subsoil (typically 30 to 40 cm depending on soil conditions) on grain yields.

Results and discussion

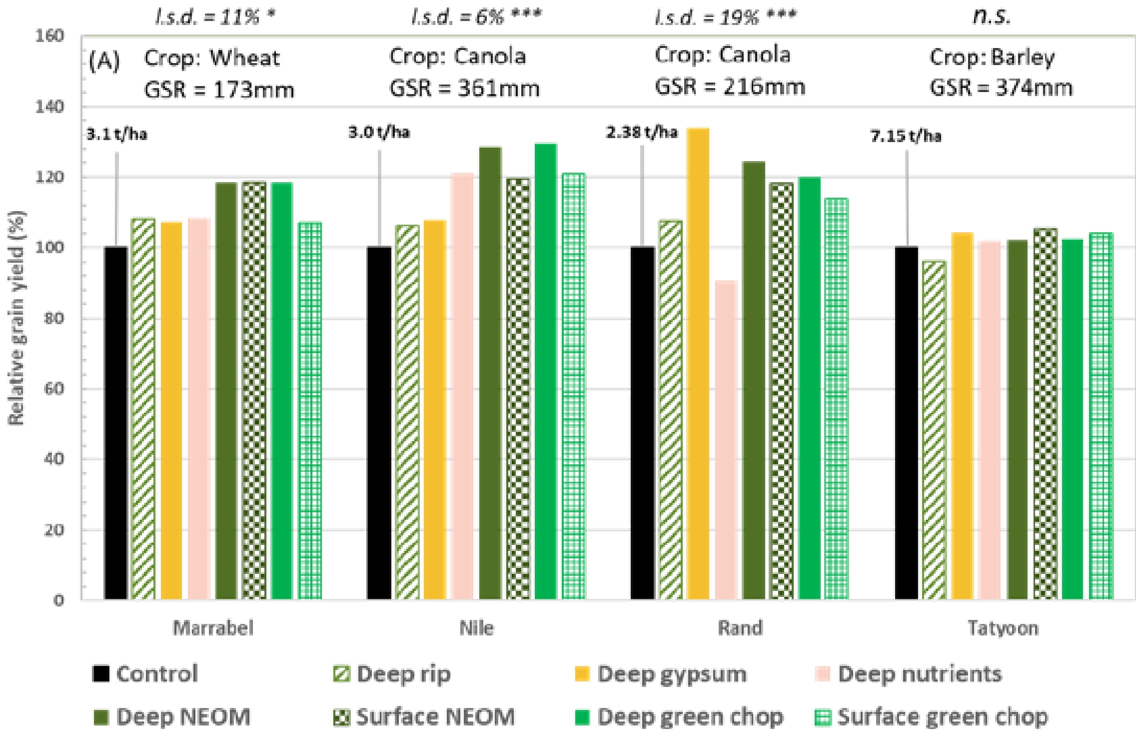
Summary of yield responses from MRZ and HRZ on clay soils

Yield responses ranged from none (or even negative) to greater than 70% for a range of crops including wheat, barley, canola and faba bean, encompassing more than 40 site x years trials. However, the majority of yield gains were between 15% and 25% and tended to occur only at particular sites. The higher magnitude yield responses tended to be in the HRZ (Figure 1), reflecting higher yielding crops. High relative responses were also recorded in the MRZ (see Figure 2), but absolute yields were lower and poor responses much more common.

There was a strong trend for most sites to either respond to soil amelioration or not, for example, Rand and Nile = positive response, Condowie and Kiata = no response over all or most years of the trial. Responsiveness was attributed principally to a combination of soil water availability and soil properties (texture and location/severity of physicochemical constraints within the soil profile). The response of two MRZ sites (Grogan, NSW and PBC, Victoria) exemplified this relationship between water and soil properties, showing no response in seasons with low growing season rainfall (GSR) but highly responsive in others, for example, 2021 – see Figure 1b.

We subsequently investigated soil moisture dynamics in the topsoil (0–40cm) using (APSIM) simulation. This modelling indicated that a combination of high clay content in the topsoil and low rainfall resulted in long periods when there was often insufficient soil water in the profile to enable decomposition of organic ameliorants, as well as a general lack of plant available water in the subsoil. This relationship between soil water availability (especially the impact of texture) is further supported by data from another project (DJP2209-002RTX: see GRDC Update presentation by Daniel Hendrie). In this project, significant responses (30-65%) to amelioration have been recorded on sections of two paddocks with sandy topsoils (Sodosols), where the amelioration zone is more likely to wet up due to lower water holding capacity. In contrast, those sections of the same paddock containing heavy clay topsoils (Vertosols), which are more difficult to wet up, were non-responsive.

Experimentation at one of the MRZ sites (PBC), where sufficient irrigation was applied prior to sowing to wet the subsoil microplots, resulted in significant crop and yield responses by barley to soil amelioration (Figure 2), whereas under 'dryland conditions', no response was recorded (Hart et al. 2022).



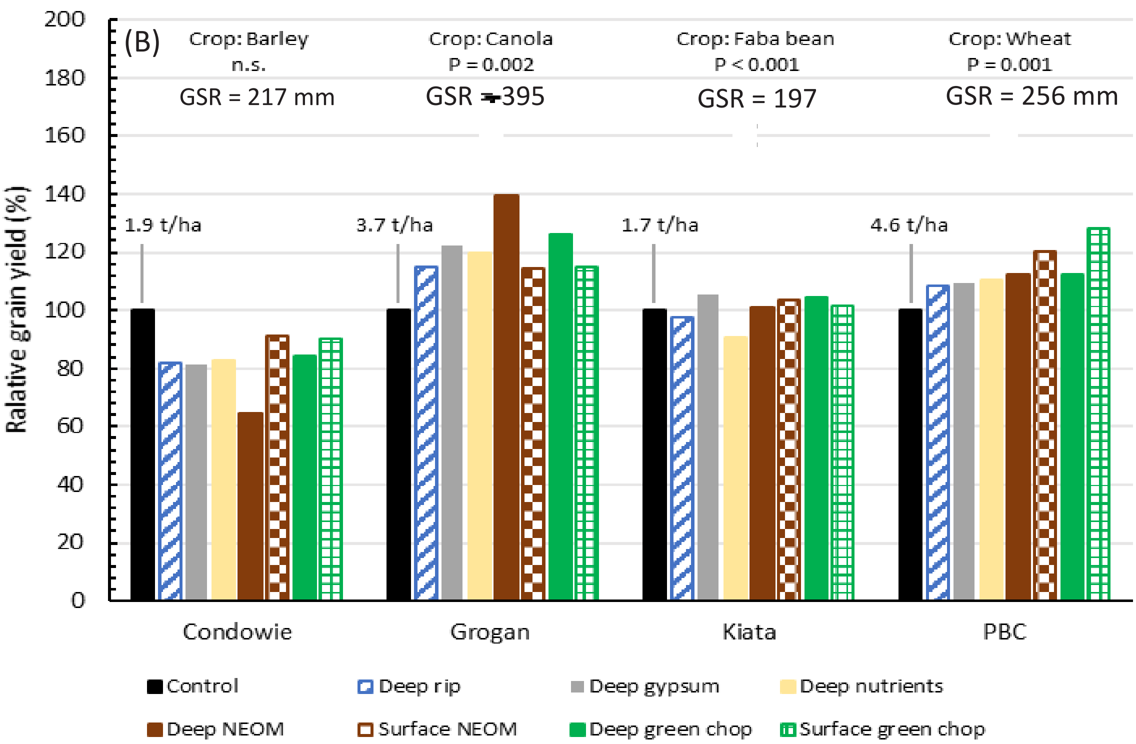


Figure 1. Relative grain yield response (%) of crops to different soil amelioration strategies with amendments applied either to the soil surface or subsoil (deep) at four sites in (A) the HRZ and (B) MRZ of south-eastern Australia. GSR = growing season rainfall (mm). The relative yield of the control treatment (no amelioration) = 100% with the value above this treatment expressed as grain yield (t/ha). 'NEOM' = animal manure pellets; 'green chop' = lucerne or field pea hay pellets. Organic amendments applied at either20t/ha (HRZ) or 15t/ha (MRZ); Deep nutrients represents the equivalent rate of N (and P) applied in the green chop. n.s. = not significant (at P = 0.05)

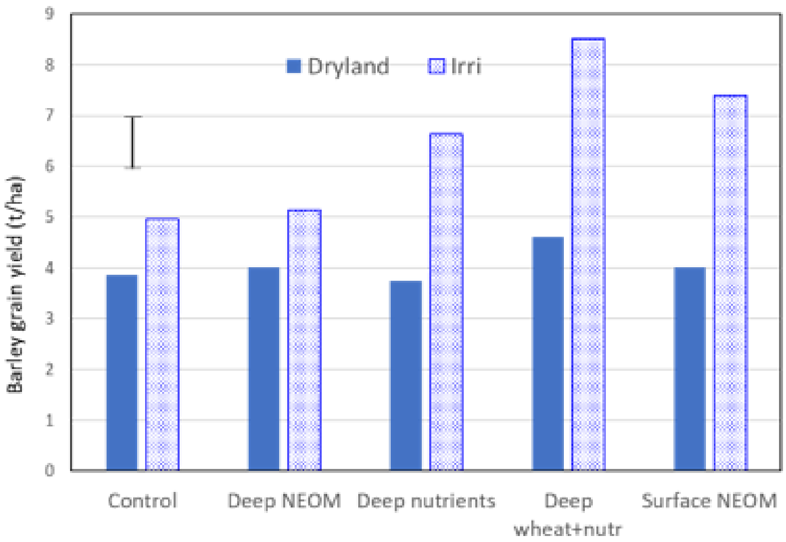


Figure 2. Grain yield response of barley to different soil amelioration treatments at the PBC site in 2020 (ameliorants were applied in 2018) under 'dryland' and irrigated subplots. NEOM = chicken litter pellets. Vertical bar is lsd (P = 0.05).

This modelling is being used to generate maps of south-eastern Australia, based on soil type and long-term climate records, of the likelihood that there will be sufficient soil water in the zone of soil amelioration (ameliorants typically placed at 30–40cm depth) for subsoil amelioration to have the potential to improve yields.

A key consideration in determining whether soil amelioration is likely to benefit yield and profit is the depth within the profile at which soil physicochemical constraints occur. The severity of most physicochemical constraints intensifies with soil depth, which reflects increasing clay content (Adcock et al. 2007). Current subsoilers have limited ability to physically place large quantities of ameliorants (15–20t/ha), whether it is gypsum or organic matter, at soil depths greater than 35cm. This is especially the case on dense clay soils in MRZ areas in most years, although this is less of an issue in HRZ due to the higher soil water levels remaining over the summer fallow which reduce soil strength. Examination of DAV00149 sites that regularly failed to produce yield responses to soil amelioration indicated that constraints such as sodicity (dispersion) did not become potentially limiting to most crops until depths >60 cm were reached. This was particularly the case with Vertosols (for example, Kiata). In contrast, Sodosols, Calcarosols and Chromosols (except where animal manures are applied) (DAV00149 SAGI analysis), duplexes (Hendrie et al. 2023) and sandy soils (Unkovich et al. 2023) tend to be consistently more responsive to soil amelioration. This soil type effect could be due to the ability of limited rainfall events to wet the amelioration zone, ease of inserting ameliorants at depth, or other factors e.g. overcoming high soil strength (Unkovich et al 2023).

The knowledge developed in these trials has been used to develop a simple decision tree when assessing whether to ameliorate a subsoil or not (Figure 3). The first factor to consider is whether soil constraints are consistently limiting achievement of the rainfall-limited yield potential over several seasons (for example, through use of header yield maps). Due to high upfront costs, most soil amelioration strategies require a 'pay-back' period of three to four seasons. Similarly, the relative size of this yield gap needs to be greater in lower yielding environments, for example MRZ compared to HRZ systems, as the size of potential yield responses (t/ha) to amelioration are inherently smaller due to less rainfall. The decision tree focuses primarily on biophysical determinants (namely, soil type and properties, soil water availability) before moving onto more detailed mapping and soil analysis. Only then are logistical and financial considerations, for example availability and costs of suitable ameliorants, considered.

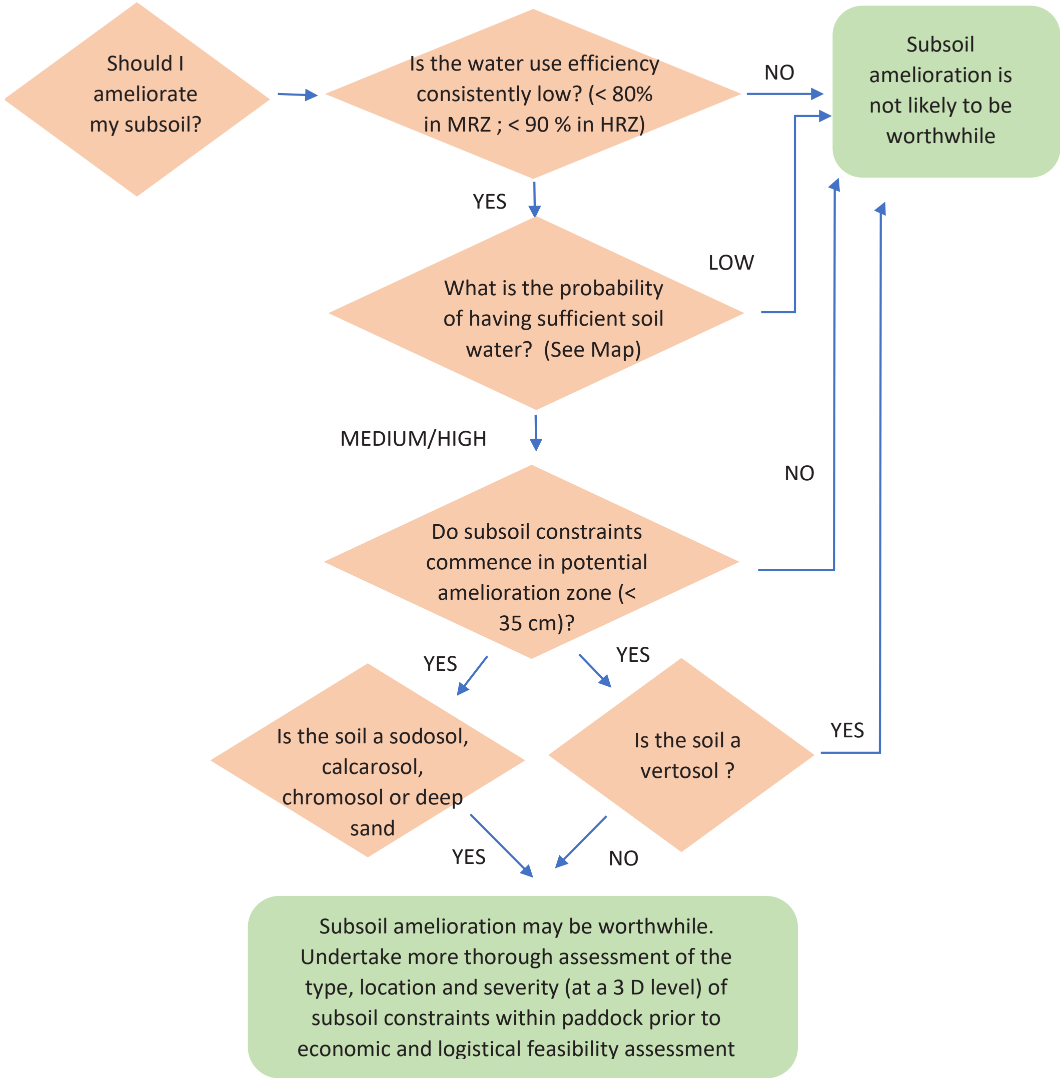


Figure 3. A decision support framework for assessing whether to ameliorate subsoils for medium and high rainfall zones of south-eastern Australia.

Conclusion

A key feature of subsoil constraints, which generally intensify with increasing soil profile depth and clay content, is that crop growth will only be reduced when subsoil water is present (Nuttall & Armstrong 2010). Similarly, subsoil amelioration will only mitigate a soil constraint if sufficient soil water is present in the amelioration zone and that available machinery can readily place a suitable ameliorant (organic matter or gypsum) in direct proximity to the constraint/s. Current continuous cropping systems based on heavy clay soils in medium (<420mm annual) rainfall zones of south-eastern Australia will rarely have sufficient water present to drive soil amelioration and boost grain yields. However, in regions with higher rainfall and soil types that are characterised by coarser texture topsoils and physicochemical constraints being located within the top 35 cm, detailed soil mapping and analysis that accounts for spatial variability in soil constraints within a paddock (see Hendrie et al. 2023) and associated economic analysis is justified and can potentially produce reliable responses to soil amelioration and improved profitability.

Acknowledgements

We would like to acknowledge the GRDC, The Australian Government (through The National Landcare Program) and our various host organisations for co-funding this research and analysis through 'Understanding the amelioration processes of the subsoil application of amendments in the Southern Region (DAV00149) and 'Soil Amelioration Extension Program in Victoria's MRZ and HRZ' (NLP 4-GKXBV5N/DJP2204-011SAX). We are also very grateful to our numerous grower co-operators who have hosted our field trials and the range of technical staff for helping conduct the field trials.

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Using resistance surveillance, IPM demonstrations and social benchmarking to improve redlegged earth mite management

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GRDC project code: CES2010-001RTX

Keywords

- insecticide resistance, integrated pest management, redlegged earth mite, social research.

Take home messages

- Due to evolving resistance in the redlegged earth mite, there is a need to reduce reliance on current insecticides and rethink management options for this pest.
- Detections of populations of RLEM resistant to SPs and OPs continue to increase, with the known range expanding, particularly in eastern Australia.
- Growers can keep RLEM under economic thresholds with minimum insecticides and preserve higher densities of beneficials.
- Social benchmarking has identified attitudes towards insecticides and IPM, and showed that that agronomists can be more risk adverse than growers.

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 grain and pasture regions affected by this pest, resistance surveillance and the development of up-to-date management recommendations help to maintain the effectiveness of current chemical control options. Integrated pest management (IPM) strategies provide alternatives to insecticide use and support growers' efforts to manage insecticide resistance. Social research develops our understanding of current knowledge and attitudes regarding insecticide resistance management. These insights are used to ensure that management recommendations are applicable and achievable.

In this presentation, we will:

- present data on the current resistance status of RLEM in Australia
- showcase results from the project's IPM demonstration sites
- present and discuss the project's social benchmarking research, and
- provide recommendations about insecticide resistance management and improved control methods to help growers and advisors stay on top of RLEM pest problems this year.

Field surveys and resistance testing

Since the first detection of SP resistance in RLEM in 2006, resistance surveillance has been undertaken every year, covering a wide geographical range throughout Western Australia and eastern Australia (including SA, Victoria, and New South Wales). RLEM populations collected for the resistance screening have been mostly collected from a mixture of paddocks with reported chemical control failures and paddocks with high insecticide and intensive cropping usage, with some indiscriminate collections also undertaken from paddocks and roadside vegetation. Samples of mites from each population have been screened for SP and OP resistance using phenotypic laboratory bio-assays (Arthur et al. 2021) and/or genetic markers targeting the known resistance mechanism to SPs (Edwards et al. 2018).

Following the screening, growers and advisors have been provided with a full report outlining the type of resistance present on their farms. The report is accompanied by management recommendations that are specific to the type of resistance present. Using this information, growers can minimise RLEM chemical control failures and the evolution and spread of insecticide resistance. More broadly, the surveillance and mapping of RLEM resistance provide important information that assists growers to implement successful management strategies to minimise the impact of RLEM. Resistance surveillance information is also used to update the RLEM Resistance Management Strategy (RMS).

IPM demonstration sites 2022

On-farm trials were established to demonstrate IPM approaches and novel control strategies, that is, reduced insecticide applications for RLEM control. These demonstration sites help to make the research findings available to Australian grain growers to support the widespread adoption of IPM for RLEM control. The IPM demonstration sites are in Stoneleigh and Tennyson (Victoria). Both sites compare conventional farming practices to more novel farming approaches and the effect they have on RLEM abundance, predatory mites, and other beneficial invertebrates.

Stoneleigh was sown with wheat for the 2022 growing season. Here, the three different management scenarios were composed of two novel management plots – 'Novel' and 'Novel+' – and a 'Conventional' plot, all of which were ~10ha. The Novel plot is how the rest of the paddock has been traditionally managed by the grower. The additional Novel+ examined the effect of no fungicide applications. All plots received the same fertiliser treatments.

At the Tennyson site, the paddock was also sown with wheat for the 2022 growing season. This site compares RLEM abundance with conventional farm management practices with a novel approach that uses few chemicals and improves crop health and soil nutrition by adding biological inputs such as vermicast extracts, fulvic powder, and biofertilisers. In the 2022 season, three management scenarios were demonstrated: two conventionally managed plots and one novel plot, all of which were ~10ha.

Within the plots at each site, 15 observations were made at four times throughout the growing season. Each observation point was a 50cm x 50cm quadrant which was sampled for mites and other invertebrates using a Stihl vacuum blower with a fine mesh over the end of the suction tube. RLEM and other invertebrates were counted. Plots were harvested at the end of the cropping season and yield data will be used to conduct a cost-benefit analysis to compare the profitability of the different treatments.

Social benchmarking

Using a national online survey, we investigated the current knowledge, practices, and attitudes of growers and advisors relating to RLEM insecticide resistance management. We aimed to understand how chemical-based management of RLEM is influenced by variables such as risk attitude, risk perception and knowledge. The findings provide information on current barriers to the adoption of sustainable management practices in different sub-populations and will inform the development of improved training and awareness outputs.

The survey was 24 questions long and was divided into the following categories:

- demographics
- insecticide use patterns
- attitude towards risk in their management practice/advice
- knowledge of RLEM and insecticide resistance, and
- connectivity in their community.

Both growers and advisors were asked a range of questions about their chemical usage, attitude to risk about pest management, knowledge of the RLEM resistance status, ability to correctly identify the mite, and lifecycle, and estimate the number of non-chemical options available.

Results and discussion

Field surveys and resistance testing

Resistant RLEM populations have been found across Western Australia, South Australia, and Victoria since resistance surveillance began in

2006. Screening undertaken between 2006 and 2022 found SP resistance to be widespread across the southern regions of WA and in some parts of South Australia (Arthur et al. 2021). OP resistance has been detected in the southern regions of Western Australia and parts of South Australia and Victoria.

Within WA, the current distribution of SP and OP resistance is widespread, covering the southwest, great southern, south coastal and wheatbelt regions (Figure 1). Resistance in RLEM appears to be increasing in WA, with new resistant populations being detected each year. For example, RLEM resistance to OPs has only just been detected for the first time last year in the southern coastal regions of WA (Mata et al. 2022).

Over the last few years, we have seen a major increase in RLEM insecticide resistance in eastern Australia, particularly within South Australia. In South Australia, resistance was first discovered in 2016, and since then, resistance has been detected in several areas including Kangaroo Island, the Fleurieu Peninsula, and the south-east region (Figure 1). Over the last couple of years, there has been an increase in resistant populations to SPs and OPs in these areas, particularly in the south-east region. More recently, resistant populations have been detected in the mid-north region.

Resistance in Victoria was first detected in 2018 to OPs, in 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 in Minimay in the Wimmera region. There has been no SP resistance detected within Victoria to date.

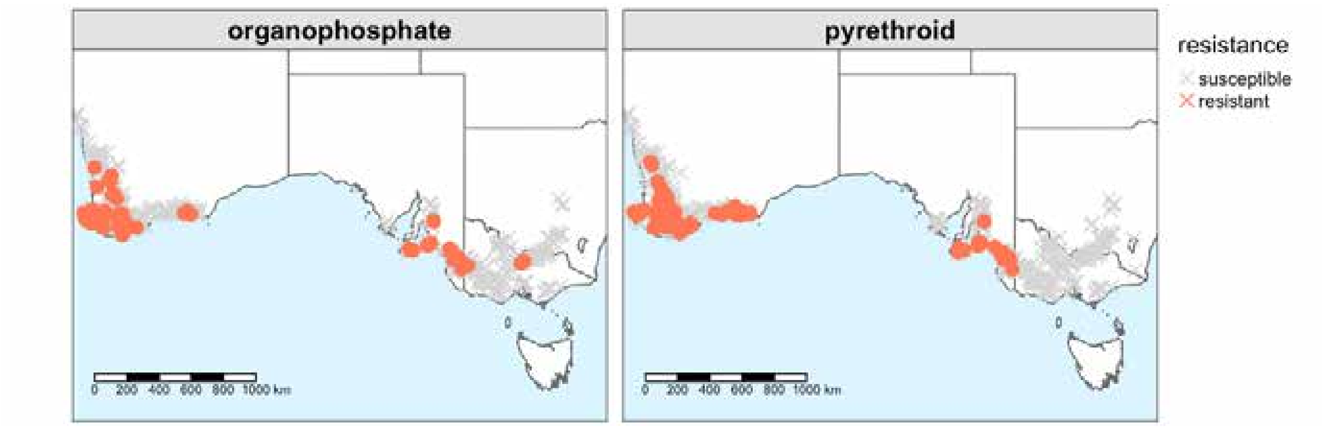
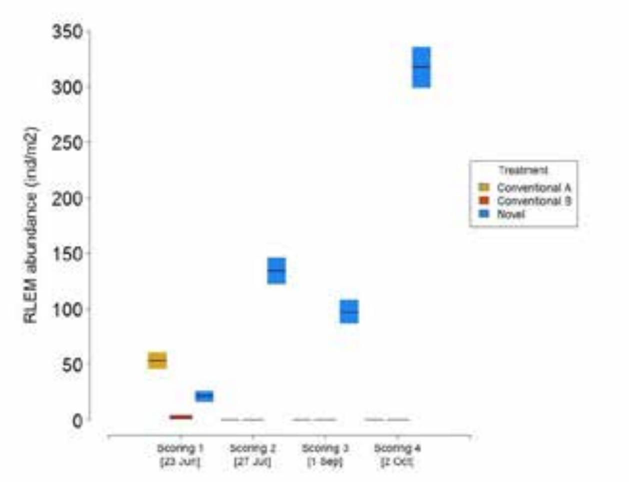


Figure 1. Current resistance status of RLEM resistance in Australia as of 2022 to OPs and SPs.

IPM demonstration sites

Across both demonstration sites, unsurprisingly, our findings show that an SP foliar application greatlyreduced RLEM numbers when applied to the conventional plots (Figures 2 and 3). Importantly, in the plots that did not receive an insecticide spray application, RLEM remained well below the economic thresholds for wheat. The economic threshold for wheat is 5 000 mites per m^2 (Miles 1996). Although the trials are still in their infancy, these initial findings suggest that the current IPM management strategies being employed at each site provide a level of natural suppression against RLEM. Yield data and cost-benefit analysis for the 2022 growing season are yet to be analysed.



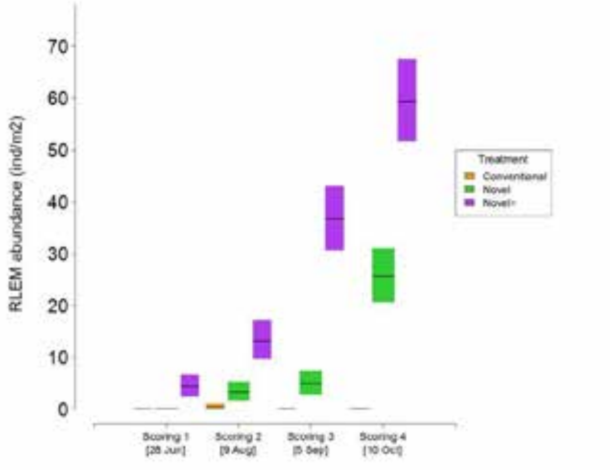
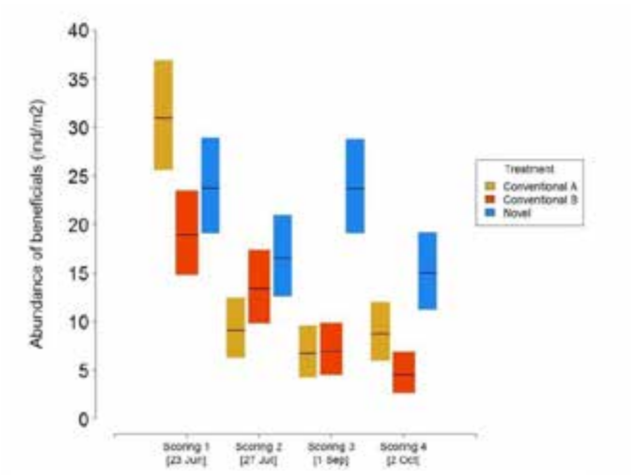


Figure 2. RLEM abundance by treatment and scoring timepoint at the Tennyson IPM demonstration site. The black horizontal lines represent the mean response and the coloured boxes the associated uncertainty (95% Credible Intervals). Ind: Individuals.

Figure 3. RLEM abundance by treatment and scoring timepoint at the Stoneleigh IPM demonstration site. The black horizontal lines represent the mean response and the coloured boxes the associated uncertainty (95% Credible Intervals). Ind: Individuals.

Our analyses also indicate that the foliar SP application had a negative effect on predatory snout mites and other beneficial invertebrates. In the conventional plots at the Tennyson site, beneficial abundances steadily declined over the season (Figure 4). This suggests the insecticide had a lasting impact on the populations of beneficial species. At the Stoneleigh site, populations of snout mites and other beneficials built up over the season in both novel plots, but not in the conventional plot (Figure 5).



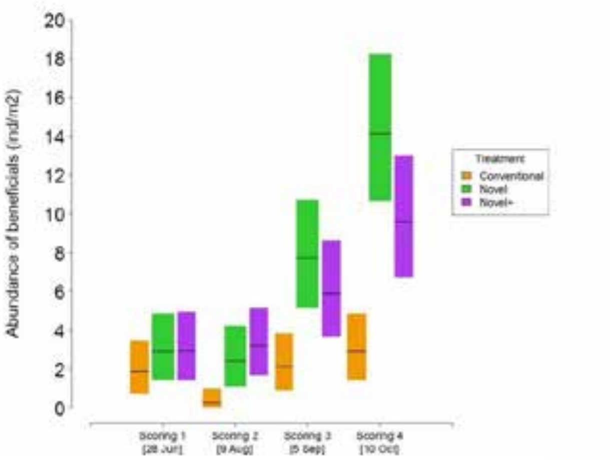


Figure 4. The abundance of beneficial insects, spiders and mites by treatment and scoring timepoint at the Tennyson IPM demonstration site. The black horizontal lines represent the mean response and the coloured boxes the associated uncertainty (95% Credible Intervals). Ind: Individuals.

Figure 5. The abundance of beneficial insects, spiders and mites by treatment and scoring timepoint at the Stoneleigh IPM demonstration site. The black horizontal lines represent the mean response and the coloured boxes the associated uncertainty (95% Credible Intervals). Ind: Individuals.

Social benchmarking

A total of 273 responses were received. When partial and invalid responses were removed (for example, had not encountered RLEM before or did not work as a grower or advisor in Australia), this resulted in 93 responses from growers and 97 responses from advisors. When growers were asked how often they apply foliar insecticides specifically for control of RLEM, 5% answered several times a season, 35% every year, 25% once every 2–3 years, 9% once every 4–5 years, 14% rarely (once in 10 years), 11% never and 1% unsure. In relation to the use of IPM, Figure 6 shows how often respondents reported they employ an IPM mindset. When making RLEM management decisions, 72% of growers consider environmental factors and 77% consider paddock history. For advisors giving management support, 81% consider environmental factors and 88% consider paddock history. There were very few respondents who self-reported never having an IPM mindset. Responses to risk questions can be seen in Figure 7. One observation from these results is that growers are more worried about economic loss, but advisors are much more cautious about adopting new practices and wanting to see the results from farm trials before trying practices on their farms.

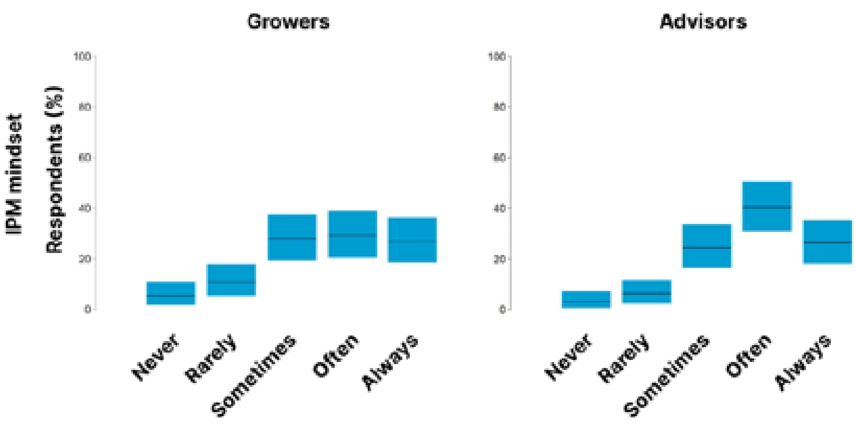


Figure 6. Growers (left) and advisors (right) responses when asked how often they employ an IPM mindset when making RLEM management decisions or providing advice. The black horizontal lines represent the mean response and the blue boxes the associated uncertainty (95% confidence Intervals).

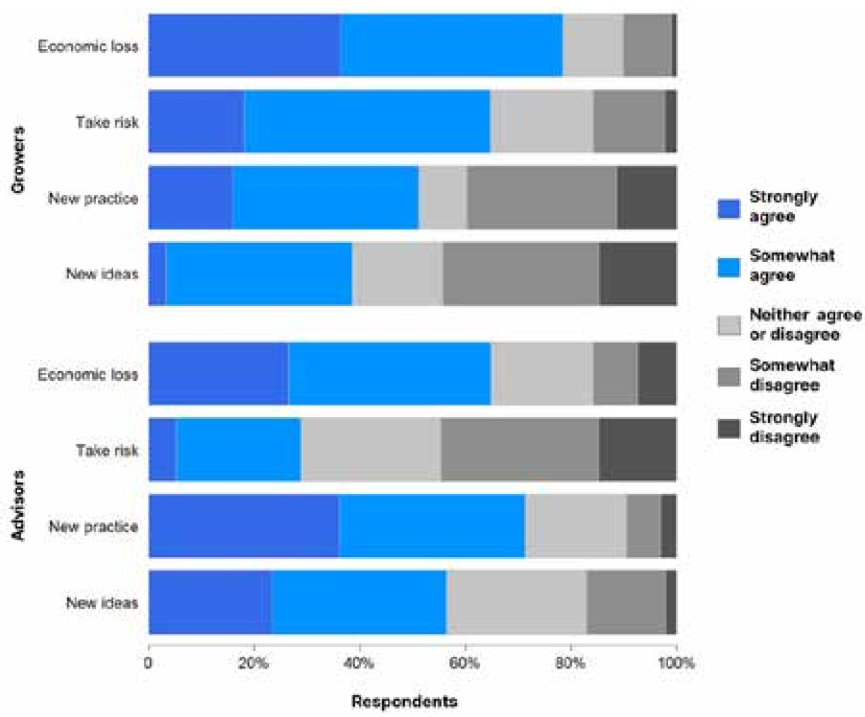


Figure 7. Growers (top) and advisors (bottom) responses to questions related to risk in on- farm pest management. The following abbreviations were used for each survey question: Economic loss - I am concerned about economic loss as a result of invertebrate pest damage; Take risk - I am willing to take risks when it comes to farming; New ideas - I am cautious about adopting new ideas and farm practices; New practice - A new farm practice must be proven on other farms or trials before I will use it.

Conclusions

The ongoing surveillance of RLEM provides growers with insight into the resistance status in their region, which can inform management decisions. In areas with high levels of resistance or risk of resistance, growers and advisors can use the RLEM RMS to inform their management practice. Key recommendations for RLEM control include:

- assess RLEM populations over successive checks to determine if chemical control is warranted
- do not use the same chemical group across successive spray windows (on multiple generations of mites) as this will select for resistance to that chemical group
- co-formulations or chemical mixtures are best reserved for situations where damaging levels of RLEM and other pest species are present, and a single active ingredient is unlikely to provide adequate control
- consider the impact on target and non-target pests and beneficial invertebrates when applying insecticide sprays. Where possible, use target-specific 'soft' chemicals, especially in paddocks with resistant RLEM
- if you experience a chemical control failure involving RLEM and/or suspect insecticide resistance, contact DPIRD (WA) or Cesar Australia (SA, Vic, NSW) who can assist with advice and/or resistance testing.

The social research enables us to better understand motives and identify knowledge gaps, which will be used to produce regionally relevant management recommendations and extension materials which address the concerns of growers to help increase the adoption of IPM practice.

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Redlegged earth mite best management practice guide – southern (https://grdc.com.au/resources-and-publications/all-publications/publications/2020/redlegged-earth-mite-best-management-practice-guide-southern)

Free RLEM insecticide resistance testing (https://cesaraustralia.com/pestfacts/free-rlem-insecticide-resistance-testing/)

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Notes

To what extent does legume break crop frequency reduce long-term N fertiliser requirements?

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Keywords

- N fertiliser, global warming potential, gross margin, legume.

Take home messages

- In an above-average growing season in the southern Mallee, more than 35kg N/ha fertiliser was required to maintain the N balance in wheat following 1- and 2-year legume phases.
- Modelling across rainfall environments suggests including legumes in crop sequences reduces the N bank target and the amount of fertiliser required to top-up soil mineral N to meet N bank targets.
- Including grain legumes (GL) improved predicted sequence gross margins (GM) at all sites compared to continuous cereal (CC). Sequences with brown manure (BM) sequences were less profitable than GL but still had a positive gross margin.
- Higher legume frequency reduced the global warming potential emissions from soils at low and medium rainfall sites, but it increased at higher rainfall sites.

Background

Removal of nitrogen (N) deficiency has the potential to increase Australian wheat yields by 40% (Hochman and Horan 2018). However, N fertiliser costs remain high as we enter the 2023 growing season (for example, urea currently ~$1100/t), with potentially large N outlays required following large exports from the 2022 grain harvest in much of the southern grain belt. Further, the agricultural industry is under increasing pressure from policy makers to consider how to increase food production and soil fertility while reducing environmental impact. The question facing Australian wheat growers is where best to source N to profitably increase crop production whilst also minimising environmental impacts?

An emerging approach to determining the amount of N to supply to crops has been coined the "N Bank" (NB) strategy and is in early phases of testing (Hunt et al. 2022, Meier et al. 2021, Smith et al. 2019). In this strategy, N fertiliser is used to maintain a base level of mineral N in the soil which is adequate to achieve water-limited yield potential in most seasons. The optimal base level of fertility (NB target) varies with production environment and is strongly influenced by average annual rainfall (Meier et al. 2021).

All previous evaluations of N banks have assumed continuous wheat (Meier et al. 2021, Smith et al. 2019) or non-legume crop sequences (Hunt et al. 2022), with no input of biologically fixed N. However, most Australian farming systems incorporate a legume – be it a pulse crop such as lentil or chickpea, an annual forage such as vetch or French serradella, or ley pastures of subterranean clover, medic or lucerne. Previous research reports that combining legume and fertiliser sources of N can be used for improved soil fertility and productivity outcomes (Armstrong et al. 2019, Muschietti-Piana et al. 2020). However, it is not known to what extent the inclusion of legumes in crop sequences changes optimal NB targets, or to what extent N fertiliser can be reduced to meet the NB targets. Following the identification of negative N balances in a range of legume sequences in a field experiment in an above-average growing season, we use the farming systems simulator APSIM to quantify the contribution of legumes (brown manure and grain legume) to the long-term environmental optimal NB target in low to high rainfall environments in South Australia.

Method

N-supply contribution of legumes to the cereal phase (single year field experiment)

Wheat (cv. Scepter) yield following a 1- or 2-year vetch or medic phase was measured in a 2020 field experiment in Lameroo, SA to determine the N-supply contribution and benefit of legume inclusion in the farming system, and to calculate a partial N-balance (that is, losses are not accounted for) of different legume options:

Partial N-balance = (N fertiliser + N fixation) – (export in grain)

Simulated long-term contribution of legumes to the cereal phase

APSIM V7.10 (Holzworth et al. 2014) was used to simulate wheat yield and quantify the N supply following phases of legumes (field pea) over a 30-year period inclusive (1991–2020). Wheat crops were grown in sequence with grain legume (GL) and brown manure (BM) legumes at 5 intensities (0%, 25%, 33%, 50%, 67%, where e.g., 25% = a legume grown 1 in 4 growing seasons etc.) to determine the effect of each sequence*intensity on the NB target and the subsequent effect on wheat yield. Nitrogen treatments were nil fertiliser (control) and the NB (with NB targets of 20–360 kg N/ha in 20kg N/ha increments) method as per Meier et al. (2021). Nitrogen fertiliser was only applied to wheat crops in the sequence. All wheat crops received top-up N fertiliser at sowing to 40kg N/ha if soil mineral N in the surface 1m of soil was less than 40kg N/ha. In NB treatments, wheat crops received top-up N to the amount of the NB at 65 days after sowing. Nitrogen treatments were applied as a factorial of sequence*intensity combinations. The optimal NB target was defined as the first treatment to deliver a median yield of 80% of water limited potential yield (PYw) within each legume (GL, BM) and intensity (0%, 25%, 33%, 50%, 67%) combination. The value 80% of PYw is assumed to be economic yield (EY) as defined by (Fischer 2015).

Sites were selected to represent a gradient of annual rainfall (Table 1). Simulations were from 1971–2020, but the first 20 years were discarded to enable soil water and N to achieve equilibrium. The results presented are the subsequent 30 years (1991–2020). Wheat was sown at 150 plants/m2, with a mid-fast spring cultivar (for example, Scepter). In GL and BM sequences, Kaspa field peas were sown on 15-May at 40 plants/m2. In BM sequences, the field pea was terminated at the start of podding. All crops were sown at a depth of 30mm and a row spacing of 300mm. No frost or heat penalties were applied to wheat and legume grain yields.

Table 1: The mean rainfall, patch-point dataset (PPD) station number, and key soil characteristics of the four sites used in the simulation study.

	Location			
	Waikerie	Lameroo	Bordertown	Millicent
Location	-34.1778°N, 139.9806°E	-35.3288°N, 140.5175°E	-36.3125°N, 140.771°E	-37.5872°N, -37.5872°E
PPD weather station no.	024018	25509	025501	026018
Avg annual rainfall (mm; 1990–2019)	263	346	448	704
Growing season rainfall (mm; 1990–2019)	161	236	336	552
Rainfall zone	Low	Low	Medium	High
Organic carbon (%; 0–10cm)	0.3	0.6	1.7	5.0
pH (0–10cm)	8.1	7.4	7.8	8.4
APSoil No.	589	253	344	1254

Calculations

Gross margins and soil-based greenhouse gas emissions (GHG)

Gross margins (GM) were calculated using industry benchmark data for Australian Premium White (APW) wheat and field pea (PIRSA 2022). GMs for BM field pea were calculated using the same expenses as field pea harvested for grain except for seed treatments, levies, chemicals and grain freight. Variable costs were applied to locations based on low (Lameroo, Waikerie), medium (Bordertown) and high rainfall (Millicent) zone estimates (PIRSA 2022). GMs presented are the mean across the simulated period.

For each simulation, GHG emissions were calculated from emissions of N2O from the soil profile, and CO2 associated with the change in soil organic carbon (SOC) stocks in the surface 0.3m of soil. The emissions of N2O were converted to common units of carbon dioxide equivalent (CO2e) values using the 100-year conversion factor of 298 (IPCC 4th assessment report, IPCC 2013), to enable the different GHGs to be summed to determine the net GHGs from each scenario. The change in SOC was converted to carbon dioxide equivalent (CO2e) values by multiplying by 3.67 to obtain the equivalent mass of CO2 (IPCC 2013). The net global warming potential (GWP) of each simulation was reported as the sum of these CO2e values. The GWP presented are the mean the simulated period.

Results and discussion

Field experiment

Long-term growing season rainfall (April–October, 1990–2020) in Lameroo is 236mm, in 2020 it was 343mm. The above-average rainfall, and minimal frost and heat stress resulted in 2-year medic pasture increasing subsequent wheat yield by 2.9t/ha (88%) relative to the continuous cereal control, while an annual grain legume (field pea) provided 1.9t/ha (58%) benefit compared to continuous cereal treatments. The pastures that were regenerating in 2019 (2-year pasture phase) provided a higher break crop effect compared to those that were sown in 2019, but all provided a yield increase in subsequent wheat of more than 48% (Table 2). The yield increase could be attributed to greater spike number m2, harvest index (HI) and/or grain weight (data not shown) supported by higher N supply (Table 2) and reduced disease incidence (take-all and rhizoctonia, data not shown) after 2019 legume treatments. Nitrogen inputs were less than N removal in all legume treatments resulting in negative partial N mass balances (-19 to -30kg N/ha) in the favourable 2020 growing season, suggesting that the legume-cereal sequences mined soil organic N and thus, soil organic matter. Long-term simulation that takes into consideration the highly variable climate of the region enables us to determine the long-term impact of these sequences on N supply.

Table 2: The partial nitrogen-balance of forage and grain legumes sequences in a field experiment in Lameroo, SA 2020.

2018/19 crop type	Measured 2019 N fixation (kg N/ha)	2020 Wheat grain yield (t/ha)	2020 Grain protein (%)	2020 N removed (kg N/ha)	N balance (kg/ha)
2nd year Medic	44	6.2	10.1	109	-30
1st year Medic	29	4.9	9.6	84	-20
Brown-manure vetch	46	5.7	10.2	101	-20
Field pea	46	5.2	9.4	108*	-27
Barley	0	3.3	9.4	54	-19

**N removed also includes from field pea grain yield in 2019.*

Simulation experiment

Simulation revealed that locations with annual rainfall of 263–704mm had an optimal NB target under continuous cereal rotations of 60–220kg N/ha, in which the mean N applied to maintain the optimal NB target (target that achieves 80% water-limited water potential on average) ranged from 44–146kg N/ha (Table 3). The simulation study demonstrated that legume phases at 25–75% intensity can reduce and sometimes eliminate the need for long-term mean fertiliser N application required to maintain the optimal NB, however each strategy had varying economic and environmental implications. The number of legumes required to reduce N application by 20kg N/ha was one in three for GL and BM at Waikerie; one in three GL, one in four BM at Lameroo; one in three GL, one in four BM at Bordertown; and one in three for GL and BM at Millicent (Table 3). In practice, grain legumes (for example, lentil, field pea, chickpea) grown at high intensity (two grain legume crops for every cereal crop) would require careful management of both foliar (for example, ascochyta blight), and root disease (for example, root lesion nematodes).

Using the 2022 'Farm gross margin guide' price for urea ($1500/t urea; PIRSA 2022), applying N to target the optimal NB with fertiliser alone for 0.8 water limited yield potential was profitable at all sites. The most profitable sequences included GLs, however BM sequences also maintained positive GM at all intensities and sequences at all sites (Table 3).

In terms of environmental impact, the optimal NB target was reduced when legume frequency was increased due to an increase in soil total N (data not shown). Nitrogen losses by denitrification and leaching were modest at 1.5-19% of total N inputs, with the highest losses in Millicent. Targeting an optimal NB reduced mining of SOC and therefore also reduced CO2 emissions from the soil, compared to under-fertilising in NB scenarios below the optimum which resulted in greater emissions due to mining of soil organic matter (data not shown). Lameroo, Waikerie and Bordertown had negative GWP (abatement) when targeting the optimal NB with fertiliser alone, but Millicent did not (Table 3). At Lameroo and Waikerie, increasing the intensity of legumes reduced mean GWP across the simulation period. At higher rainfall sites (Bordertown and Millicent), GWP increased as legume frequency increased, associated with higher rainfall and residue turn over. Note that these calculations don't currently include emissions associated with fertiliser production and are only soil based (N2O and CO2).

Table 3: Optimal NB target, mean (1991–2020) N applied to maintain NB target, yield, sequence gross margin (GM) and net global warming potential (GWP) for the minimum NB to achieve 80% of yield potential when a grain legume or brown manure legume is included in the sequence at increasing frequency (0–67%). CC=continuous wheat, GL=grain legume, BM=brown manure. Negative net GWP values occur where decrease in CO2e associated with increase in SOC exceeded emissions of N2O (i.e., net abatement occurred).

Location	End use	Legume intensity %	Optimal NB target (kg N/ha)	N applied to maintain N-bank target (kg N/ha)	Wheat yield t/ha	Legume yield t/ha	GM $/ha/yr	Net GWP Kg CO2e /ha/yr
Waikerie	CC	0	60	44	1.9	0	49	-267
	GL	25	60	39	1.9	1.8	177	-344
		33	40	22	1.8	1.8	261	-345
		50	0	7*	1.7	1.7	333	-369
		67	0	3*	1.7	1.6	344	-396
	BM	25	60	36	2.1	0	60	-373
		33	40	18	2.0	0	99	-381
		50	0	1*	2.2	0	110	-445
		67	0	0	2.4	0	23	-444
Lameroo	CC	0	100	85	3.0	0	72	-90
	GL	25	100	81	3.1	2.2	268	-207
		33	80	61	3.0	2.2	371	-213
		50	60	37	3.0	2.2	509	-268
		67	0	0	2.7	2.1	584	-303
	BM	25	80	61	3.0	0	131	-69
		33	60	40	2.8	0	160	-56
		50	40	12	2.9	0	190	-102
		67	0	0	3.1	0	101	-83
Bordertown	CC	0	160	156	5.8	0	372	-392
	GL	25	140	134	5.6	5.0	769	-333
		33	120	113	5.4	4.9	927	-282
		50	80	72	4.9	4.8	1160	-136
		67	60	45	4.5	4.5	1260	-136
	BM	25	160	151	6.0	0	280	-78
		33	120	112	5.6	0	325	55
		50	80	68	5.9	0	388	207
		67	0	0	5.6	0	305	524
Millicent	CC	0	220	146	6.6	0	636	770
	GL	25	220	144	6.9	5.3	983	1043
		33	160	90	6.2	5.2	1181	1218
		50	120	47	6.7	5.2	1544	1256
		67	120	45	6.7	5.2	1597	1582
	BM	25	240	157	6.9	0	405	1419
		33	180	105	6.2	0	438	1623
		50	120	45	6.5	0	534	1771
		67	120	29	6.6	0	297	2309

**starter fertiliser only*

Conclusion

After an above-average growing season in 2020, there was a large export of N in grain that resulted in a negative N balance even following a legume manure and a 2-year legume phase. A similar scenario is likely following the 2022 growing season. Our field experiment and simulation show that using both legumes and fertiliser as sources of N to maintain an NB target can help to build up total soil N. The simulations predict that over the period 1991–2020, high intensity legume phases can reduce or completely remove mean fertiliser N application required to maintain an optimal NB target for cereal production at the four sites evaluated and reduce the optimal NB target. Grain legumes and brown manures maintained positive GM, but in high rainfall environments, increased GWP at high intensity. The strategies evaluated in this simulation study should be validated with long-term field experiments.

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The Frost Learning Centre

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SAGIT Project Code: MHR121

GRDC Project Code: SAG2107-001OPX

Keywords

- frost, ice nucleation, mitigation, tolerance.

Take home messages

- Managing frost risk and impacts can only be achieved by implementing strategies relevant to frost zones.
- Don't implement frost risk strategies if you don't experience frost losses – frost risk management almost invariably means reducing income in non-frost areas.
- Think holistically – what can be done to avoid frost, what frost tolerance is available, what can be planned as mitigation should frost occur.
- Understand frost – temperature, ice nucleating bacteria, the window of damage, what is your particular financial exposure.

Background

Frost is a major constraint to production of crops in many areas of South Australia. To make real inroads into managing frost, we should aim to put strategies in place for those areas that are often, or severely, impacted, while maintaining the production of high yielding, high value crops where there is no risk of frost having an impact. In this paper, we define the high loss areas as 'Frost Red Zones' and the areas that never get frosted as 'Frost Green Zones'. Between the Red and Green Zones is an area that we call the 'Amber Zone' – it varies in size depending on how severe the frost is, but it never reaches the Green Zone and always emanates from the Red Zone.

The correlation between temperature and frost damage is low, except at the extremes where no damage occurs above a certain temperature and complete desiccation occurs below a very low temperature. Within these extremes there are influences of plant physiology and ice nucleation that influence the formation of ice, which is what causes cell damage. Bacteria have the most influence of all nucleators. A resilient farm system also limits losses when frost damage occurs.

Method

The Frost Learning Centre (FLC) is located near Farrell Flat and is situated where there is a 'Red Zone' and a 'Green Zone' available in the same paddock.

Individual research components are conducted in the 'Red Zone' with complementary trials in the 'Green Zone'. This allows for comprehensive research where frosts occur, but the impact of the treatment on yield where there are no frosts can be assessed. By conducting research in this manner, the impact of adopting Red Zone tactics in Green Zones and vice versa can be assessed. This additionally results in an assessment of which Red Zone tactics have some application in Amber Zones, and also, where we might treat an Amber Zone more like a Green Zone.

One of the difficulties of conducting frost research is the frequency and extent of frosts themselves and site selection. There must be frost in order to obtain damage, but when repeated frosts occur, it may be impossible to determine which one actually caused the resulting damage. However, if there are no frosts, then the research has no application. There was substantial frost damage in 2019, but it is inconclusive if it was caused by one of many events, and if so, which one. Damage could also have been due to more than one event, where some damage occurred with one and different, or additional, damage occurred with another frost event.

By using structures that protect plants from freezing when a frost occurs (frost shelters), and by using techniques that can induce freezing when otherwise it wouldn't have occurred, the FLC project has been able to more accurately define damage and responses to interventions that have been researched. Damage was identified visually and in 2021, wheat heads were dissected in a number of trials and individual grain sites assessed for missing (frost before, at or very shortly after flowering) or 'frosted' (between 1mm grain length and full grain size).

Thermal imagery is a useful tool in determining treatment responses and has been used at the Frost Learning Centre.

Research conducted by Amanuel Bekuma, Brenton Leske and Ben Biddulph from Department of Primary Industries and Regional Development (DPIRD), WA into the role of ice nucleating bacteria in freezing has played an important role in assessment of treatments at the FLC.

Results and discussion

Frost incidence at the Frost Learning Centre

The correlation between Stevenson Screen temperature, air temperature at the crop canopy and crop surface temperature can be relatively poor. Results from 2021 and 2022 confirm previous experiments that air temperature is not a reliable guide to frost damage.

2021

There were 48 events, between 19 July and 9 November 2021, recording below 2oC at 1.25m in a Stevenson Screen above bare ground (2.2oC would indicate frost conditions are met at ground level).

Severe frost damage was recorded at the site from spring frosts.

There were five consecutive nights from 24 August at or below -1oC, 14 events in September below 2oC with six below 0oC, 13 events below 2oC in October with eight below 0oC and two in early November, with one at -1.5oC. Super High Oleic (SHO) was a component of research at the site and frosts on December 8 & 9, 2021 damaged heads prior to flowering.

2022

There were 27 events from 19 July to 30 November and a further two on 8 December and 14 December.

There were seven events in August, nine in September, four in October and two in November. Six consecutive nights below -1oC were recorded late August/early September and one event below -1 on 9 October and again on 14 December. All crops, except for SHO safflower, had completed grain filling by 14 December.

There was very little frost damage observed due to spring frosts in 2022.

A snapshot of selected research conducted at the Frost Learning Centre

Frost avoidance

Avoiding frost is an important factor in reducing losses. Generally, frost avoidance is achieved by having crops at sensitive growth stages after the 'frost period' has ended. This has involved later maturity driven by later seeding or longer season cultivars. The downside of this tactic is that for many areas of SA, delaying maturity increases exposure to hot conditions and declining soil water with reduced rainfall during usual spring conditions. In SA, there are opportunities with wet, cooler springs (such as 2022), but they are usually unable to be predict accurately at planting time. Nonetheless, some areas of the Mid North, Mt Lofty Ranges and South-East have a higher proportion of favourable rainfall, temperature and soil types where avoidance can be practiced successfully.

Occasionally, having early maturity, prior to frosts, can be successful. Planning an earlier maturing escape is particularly difficult.

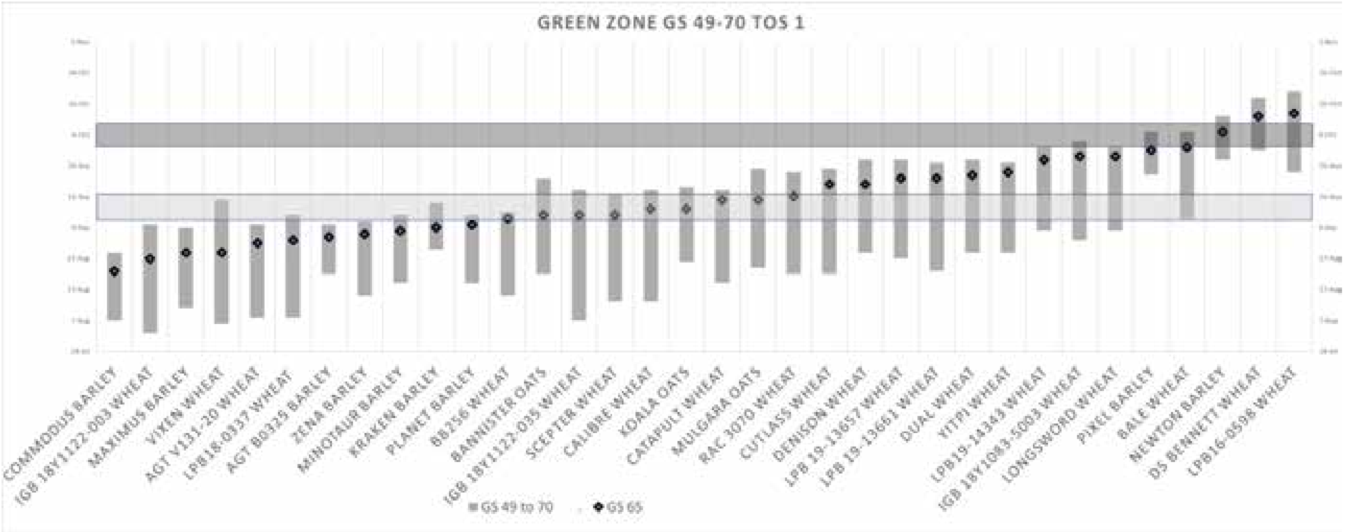

Figure 1. Phenological development of wheat, barley and oat cultivars sown on April 17 2022 showing Zadok's GS 49 to 70, highlighting GS 65 and optimum flowering window for Frost Green Zone (dark shading) and Red Zone (light shading). Note: varieties in the figure are protected by PBR.

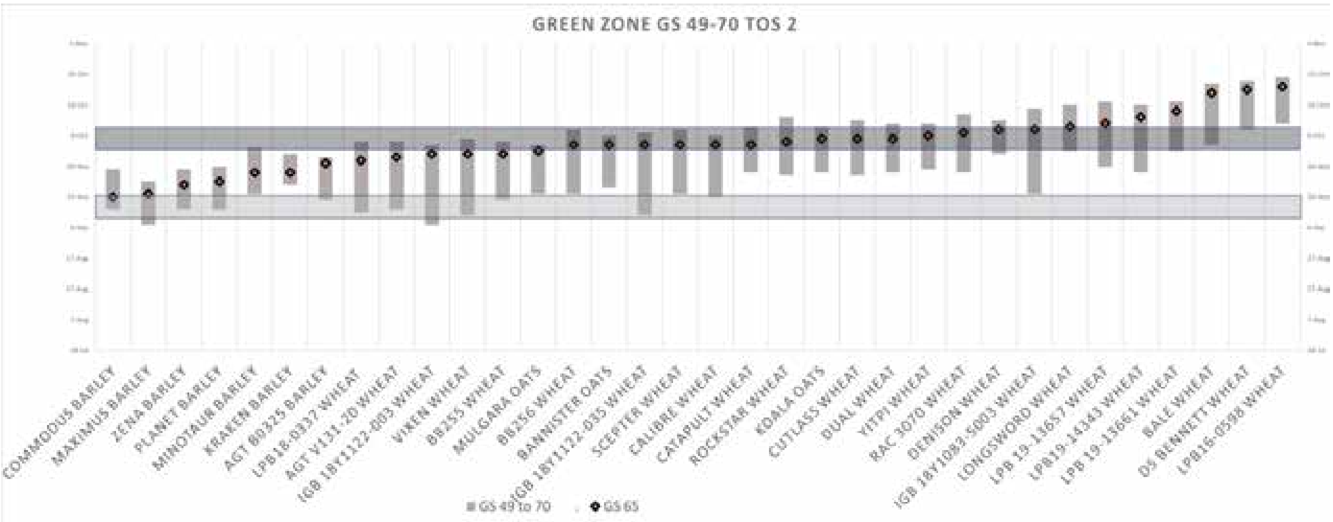

Figure 2. Phenological development of wheat, barley and oat cultivars sown on May 17 2022 showing Zadok's GS 49 to 70, highlighting GS 65 and optimum flowering window for Frost Green Zone (dark shading) and Red Zone (light shading). Note: varieties in the figure are protected by PBR.

Severe yield reduction was observed with barley in the Phenology Trial in both years. While barley is reputed to be less susceptible to frost than wheat, most commercial varieties in SA are short season, temperature driven types. Early maturity at the Frost Learning Centre has negated any tolerance advantage.

Delay and reset

A potential method to avoid frost is to provide some sort of intervention that will delay the susceptible growth stages. This can mean that early maturing varieties can still be sown earlier but manipulated during the season. In practice, this would be achieved by grazing with livestock, mechanical removal (for example, slashing) or chemical intervention (for example, a spray application of defoliant).

Repeated (rotational) grazing from GS14 to GS30 resulted in delay to GS65 by 3–14 days, depending on variety. This treatment is known as a 'delay' intervention. Delay treatments are also influenced by duration, repetition and intensity. A defoliation aimed to reduce apical dominance at around GS 31-32 is done later and is often referred to as a 'reset'. When comparing delay and reset, the latter results in very substantial loss of biomass and recovery is dependent on soil water availability and maturity type. Early season, temperature sensitive wheat cultivars tend to rapidly move through growth stages in response to high spring temperatures without biomass recovery. Yield loss is very high with these varieties and less impacted with photoperiod and winter cereals.

Delay and reset treatments were analysed for the presence and distribution of ice nucleating bacteria. There was a significant reduction of bacteria in delay treatments which could be explained by the fact that repeated mowing actually removes leaves that, left untreated, would later senesce, containing high levels of ice nucleating bacteria. There is evidence to suggest that grazing with sheep has a similar impact, with lower frost damage recorded in grazed crops, and these results may be as much attributed to ice nucleating bacteria as to delay in maturity.

Frost tolerance

Oats were the most tolerant cereal crop in 2021 with the highest grain yield in TOS 1 and the least amount of measured grain loss. All varieties of wheat and barley when sown at the end of April recorded yield loss due to frost, with the lowest losses associated with later maturing varieties (DS Bennett⁽ᴾ⁾/Denison⁽ᴾ⁾). The yield of Mulgara⁽ᴾ⁾ and Kingbale⁽ᴾ⁾ oats grain was substantially higher than all other wheat varieties and barley. When sowing was delayed until May, grain yield of wheat was higher than when sown earlier, with lower levels (but not absence) of frost damage.

Stubble

Results using thermography and temperature loggers confirmed lower surface and air temperature where stubble exists, while light coloured stubble produced a lower minimum temperature than dark coloured stubble. As the season progressed, the direct influence of stubble on canopy temperature diminished until, at canopy closure, the impact of stubble on canopy temperature was unable to be detected. However, at that point in time, the stubble is primed with ice nucleating bacteria and is in close contact with senescing leaves. Research conducted by Dr Ben Biddulph and Dr Amanuel Bekuma at DPIRD, WA has thermal imagery showing freezing developing from the base of the plant upwards in response ice nucleation initiated by Pseudomonas syringae and Pantoea agglomerans.

The retention of cereal stubble in Red Zones increases the risk of frost damage in subsequent crops. Removing stubble or manipulation of rotational options may be necessary in these Zones.

Biomass production

Crop growth and biomass is driven by temperature, and in cold environments, winter temperature can severely limit production. Most of SA is cool, where daytime temperatures are rarely limiting to plant growth. However, there are areas that are cold, and these are generally defined by altitude. For this research, we have suggested cool areas are less than 250m above sea level and cold areas greater than 250m. A successful tactic where frost is not an issue (Green Zone) is to establish crops early to maximise biomass production prior to winter, which can then be maintained over winter. However, in a Red Zone, an increase in early biomass may also be associated with early maturity, resulting in high frost losses.

Winter biomass production might be increased by maximising light interception without enhancing maturity.

FLC research (McCallum 2021) indicated that some tactics to increase winter biomass production, such as species choice, row spacing and plant density, can impact frost damage.

Dual purpose cereals

Dual purpose, in this context, refers to wheat, barley or oats that can be grown for either grain production or hay production. Hay production is a common practice in Red Zones, where markets exist. To gain international market acceptance, there is a strong preference for awnless wheat or barley hay. However, just removing awns doesn't mean that hay quality is acceptable. This research endeavours to investigate options to provide satisfactory grain yield and quality to meet export hay specifications. It has particular relevance for frost management so that a decision at seeding time can be made with either end use as a possibility, or if frost damage occurs, high quality hay can be produced.

Figures 3 and 4 show biomass yield and grain yield in the presence of frost. The decision to cut for hay or leave for grain may be dependent on the extent of frost damage.

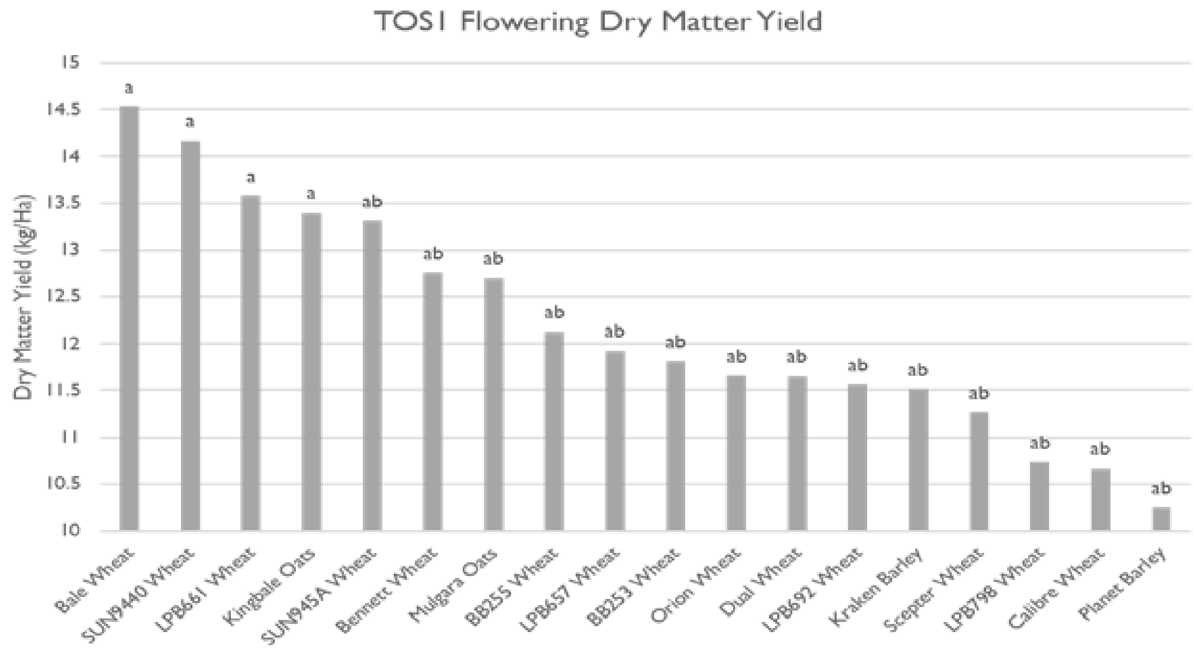

Figure 3. Dry matter yield at flowering of wheat, barley and oats, Frost Learning Centre sown April 28, 2021. Note: varieties in the figure are protected by PBR.

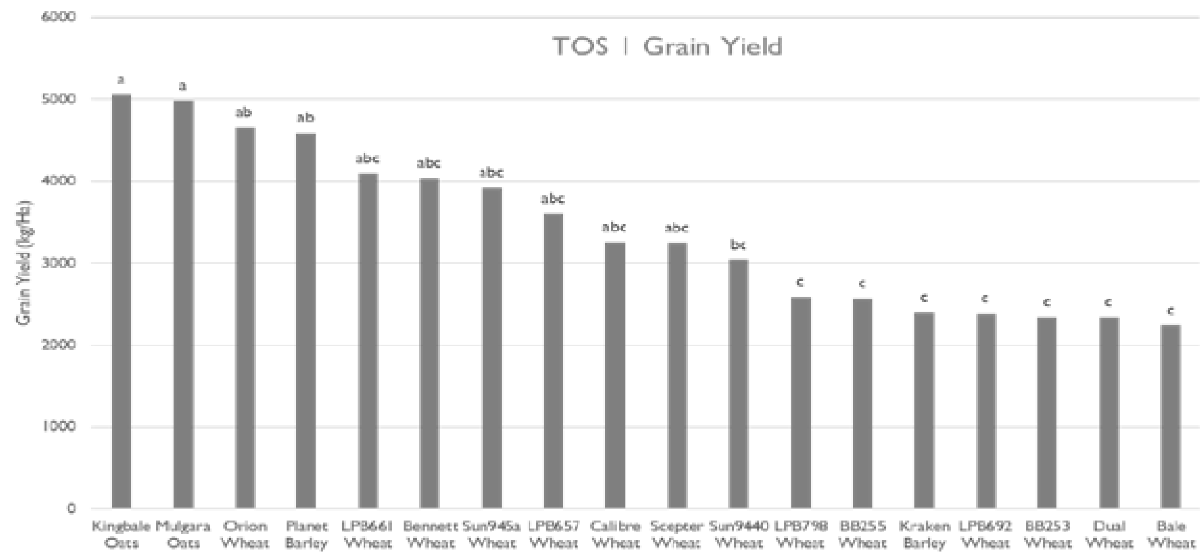

Figure 4. Grain yield of wheat, barley and oats, Frost Learning Centre sown April 28, 2021. Note: varieties in the figure are protected by PBR.

Additional research projects conducted at the Frost Learning Centre in 2021 and 2022 included:

- evaluation of varieties and variety mixes in barley
- intercropping pulses (2021) in collaboration impact of vegetative damage on grain yield of lentils (2022)
- impact of nitrogen nutrition, seeding rate and canopy development on frost damage of wheat (2021,2022)
- biomass production of cereals, grasses, legumes, canola and mixed species (2022)
- spatial variability of frost damage for frost researchers (2021,2022)
- spectral data to rapidly identify frost damaged wheat (2021)
- distribution of ice nucleating bacteria in plants (2021,2022)
- product application to suppress ice nucleating bacteria (2021,2022)
- investigation time of sowing of Super High Oleic Safflower in frost avoidance (2021,2022).

Conclusion

Frost management needs a multi-faceted approach. Financial exposure to frost losses varies between farm businesses. There is no silver bullet but implementing management using a zone approach allows minimisation of financial loss in Red Zones, while maximising returns in Green Zones. Some growers have a high exposure to Red Zones, while others have nothing but Green Zones. The adoption of frost risk management should be driven by the relative and total amount of each zone.

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Useful resources

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

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The key profit levers for sandy soils amelioration

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GRDC project codes: CSP00203, GRDC00432

Keywords

- amelioration, crop water use, sandy soil, soil constraints.

Take home messages

- Recent work in the Sandy Soils Project (CSP00203) has focused on consolidating our knowledge on identifying constraints, optimising machinery set-up and selection to ameliorate the constraint, predicting the crop response to the treatment and analysing the profit/risk implications for these responses.
- Key levers for profit from amelioration of sandy soils include:
  - Our ability to predict the response to amelioration which relies on knowing the constraint (and severity) and the tool to address the constraint
  - The scale of the amelioration project (for example, area ameliorated per annum, options for machinery investment)
  - Our ability to manage the workflow effects of amelioration (post-amelioration traffic, seeding management, crop sequence management).

Background

Recent surveys of growers in Southern region landscapes indicate that 50% of growers have ameliorated some sand in the last five years and they plan to double the amount of sand ameliorated in the next five years. There is recognition across the industry that understanding the constraint to be ameliorated, how to best tackle that constraint from an engineering perspective and how to integrate it into whole-farm management considerations is critical to the successful adoption of amelioration techniques. Crop productivity on sandy soils is commonly limited by a range of soil constraints that reduce root growth, crop tillering and grain number. Constraints can include a compacted or hard layer preventing root proliferation, a water repellent surface layer causing poor crop establishment, soil pH issues (both acidity and alkalinity), and/or poor nutrient supply. The aim of the Sandy Soils Project is to increase crop productivity in underperforming sandy soils in the Southern cropping region by improving the diagnosis and management of constraints. Growers are experiencing a range of outcomes in response to amelioration efforts on deep sands. Understanding the constraints, appropriate amelioration tools and a set up that will best address the constraint are critical to success. A profit-risk analysis can help growers and advisers think through the relevant components of the costs, the expected response and financial risks associated with amelioration of deep sands. This paper focuses on high soil disturbance interventions (deep ripping and spading) that require specialised machinery to break up compacted or hard-setting layers and/or mixing of repellent layers.

Method

Constraint identification

The key measurements for constraint identification include water repellence (water drop test), soil strength (penetration resistance) or bulk density, pH and soil nutritional status. Practical approaches to assessing these constraints have been outlined in the factsheets listed under References. We utilised the techniques outlined in our factsheets to categorise the sand constraints at each of our sites as low, moderate or severe.

Testing amelioration techniques

A range of research experiments were established across the low to medium rainfall environments of the Southern region, with sites categorised according to their primary soil constraints identified. Experiments were established between 2014 and 2019, while a broader validation trial program was established between 2019 and 2021, including a range of deep ripping (30–60cm deep), spading, inclusion ripping and/or inversion ploughing approaches, with/without additional amendments (fertiliser, N-rich hay, chicken manure, clay). Practical advice on the set up and operation of these treatments is outlined in the factsheets listed under References. In all experiments the effects of amelioration on crop growth and yield were monitored, while the research program had a further set of more detailed soil and crop measurements. In all, there were 32 experimental sites with 105 site years of data collected. All yield results have been collated and analysed and are available via the SANDBOX App (which will be searchable via the CSIRO Data Access Portal in the coming months). In this paper, we present yield responses according to machinery treatment (ripping, spading) and constraint category.

Economic analysis

Utilising grain yield responses, the discounted cashflow response to amelioration was evaluated for cost:benefit outcomes in response to ripping and spading based on costs provided by grower and industry consultation (ripping outcomes using a cost of $90-120/ha depending on ripping depth), 5-year average grain prices from the Gross Margin Guide (wheat (APW) five-year price was $295/t, PIRSA, 2021) and a future discount rate of 6%. The cash flow outcome is presented here as the net present value (NPV) for ripping treatments. Where NPV is positive, it reflects that the present value of the future cash flow is bigger than the initial investment. Several case study farms were developed to evaluate deep ripping as a 'farm investment project'. Using a 4,800ha cropping farm with three land classes of responsiveness to ripping, we had a base scenario where 317ha were ripped in each year for five years (made up of 190ha of class A responsive land, 95ha of class B responsive land and 32ha of class C responsive land), with fuel costs of $60/hour and a two week program of work. Class A responsive land assumed 0.7t/ha cereal benefit in year one, 0.31t/ha cereal benefit in year two, 0.1t/ha legume benefit in year three, while Class B land achieved 70% of the Class A response and Class C achieved only 10% of the Class A response. The capital investment for this base scenario was an $80,000 ripper and 30% of tractor cost, which was disposed of in year six. The base scenario was compared with scenarios of doubled fuel costs, a reduced responsive area by assuming 10% less class A land and 5% more Class B and C land, halved the capital cost), utilised contracting for the ripping at $80/hour, or doubled the treated area in each year.

Results and discussion

Yield responses

The crop response to sandy soil amelioration varies according to primary constraint. Figure 1A shows the level of ripping responsiveness over time for soils with moderate and severe physical constraints. While the initial response to ripping is similar for both categories, the cumulative response is greater for sands with a severe physical constraint. Figure 1B shows the level of spading responsiveness over time for soils with nil through to severe repellence.

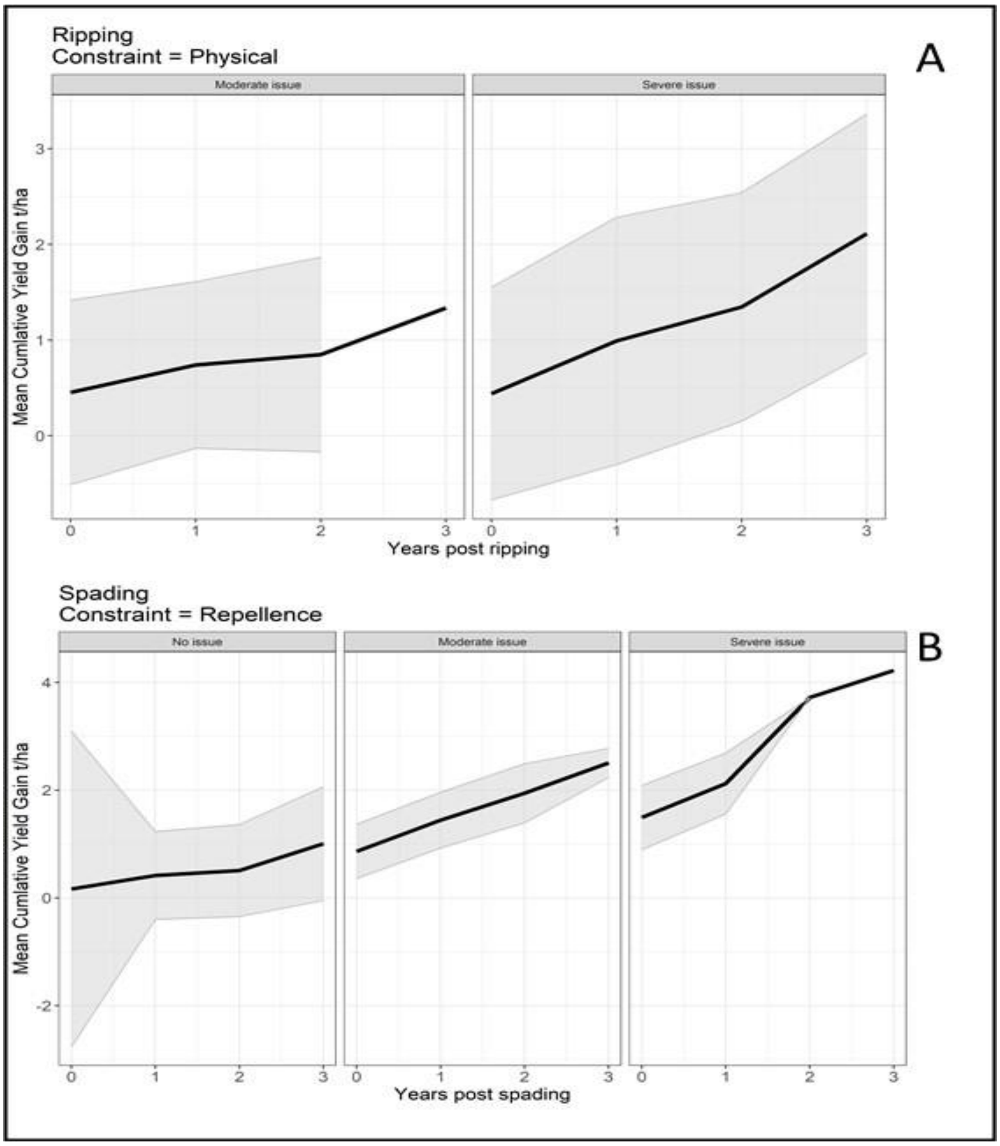

Figure 1. Southern Sandy Soils Project cumulative yield responses (as mean in bold line and cv in grey shadow) over time to (A) ripping and (B) spading (amelioration occurred in year 0). The responses have been separated according to the category of constraint and we present the examples of ripping responses according to categories of soil physical constraint (measured by soil strength) and spading responses according to repellence (measured by water drop penetration test).

The amelioration of repellence relies on the mixing or dilution of surface soil with repellence. The results show that more repellent sands generate a greater cumulative yield response to spading. The shading (r coefficient of variation) in the figure demonstrates that there is still quite a range of possible outcomes within each category of constraints, which arises due to seasonal constraints, variation in the soil constraint and post-amelioration management (for example, nutrient input, crop establishment, erosion) (Figure 1).

Net present value responses

With rapid changes in the costs associated with soil amelioration, it is imperative to continually review the economic outcome of treatment responses across the project database. Here we restrict the presentation of data to the ripping responses and demonstrate that, despite the shifts in costs and prices over the project time frame, there were still substantive gains from amelioration responses in many cases (Table 1). We have also related the site and treatment to the soil constraints, run of seasons with respect to rainfall (shown as deciles) and number of years for which the response was monitored. This extra information explains the level of response as NPV in many cases (Table 1), where the response may have been limited by either only a moderate constraint or due to a very poor run of seasons (for example, Carwarp and Waikerie). Some uncertainty remains for some sites where the physical constraint was categorised as severe (for example, Buckleboo and Cummins) but the response did not generate a positive NPV.

Table 1: Cumulative net present value in response to ripping treatments (compared with an unripped control) implemented across the southern cropping region.

Site	Rip Depth (cm)	Rainfall Deciles	Physical Constraint	Repellence Constraint	Total Years since Treatment	Cumulative Net Present Value ($/ha)
Bute	50	2/10/3/2/1/6/4	Severe	Moderate	7	1244
Lowaldie	60	2/7/2	Severe	Moderate	3	574
Younghusband	50 inclusion	7/6	Severe	Severe	2	517
Murlong	40	2/2/5/5	Severe	Severe	4	454
Ouyen	30	6/2/2/8/2	Severe	Low	5	453
Lowaldie	40	2/7/2	Severe	Moderate	3	386
Koolonong	50	1/9/4	Moderate	Low	3	358
Mt Damper	45 inclusion	3/4/4	Moderate	Moderate	3	315
Karkoo	40	6/6/7	Moderate	Low	3	274
Murlong	30	2/2/5/5	Severe	Severe	4	258
Younghusband	50	7/6	Severe	Severe	3	235
Kybunga	50	1/4/3	Moderate	Moderate	3	231
Karkoo	40 inclusion	6/6/7	Moderate	Low	3	230
Warnertown	50 inclusion	2/9/3	Moderate	Moderate	3	170
Kybunga	30	1/4/3	Moderate	Moderate	3	168
Warnertown	50	2/9/3	Moderate	Moderate	3	147
Tempy	50	2/8	Moderate	Moderate	2	73
Warnertown	30	2/9/3	Moderate	Moderate	3	71
Bute Boundary	30	2/1/6/4	Moderate	Low	4	66
Tempy	50 inclusion	2/8	Moderate	Moderate	2	31
Buckleboo	45	1/6/5	Severe	Low	3	15
Buckleboo	45 inclusion	1/6/5	Severe	Low	3	-39
Buckleboo	35	1/6/5	Severe	Low	3	-48
Cummins	30	4/5/5	Severe	Moderate	3	-50
Carwarp	30	1/1/5	Severe	Low	3	-53
Waikerie	60	1/1/8/1	Severe	Low	4	-106
Carwarp	60	1/1/5	Severe	Low	3	-115
Sherwood	30	3/6/4	Moderate	Low	3	-123
Yenda	60	2/1/2/8/7	Severe	Low	5	-137
Waikerie	30	1/1/8/1	Severe	Low	4	-143
Bute Boundary	50	2/1/6/4	Moderate	Low	4	-254

Farm level responses

Here we present one case study farm from a Mallee environment as an example of the several that we have produced across the project geography. Relative to the range of possible outcomes shown in Figure 1 and Table 1, the baseline scenario is for a farm with a relatively moderate level of response (1t/ha yield benefit in the first three years) which has a payback period of six years (Figure 2). The scenario of assuming all Class A responsive land demonstrates the scaled-up outcome if we assume that the responses observed in field trials occur across all the ripped land on a farm. This has a shorter payback period with substantially more cash flow, which shows the baseline scenario is relevant for growers who have a range of different sand types and who have co-occurring constraints which might restrict the response to ripping (Figure 2). The scenarios of half the capital investment (for example, machinery sharing options) and the utilisation of a contractor demonstrate the impact that alternative approaches to the capital expense of implementing amelioration projects have for on-farm cash flow. The example of doubling fuel costs highlights the need to monitor and estimate costs, particularly in low rainfall regions when average yield gains can be limited (Figure 2).

There are some important post-amelioration considerations that ensure success. These include paddock trafficability, the ability to successfully establish the first crop and the effect that the ameliorated area has on workflow across the paddock. While we have a limited set of experiments that have tested the role of seedbed preparation (McBeath and Moodie 2020) and crop type or sequence effects (Moodie et al. 2022) on amelioration outcomes, recent grower interviews indicate that the need to understand these factors can be important barriers to the adoption of amelioration of sandy soils.

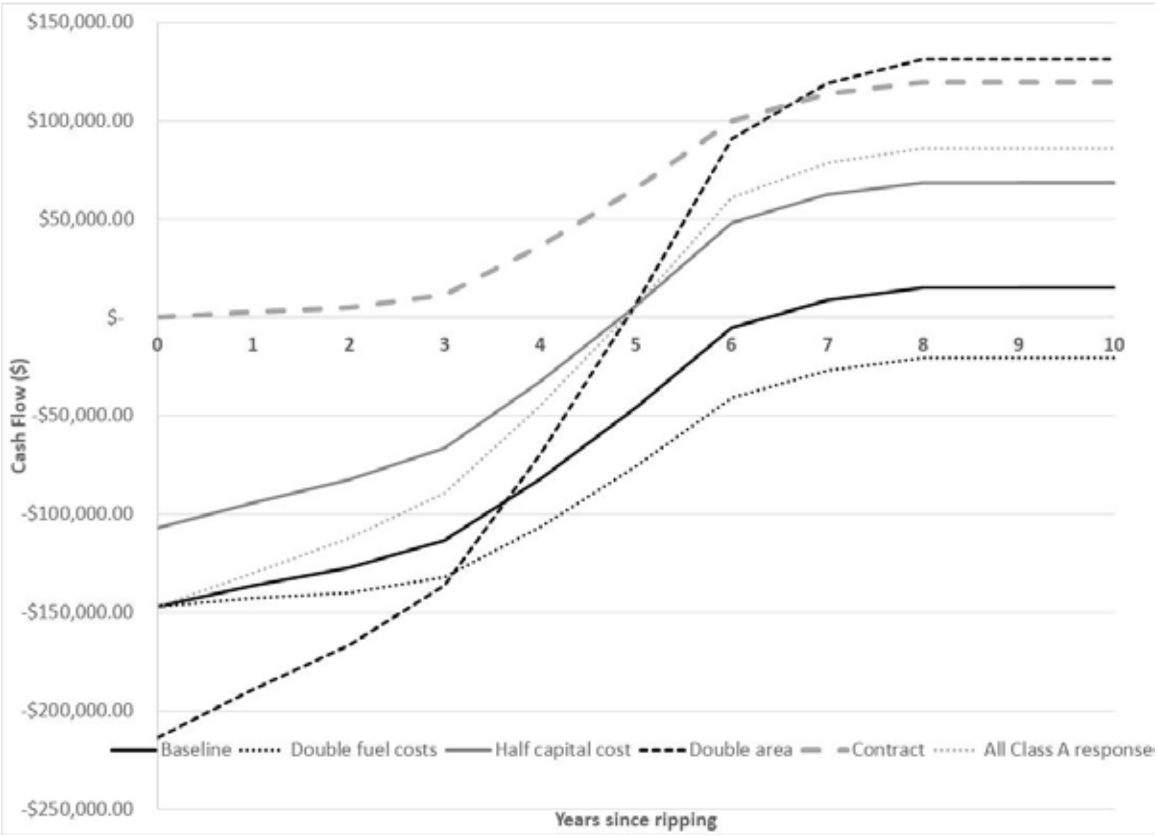

Figure 2. Case study farm predicted cash flow in response to changes in the farm amelioration 'project' including doubling of fuel costs, halving the capital cost, doubling ripped area, assuming all ameliorated land has a 'Class A' level of response and utilising a contractor instead of upfront machinery investment.

Conclusion

The ability to predict the profitability of sandy soil amelioration is dependent on understanding the constraint and the tool that best ameliorates that constraint. This is challenging because these constraints in a paddock can change in both space and time. However, the approach to the amelioration 'project' on the farm, with respect to the amount of land ameliorated per year and the level of investment made in required machinery, are decisions that can also have a major influence on profitability.

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Useful resources

Measuring constraints on sands to inform management. Diagnosing sandy soil constraints: water repellence and pH extremes Factsheet https://grdc.com.au/diagnosing-sandy-soil-constraints-water-repellence-and-ph-south-west

Measuring soil strength with a penetrometer. Diagnosing sandy soil constraints: high soil strength Factsheet https://grdc.com.au/diagnosing-sandy-soil-constraints-high-soil-strength-south-west

Crop nutrition for sandy soils. Diagnosing sandy soil constraints: Nutrition Factsheet https://grdc.com.au/diagnosing-sandy-soil-constraints-nutrition-south-west

Understanding passive inclusion ripping https://grdc.com.au/inclusion-ripping-technology-national

Understanding the process of soil profile mixing with rotary spaders. Soil mixing by spading Factsheet. https://grdc.com.au/soil-mixing-by-spading-national

Technology considerations for cost-effective subsoil loosening. Ripping technology Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2022/ripping-technology-national-fact-sheet

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Nutrition strategies to mitigate yield losses following waterlogging

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Southern Farming Systems.

GRDC project code: SFS2109-001SAX

Keywords

- growth stages, management techniques, nutrients, waterlogging.

Take home messages

- It is critical to understand the crop growth stage during waterlogging to determine potential yield impacts.
- In these trials, nutrition post-waterlogging did not influence grain yield, except in the trial at Hagley, where yields increased with higher rates of applied nitrogen.

Background

Waterlogging issues and drainage solutions are a high priority for farming systems in the high rainfall zones (HRZ) of Victoria and Tasmania. In 2021, these areas experienced a higher-than-average rainfall season, particularly through the winter months of June and July.

Waterlogging creates a stressful environment for plants to grow in and can result in reduced yields, and in severe cases, plant death. The growth stage of the crop during a waterlogged period is essential to understanding the effects it can have on final grain yields. Waterlogging close to sowing will affect germinating seeds and young seedlings, and as these plants do not have well-established root systems, the effects can be severe. If a soil is waterlogged during June–July in south-west Victoria or Tasmania and the crop is well established, final yields may not be severely impacted, as soils are cold, the demand for oxygen is low, and plant growth is slow (https://soilquality.org.au/factsheets/waterlogging). Established plants will be most affected when they are rapidly growing, as such, prolonged waterlogging during the warmer spring period is when yield penalties may be most severe. The HRZ of Victoria and Tasmania is particularly prone to waterlogging conditions, with high rainfall and sodic (dispersive) subsoils.

Under waterlogged conditions, nitrogen is lost from soils through denitrification and leaching, and during this period, plants also have a limited ability to uptake nutrients. Providing the crop with adequate nutrition following a waterlogged period is therefore of utmost importance to help the plants recover from this stress.

Method

Four trials were established in locations that had experienced some degree of waterlogging throughout the season. This report focuses on three of those four trials. The trials were located at Vite Vite North and Streatham in Victoria and Hagley in Tasmania (Table 1). Vite Vite North and Hagley were small plot trials, while the Streatham trial was located in part of a grower's paddock.

Table 1: Trial location, crop type, variety, sowing date and starting fertiliser.

Location	Crop Type	Variety	Sowing Date
Streatham, VIC	Canola	45Y28 RR	10-Apr-21
Vite Vite North, VIC	Faba Bean	PBA Samira$^{(b)}$	30-Apr-21
Hagley, TAS	Wheat	RGT Calabro	12-May-21

The treatments varied across the locations, with the main products used including urea, sulphate of ammonia (SOA) and trace elements. Nitrogen in SOA is in a more readily available form for plant uptake than urea. This was applied in combination with urea to determine if this immediate uptake was beneficial when recovering a waterlogged crop. The trace elements applied across the canola was a product called Maximise (Zn, Cu, Mo, and B). In the wheat, the product Awaken (N, K_2O, B, Cu, Fe, Mn, Mo, and Zn) was applied. These were used to ensure crops were not nutrient limited. In the wheat, they were applied at least two weeks following the initial nitrogen recovery application when the crop was actively growing again, to improve efficiency of plant uptake.

Streatham, VIC

This trial looked at three methods of nutrition recovery. Applications were made at GS67, flowering declining (Table 2).

Table 2: Recovery canola at Streatham.

Treatment	Date Applied	Product	Rate/ha
1	22-Sep-21	Urea	220kg
2	22-Sep-21	Urea	175kg
		SOA	100kg
3	22-Sep-21	Urea	175kg
		SOA	100kg
		Trace elements	3L
4	Nil control		

Rainfall at the Streatham site was above average in May, June, and July, with a total of 206mm falling across the three months. A moisture probe at a nearby site at Westmere showed plant available water at its peak at 97% in August, up from 90% in July. It then began to decline from September to the end of the season. The location of this trial was in a low-lying area of the paddock and the plants displayed visible symptoms of waterlogging, such as reduced plant growth and yellowing, particularly compared with other areas of the paddock.

Vite Vite North, VIC

The faba bean trial at Vite Vite North had five rates of urea applied at 10% flowering, which occurred in mid-August (Table 3). The application rates ranged from 0 to 240kg/ha urea. Monoammonium phosphate (MAP) was applied at sowing across the whole trial at a rate of 100kg/ha.

Table 3: Recovery faba beans at Vite Vite North.

Treatment	Date Applied	Urea/ha
1		0kg
2		60kg
3	19-Aug-21	120kg
4		180kg
5		240kg

Rainfall at the Vite Vite North site was well above average in May, June, and July, with a total of 254mm of rain falling across the three months. A moisture probe at Vite Vite showed plant available water was at 95% from mid-June to mid-July and then moved to 100% until mid-August, after which it started to decline.

Hagley, TAS

The recovery wheat in Tasmania had seven treatments, as outlined in Tables 4 and 5. Each treatment was replicated at a full and reduced nitrogen rate. The urea was applied over three timings, 10 October when the crop was at GS32 (flag minus 2), 28 October at GS39 (flag leaf fully emerged), and 12 November at GS45 (boots swollen). The SOA was applied on 17 October at GS33, and the trace elements eleven days later on 28 October. No nutrition had been applied to the trial prior to this, except 100kg/ha MAP at sowing. Hagley received above average rainfall through July and August, with a total rainfall of 218mm across the two months.

Table 4: Summary of treatments of the recovery wheat at Hagley.		
Treatment		**Applied N**
1	Urea	Full rate (180kg N/ha)
2	Urea + SOA	
3	Urea + SOA + Trace elements	
4	Urea	Reduced rate (100kg N/ha)
5	Urea + SOA	
6	Urea + SOA + Trace elements	
7	Nil control	

Table 5: Detailed treatment list of products, rates, and timings of applications at Hagley.

Treatment			Product	Rate/ha	Growth Stage
Full rate (Total applied 180kg N/ha)	1	10-Oct-21	Urea	175kg	GS32
		28-Oct-21		175kg	GS39
		12-Nov-21		45kg	GS45
	2	10-Oct-21	Urea	130kg	GS32
		17-Oct-21	SOA	100kg	GS33
		28-Oct-21	Urea	175kg	GS39
		12-Nov-21	Urea	45kg	GS45
	3	10-Oct-21	Urea	130kg	GS32
		17-Oct-21	SOA	100kg	GS33
		28-Oct-21	Urea	175kg	GS39
			Trace elements	3L	GS39
		12-Nov-21	Urea	45kg	GS45
Reduced rate (Total applied 100kg N/ha)	4	10-Oct-21	Urea	175kg	GS32
		28-Oct-21		45kg	GS39
	5	10-Oct-21	Urea	130kg	GS32
		17-Oct-21	SOA	100kg	GS33
		28-Oct-21	Urea	45kg	GS39
	6	10-Oct-21	Urea	130kg	GS32
		17-Oct-21	SOA	100kg	GS33
		28-Oct-21	Urea	45kg	GS39
			Trace elements	3L	GS39

Results and Discussion

Streatham, VIC

Peak nitrogen requirements in canola are from the start of flowering to the end of pod formation. The application timing, towards the end of flowering for this trial, was very late in-season compared to standard practice.

The applications in this trial did not result in any differences in grain yield or oil content (Table 6). A target biomass for optimal yield potential in canola is considered around 5t/ha by the start of flowering. An average biomass of 5.3t/ha was measured towards the end of flowering, prior to nutrition applications being made. The critical period for yield determination in canola is 300-degree days from the start of flowering, which is approximately 30 days in the south-west Victorian environment. Moisture probes in the area showed plant available water to be at its peak in August. Hence, the timing of waterlogging in this situation may have reduced negative effects on grain yield, as despite appearing visually impacted by waterlogged soils, the trial overall yielded well, with an average yield of 4.1t/ha.

Table 6: Canola recovery yield and oil content Streatham.

Treatment	Product	Yield (t/ha)	Oil (%)
1	Urea	3.9 -	44.0 -
2	Urea + Gran Am	3.8 -	45.0 -
3	Urea + Gran Am + Traces	4.7 -	46.2 -
4	Nil	4.1 -	46.5 -
p-value		0.08	0.06
Lsd		n.s.	n.s.

Post-harvest soil tests were taken in late February to determine if the additional nitrogen applied would remain available to the crop for the following season. The soil test results showed no significant differences in total nitrogen between any of the treatments, including the nil.

Vite Vite North, VIC

At Vite Vite North, the waterlogging occurred in the very early stages of flowering in the faba beans. Applying nitrogen did not result in any significant differences in grain yield (Table 7). Pulses are typically not well suited to waterlogged conditions. Of all the pulses, faba beans however are considered the most tolerant (https://grdc.com.au/resources-and-publications/grownotes/crop-agronomy/faba-beans-western/GrowNote-Faba-Bean-West-14-Environment.pdf). The trial reached full flower towards the end of August. Yields achieved in this trial would indicate that, although soils were at field capacity through July and August and some visual signs of waterlogging were evident, the impact of waterlogging on final grain yield was not severe.

Table 7: Recovery faba beans at Vite Vite North.

Treatment	Urea (kg/ha)	Yield (t/ha)
1	0	7.9 -
2	60	8.3 -
3	120	8.6 -
4	180	7.5 -
5	240	7.8 -
Lsd		1.12
p-value		n.s.

Post-harvest soil tests indicated that nitrogen available in the soil in the 0–60cm zone was above 120kg N/ha across all treatments (Figure 1). On average, the nil treatment had 22kg N/ha more nitrogen compared with treatments where applications had been made. It could be that the plants were more efficient at fixing their own nitrogen where no nitrogen had been applied.

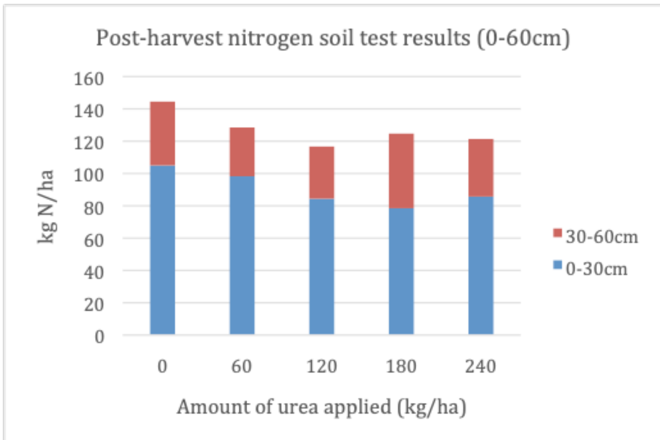

Figure 1. Post-harvest nitrogen soil test results across the five treatments at Vite Vite North. Results are from 0–30cm and 30–60cm zones.

Hagley, TAS

The average yield for wheat in Tasmania was 9.4t/ha and this average included a nil treatment which was almost 2t/ha lower than the nitrogen treatments (Table 8). Where higher rates of nitrogen were applied, a significant increase in grain yield was achieved in two of the three treatments. Grain protein significantly increased between nil, reduced rate, and full rate treatments. The average protein value across all treatments of 7.7% indicates that nitrogen may have been a limiting factor to grain yield. Provided it is not applied too late, a grain protein of 10.8% or higher can be a good indicator that nitrogen has not been limiting.

Soil tests taken close to sowing showed a starting soil nitrogen of 120kg N/ha in the 0–60cm zone, and an estimated mineralisation of 60kg N/ha. Using the 40kg N per tonne of grain yield rule, these results indicated there was enough nitrogen in the soil for 4.5t/ha prior to the nitrogen being applied. In response to the waterlogging, conservative yield targets of 9t/ha for the full rate and 7t/ha for the reduced rate were selected. The low protein results suggest yield potentials could have been higher and higher rates of nitrogen could have been applied. In this trial, total nitrogen had a larger influence on grain yield and protein compared with product type.

Table 8: Grain yield and quality results for the wheat trial at Hagley.

	Treatment	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)
Full rate	Urea	10.3 a	8.45 a	76.4 a	0.7 -
	Urea + SOA	10.2 a	8.13 a	76.3 a	0.7 -
	Urea + SOA + Trace elements	9.6 b	8.40 a	75.8 ab	0.9 -
Reduced rate	Urea	9.6 b	7.50 b	75.6 ab	0.7 -
	Urea + SOA	9.3 b	7.50 b	75.2 b	0.8 -
	Urea + SOA + Trace elements	9.6 b	7.40 b	75.6 ab	0.7 -
	Nil	7.4 c	6.98 c	75.2 b	0.6 -
p-value		<0.001	<0.001	0.046	0.2
Lsd		0.5	0.35	0.9	n.s.

Conclusion

Understanding a plant's growth stage during a waterlogging period is critical in determining potential yield impacts. Despite presenting some waterlogging symptoms, faba beans and canola yielded exceptionally well in these trials. Average yields of 8t/ha were recorded for the faba beans and 4.1t/ha in canola, noting again that the faba bean trial was in small plots and the canola an area from a grower's paddock. The wheat at Hagley also yielded well, with an average grain yield of 9.4t/ha. These yields are likely attributed to the timing and severity of waterlogging in relation to the crop's physiological development stage. The type of product used did not influence grain yield in any of the trials. The Hagley site was the only trial to present a yield response by rate of nitrogen, with higher rates of nitrogen applied improving grain yield.

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Fact Sheets Waterlogging (https://soilquality.org.au/factsheets/waterlogging)

Nutrition Strategies to Mitigate Yield Losses Following Waterlogging (https://sfs.org.au/resource/nutrition-strategies-to-mitigate-yield-losses-following-waterlogging)

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Can we survive without glyphosate? Lessons learned from Europe, Canada and Argentina

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Keywords

- Argentina, Canada, Europe, glyphosate.

Take home messages

- In the 1970s, the herbicide glyphosate was developed, completely changing crop production practices.
- The intensification of crop production systems together with an increasing use of herbicides, including glyphosate, has a potential human and environmental cost.
- Consumers the world over want transparency in the use of agricultural chemicals, including synthetic fertilisers.
- A study tour to Europe, Canada and Argentina enabled us to discuss with growers, agronomists and researchers issues related to using glyphosate and other farm chemicals, farm practices in general, the political environment and how farming is viewed by the local and more general community.

Background

Grain farming in the 2020s is vastly different from 50 years ago. Before herbicides became available, weeds were controlled by multiple deep and shallow cultivations, often using a mould-board plough to invert the soil and bury weed seeds. In the 1970s, the herbicide glyphosate was developed by Monsanto and sold as Roundup®, completely changing crop production practices. Growers no longer had to cultivate or plough their fields to control weeds, and the previous year's crop residues were retained. Glyphosate effectively kills most weeds, annual and perennial, and growers worldwide were able to adopt minimum or no-till farming practices which resulted in:

- greatly reduced levels of erosion, by both wind and water, previous crop stubbles were able to be retained and paddocks were no longer left bare after ploughing or cultivation
- optimised timeliness of sowing, increasing yield
- reduced GHG emissions because growers used less fuel (less tractor use)
- improvement in soil 'health'. In minimum- and no-till crop establishment, the soil is not disturbed by ploughing, reducing soil compaction and, together with the residues from previous crops, helps to create a better environment for soil micro-organisms to increase soil biological activity and store soil carbon (further mitigating GHG emissions).

In the 1990s, Monsanto released Roundup Ready soybeans – a genetically modified (GM) crop in which the plant was resistant to Roundup (glyphosate), but the weeds in the paddocks were not, resulting in very effective weed control. In addition to Roundup Ready soybean, other crops such as maize, canola and cotton also have glyphosate resistant cultivars available and are widely sown. Some jurisdictions around the world do not allow the growing of GM crops, such as the EU, but even in Europe, there are some exceptions, albeit on small areas with a special permit.

The intensification of crop production systems together with an increasing use of herbicides has a potential human and environmental cost. Glyphosate is not the only herbicide which has increased in use over the last three decades worldwide (see, for example, Argentine pesticide ecotoxicity profiles for different crop production systems, Ferraro et al. 2020).

Public awareness and concern about issues related to farm herbicide and pesticide use in general is increasing (Marr 2020, Mie and Rudén 2022). The sustainability and safety of current crop production systems are widely questioned. In some countries, glyphosate use is banned for home and public garden use and is severely restricted on farmland. In France, glyphosate use is restricted to 1080g ai/ha/yr and is only available to no-till or minimum-till growers. French growers who plough are not able to use it. In Argentina, some country towns have banned the use of all agrichemicals, including artificial fertilisers, in designated areas surrounding the town, for example, in Pergamino, the agrichemical use exclusion zone is 1095m from the town's boundary.

The EU has seen several reviews of agrichemical use, particularly for glyphosate. The latest review by the European Assessment Group on glyphosate submitted an updated renewal assessment report in September 2022 to the European Food Safety Authority (EFSA) and it is expected that the 27 EU member states will discuss the evidence for and against the use of glyphosate by July 2023 (https://www.efsa.europa.eu/en/topics/topic/glyphosate).

Consumers the world over want transparency in the use of agricultural chemicals, including synthetic fertilisers. However, it is also very important for consumers to confront the reality that the earth is inhabited by 8 billion people, all of whom need to be fed. At the current level of development of large-scale food production, only industrialised agriculture, using agrichemicals and fertilisers, will be able to feed 8 billion people. Distribution and unequal access to food and resources between rich and poor nations remain hurdles still to be overcome.

The study tour took us to Europe, Canada and Argentina to learn from growers, agronomists and researchers about what is happening in relation to agrichemical use, in particular with glyphosate.

Growers, agronomists and researchers we met on the tour were open and ready to discuss not only issues related to using glyphosate, but also other farm chemicals (including synthetic fertilisers), farm practices in general, the political environment and how farming is viewed by the local and more general community. We sincerely thank the many growers, agronomists and researchers with whom we discussed many issues related to farming. It was, for us, a most enjoyable and educational time.

Results and discussion

Europe (EU member states and UK)

- The use of glyphosate in public and home gardens is banned in most EU jurisdictions.
- For agricultural production, glyphosate is available, but there are restrictions. These restrictions are not the same in all EU member states. For example, in France, glyphosate can be used only by minimum- or no-till growers prior to sowing, and the rate is restricted to 1080g ai/ha/yr. French growers who plough are not able to use glyphosate. In Germany, the maximum glyphosate rate is 1800g ai/ha/yr.
- There is no alternative broad-spectrum herbicide available in Europe. The use of paraquat is already banned.
- Since January 2022, it is forbidden in France to give advice on agrichemical use and the sale of products. Re-sellers are able to advise on how to use different products, but not advise on what or how much to use.
- In Germany, there are 77 pesticides under review for risk assessment to human health and environmental considerations. Glyphosate is not on this list because of its relatively low toxicological level (however at a political level, Germany is not likely to support the continued use of glyphosate).
- 'Biological' herbicide alternatives are being tried. We visited one large-scale trial in France where weed control efficacy of glyphosate is compared with 'biological' alternatives. It was set up two years ago and needs more time for differentiation between treatments.
- When assessing soil glyphosate residues between different farming systems, it is imperative to also measure soil AMPA (Aminomethylphosphonic acid), the residual product of glyphosate.
- In the EU, the production of canola is greatly reduced because neonicotinoid insecticides are banned. Growers regard insect control to be too difficult and have reduced the area sown to canola. There is an exemption in some jurisdictions for continued use of neonicotinoid insecticides, for example, in sugar-beet until 2023.
- Organic grain production has similar yields to minimum or no-till grown grain crops, but only on a per crop basis. Non-organic growers have a more intensive rotation (growing

- summer and winter crops often sequentially), whereas organic growers, because they need to plough and cultivate to control weeds, can only grow one crop per year resulting in lower land-use efficiency. Organic grain growers receive a premium price for their produce and additional subsidies, which means the income received from crop production is similar to that of growers who use pesticides and fertilisers.
- Cover crops are often planted between harvest of the winter crop and sowing the summer crop. Growers were enthusiastic about cover crops, but they also questioned:
  - what is the soil organic matter benefit of cover crops?
  - how much soil nitrate is used by cover crops? (High soil nitrate levels in cropping soils are a problem because of leaching of nitrate into groundwater which is used for town water supplies in Europe)
  - what are the root disease carry-over issues with different cover-crop species
  - cover crops are sprayed with glyphosate just prior to sowing the summer crop. If the fields with cover crops need to be cultivated, it is unlikely that the practice of planting cover crops will continue because of time and cost constraints. Some growers were investigating using ‘crimpers’ to terminate cover crops but reported problems with controlling vetch.
- Mice are often a serious pest in no-till systems and mouse bait can be applied only by placing it directly in mouse holes, which is time consuming and expensive (another reason not much canola is sown).
- In France, growers who apply pesticides must use a scale which measures the total amount of active ingredient applied, named the ‘Frequency of Treatments (ITF)’. If the total score reaches a certain level, no other pesticides can be applied in that year.
- Some growers are using robotics to control weeds, and several are experimenting with alternative methods of weed control, such as between row mechanical soil disturbance, which is very difficult in paddocks with retained stubbles from previous years (that is, only suitable on paddocks which have been cultivated).
- Many growers raised the issue that if they must resume ploughing, it will mean:
  - delay in timing: cultivation takes time and often results in sowing being delayed (with subsequent loss in yield)
  - soil degradation from ploughing
  - increased GHG emissions through the breakdown of soil organic matter and additional fuel consumption.
- Growers and agronomists said a detailed assessment of the impact of banning glyphosate on long-term crop yield and productivity must be undertaken before the product is banned (inclusive of an ecological assessment).
- Without glyphosate, it will be even more difficult to control problem weeds such as black grass (*Alopecurus myosuroides*)
- There is a need to communicate more effectively with the general community about food sources, how it is produced and how the world is going to feed an ever-growing population (currently at 8 billion).

Canada

- The Pest Management Regulatory Agency (PMRA) of ‘Health Canada’ regulates pesticide use under the Pest Control Products Act. In 2017, the PMRA full re-evaluation of glyphosate concluded there was no risk or concern for human health or the environment when used according to the label. Registration was resumed.
- In February 2022, the first ever intervention on a PMRA decision by the Federal Court of Appeal (brought to the Court by ‘Safe Food Matters’) occurred when the Court ordered the PMRA to review its decision to re-register glyphosate. As of November 2022, no decision has been made.
- August 2021: Maximum Residue Limits (MRL) increased for several herbicides, including glyphosate (to align with trading partners).
- If glyphosate were to be banned, growers identified ‘crop competition’ as the most likely method to achieve some level of weed control (where ‘crop competition’ can be achieved by early seeding, seeding at high rates, using narrow row spacings and growing competitive cultivars. Remote sensing for identifying weed patches, using rod weeders, weed wipers and shielded sprayers were also mentioned).
- Canadian growers do not see tillage (ploughing and cultivation) as a solution to ‘farming without glyphosate’. Tillage will result

- in soil degradation, erosion, soil structure decline, and a loss of soil organic matter, together with a subsequent increase in GHG emissions. In addition, tillage will require more diesel use, also resulting in an increase in GHG emissions.
- The loss of glyphosate will result in an increased use of other herbicides, without knowledge of their impact.
- Growing of Roundup Ready (RR) canola, soy, maize and sugar-beet has resulted in a large increase in the use of glyphosate (from 1998 to 2018, the increase was three-fold).
- Glyphosate is used pre-harvest to control weeds in RR crops.
- Many growers and consultants believe using glyphosate for desiccation is likely to be banned. It is banned already for malt barley and milling oats).
- It is essential to understand the environmental toxicity of adjuvants (such as wetters and surfactants) used in glyphosate, and other herbicide formulations.
- There is no regulatory requirement in Canada for recording pesticide use.
- Other herbicides which could possibly be used as glyphosate replacements and worthy of investigation are Group 13 clomazone; Group 14 saflufenacil; Group 14 pyraflufen; Group 28 tetflupyrolimet; Group 13 bixlozone; and Group 30 cinmethylin.
- Note - these herbicides will not be ‘substitutes’: they do not have the same ‘knockdown’ ability of glyphosate, but they do have activity on a broad-spectrum of weeds. Substituting other herbicides for glyphosate is likely to increase the total amount of herbicide applied (due to the reduced efficacy of other herbicides in killing a broad-spectrum of weeds).
- Acetic and/or pelargonic acid formulations in ‘biological Roundup’ need to be evaluated more extensively for weed control efficacy in annual and perennial weeds. In addition, these products have an unknown impact on soil biology. This also needs to be studied.

Argentina

- Over 90% of grain production is conducted by means of no-till farming practices.
- Most of the crop growing areas are double cropped: winter crops (wheat, some barley) and summer crops (soy, maize and sunflower).
- Cover crops are grown between winter and summer crops, primarily to provide cover to reduce bare ground and protect the soil from erosion, reduce weed pressure, retention of soil N (to reduce NO^3 leaching) and, if using legumes in the cover crop mix of species, to fix additional N.
- Most country towns use groundwater for drinking and leaching of NO^3 into groundwater is a major concern.
- An increasing number of country towns are banning the use of all pesticides and artificial fertilisers for a prescribed distance from the town’s perimeter (for example, in Pergamino, the ban applies to all agricultural land for 1km from the town’s boundary). There is no compensation for loss of production.
- The most common use rate of glyphosate is ~3000g ai/ha/yr.
- Argentina has a pesticide risk assessment tool, based on World Health Organisation (WHO) data, which uses pesticide acute toxicity to assess risk.
- Strong research and agronomy consulting networks such as University of Buenos Aires (Agriculture faculty) undertake detailed research into herbicide resistance; INTA (National Agricultural Technology Institute) work on cover crops, crop competition and other agronomic means to control weeds; and agronomy consulting network such as CREA (Regional Consortium of Agricultural Experimentation) work with 226 farm groups with over 2000 grower members to develop, test and share new technologies.
- Several organisations, including CREA, are investigating and testing alternatives to boom sprayer pesticide application, such as robotics, microwave and laser technology, and nano-encapsulation of herbicides which release active ingredients slowly without resulting in detrimental impact on soil biota (soil organisms).
- Research trials to develop an ‘Environmental Impact Index’, for all agrichemicals have been established.
- Organic farms receive higher prices for organic classified grain without which they would not be financially viable.
- Argentina is a member of the SPRINT (Sustainable Plant Protection Transition) project (EU based project to study transition pathways to reduced chemical inputs).

Conclusion

Our recommendation is to establish a co-ordinated network of trials and demonstrations with research organisations and farming systems groups to communicate, identify and demonstrate alternative practices to weed management.

- Work with a group of growers who keep good records of farm chemicals (type, rate, date) and soil test extensively for glyphosate and AMPA, and other farm chemical residues in soil and grain. It will be important to first determine the variability within a paddock, or even soil type within a paddock, for glyphosate/AMPA residues, to be able to develop a comprehensive, extensive, and accurate sampling regime (one of the lessons learnt from the GRDC project on soil P and N sampling).
- Long term replicated trials with FSGs (Farming Systems Groups) using experimental plot and large-scale trials using farm machinery, to quantify the impact on productivity and sustainability of glyphosate-free crop production compared with current practices: crop density (plant population, sowing rate, row width and other planting options, crop types, stubble management), weed population dynamics (time of emergence, within crop distribution, flowering and seeding times). Inclusive of detailed measurements of soil and grain glyphosate/AMPA residues.
- Impact of cover crops on weed suppression, taking into consideration soil water and soil nitrogen dynamics of cover crops versus chemical weed control during the summer fallow phase.
- Assess impact of cover crops on
  - o soil health (soil organic C, soil microbial populations)
  - o operations (time and fuel use, inclusive of GHG emissions)
  - o crop yield and financial returns.
- Investigation of alternative means for controlling weeds (within row soil disturbance, robotics, drones).
- Using the data and outcomes collected from the above small- and large-scale trials and observations, model the impact, in different environments and soil types, on
  - o weed population dynamics
  - o production, profitability and sustainability
  - o financial consequences.
- For different farming systems, calculate the impact of pesticide (herbicides, fungicides and insecticides) use on human health and environmental parameters, for example, possibly using similar tools as developed in Argentina, such as the Environmental Impact Index(EIQ) which is based on the ecotoxicological rating of individual pesticides.
- Greater clarity in the separation of agronomic advice and sales of agrichemicals may result in better environmental outcomes through optimisation of chemical inputs resulting in improved public perception of modern farming practices.
- Weed control efficacy of other herbicides which have a relatively wide range of effectiveness in controlling weeds:

Group 13 clomazone (Magister Command®)

Group 14 saflufenacil (Sharpen®)

Group 14 pyraflufen-ethyl (Sledge®)

Group 28 tetflupyrolimet (not registered in Australia)

Group 13 bixlozone (Overwatch®)

Group 30 cinmethylin (Luximax®)

Note - these herbicides will not be glyphosate 'substitutes' – they are not 'knockdown' herbicides but they do have activity on many weeds and may well assist in weed control if glyphosate was no longer available.

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The impact of soil characteristics and environmental factors on Reflex® and Overwatch® efficacy

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Keywords

- Overwatch, pre-emergent, Reflex, residual.

Take home messages

- Both bixlozone (Overwatch®) and fomesafen (Reflex®) are relatively long persistence herbicides. Ensure labelled plantback conditions are fully met before planting rotational crops.
- Length of soil persistence (carry over) will be a factor of
    - starting concentration in the soil (application rate less any losses prior to incorporation)
    - soil type
    - climatic conditions (particularly summer rainfall) post-application.

Background

The behaviour of residual herbicides when applied to the soil is a function of the starting dose rate in the soil, individual chemical properties of the herbicide, and the environment where they are placed. Understanding these factors and how they interrelate gives users a moderate to high level of predictability of performance. Detailed discussion on how chemical properties interact with the environment they are placed in can be found in https://grdc.com.au/SoilBehaviourPreEmergentHerbicides

Reflex® (fomesafen) and Overwatch® (bixlozone) are two relatively new herbicides to the Australian grains industry. Residue carry over of these herbicides has continued to be reported this season by some users in the Southen grains region. This paper will focus on these herbicides in particular and how they are predicted to behave under Australian environmental conditions.

Getting to the soil

For any residual herbicide to perform as expected it needs to enter the soil, ideally as an even deposition and close to the applied rate. If herbicide is prevented from reaching the soil in the full dose, then length of residual activity may be reduced.

Factors affecting soil entry include:

- application rate
- presence of green plant material. Any herbicide deposited on green plant material is likely to enter the green leaf material. For some herbicides (including Reflex® and Overwatch®), this may add to post-emergent control of existing weeds, however this volume of herbicide will therefore not be available in the soil for ongoing residual activity.
- stubble interception - Herbicides with a very high Koc value (for example, trifluralin Koc = 15 800, see Pesticide Properties Database) have a high affinity to bind with organic matter and will be almost impossible to wash off stubble once the spray deposit has dried.

Overwatch® (Kfoc = approximately 400, see Public Release Summary on the evaluation of the new active bixlozone in the product Overwatch® Herbicide) does not bind particularly strongly to stubble and Reflex® (Koc = 50, see Pesticide Properties Database) has very low affinity for stubble binding. Both would generally be expected to be washed off the stubble, provided there is reasonable rainfall following application.

- incorporation time - For some herbicides that have potential to be lost to volatilisation or ultraviolet light degradation, the time to soil incorporation is important.

Data suggests that neither Reflex® nor Overwatch® are particularly prone to UV loss if not incorporated. However, there may be slight loss of Reflex® should the herbicide not be physically incorporated and there is no rainfall for several weeks, particularly if this is an early autumn application under high light intensity (for example, dry sowing in March).

Volatility loss is dependent on the ambient temperature, surface type (for example, soil, plant, stubble), moisture level, wind blowing across the surface, time to incorporation and vapour pressure of the particular herbicide. While vapour pressure is a laboratory calculation under controlled and contained situations and is only one factor involved in atmospheric losses, it does provide some indication of the relativity of potential losses between herbicides.

Typically losses from herbicides with a vapour pressure less than 1mPa (@ 20oC) are negligible under most situations. Reflex® has a published vapour pressure of 4 x 10-3mPa (see Pesticide Properties Database) so loss to volatilisation is considered negligible. Herbicides with vapour pressure above 5-10mPa may experience some losses to volatilisation, especially under warmer temperatures, with labels of these herbicides tending to recommend physical incorporation soon after application to reduce the potential for loss.

Overwatch® has a published vapour pressure of 2.3mPa (@ 25oC) (see Public Release Summary on the evaluation of the new active bixlozone in the product Overwatch® Herbicide). This suggests that there may be a low potential for some minor loss prior to incorporation, especially if conditions are warmer following application. (For comparison, other common herbicides with similar published vapour pressure include clopyralid, pendimethalin and s-metolachlor which have vapour pressures of 1.4, 3.4 and 3.7mPa respectively (see Pesticide Properties Database)). Once incorporated into the soil, any losses are likely to be negligible.

- seeding systems - In broadacre grains production, herbicide incorporation is typically a combination of physical soil movement of the planter (if sowing after the herbicide is applied) and rainfall soon after application. A well set up knife point and press wheel sowing system should provide ‘reasonable’ soil incorporation, but there can be large differences between operators in the level of incorporation achieved. Where incorporation is sub-standard, there may be some ongoing losses from volatilisation or UV degradation for the herbicide where this is important.
- If the herbicide is applied post-sowing pre-emergent (PSPE) or early post-emergent in-crop, then incorporation is totally reliant on subsequent rainfall, and environmental losses may continue to occur until adequate incorporating rainfall is achieved.
- spray drift - Every spray application results in the production of some small droplets. Typically, droplets with a volume mean diameter (VMD) of less than 150µm do not have enough weight for gravity to pull these towards the spray surface and run the risk of remaining suspended in the atmosphere for long periods of time and potentially moving off the paddock (Table 1). This may result in problems with spray drift, however also results in less herbicide reaching the soil.

Table 1: Typical percentage fines of droplets with a VMD of <152µm produced by various nozzle spray qualities.

Nozzle spray quality (ASABE 572.1)	Typical % fines <152µm (v/v)*
Fine	24 – 60
Medium	10 – 24
Coarse	6 – 10
Very coarse	3 – 6
Extremely coarse	1 – 3
Ultra coarse	0 – 1

**See Overwatch® Herbicide – volatility versus spray drift*

Soil availability

Once in the soil, some of the herbicide will initially bind to soil and organic matter, with the remainder unbound and ‘available’ in either the soil water or air spaces. For a pre-emergent herbicide to be able to be taken up by the plant, some herbicide needs to be unbound and freely available. Herbicides with extremely high soil binding (for example, glyphosate, paraquat) are not active via soil uptake.

The percentage split between bound and unbound herbicide differs between herbicides and is determined by the herbicide binding coefficient (Koc) and soil type. Soil binding coefficients are generally presented as an average and range across different soil types. For the same herbicide, the binding coefficient will typically be lower when applied to light/sandy soils or those with low organic matter (indicating more herbicide will be 'available' at any point in time), while the binding coefficient is generally higher for heavier or high organic matter soils (more herbicide is bound and less available). As there is generally more herbicide 'available' to the plant in light sandy or low organic matter soils at any point in time, it is typical to see more adverse crop effects in these soils, all other factors being equal.

The binding coefficient for Reflex® is relatively low, with Overwatch® having slightly increased binding. However, for both herbicides, it would be expected that there is likely to be substantial 'available' herbicide present in the soil water phase. As the 'available' herbicide is used up (taken up by plants or lost to microbial degradation), some previously bound herbicide is released back into the soil water to maintain an equilibrium.

To understand soil mobility, the solubility of the herbicide also needs to be considered. Solubility of Overwatch® and Reflex® are both relatively low at 40mg/L (see Public Release Summary on the evaluation of the new active bixlozone in the product Overwatch® Herbicide) and 50mg/L (see Pesticide Properties Database) (at 20oC), respectively. In summary, this means that Reflex® is largely unbound to soil and organic matter, but the lower solubility will mean that a higher volume of rainfall will be needed to move the herbicide down the soil profile. The additional binding of Overwatch® will mean that more herbicide is likely to remain closer to the soil surface, however that does not exclude the possibility of some herbicide moving deeper in the profile, particularly under heavy rainfall and lighter soil types with larger air spaces.

As Reflex® is somewhat mobile, it is likely that the germinating crop will come into contact with some herbicide and crop tolerance is based on the crop being able to rapidly metabolise the herbicide. Crops with high tolerance can sustain a PSPE application in most situations (that is, herbicide placed directly above the crop row), although damage may still be evident under conditions where metabolism is reduced. For less tolerant crops, label directions may require reduced rates and incorporation by sowing (IBS) only, which removes some treated soil from the planting furrow. While IBS reduces the total amount of herbicide exposure, a moderately mobile herbicide, such as Reflex®, may move back into the planting line with following rainfall, so IBS alone does not completely remove the risk of crop injury.

The increase in soil binding of Overwatch® allows users to better utilise positional safety for crop tolerance. The lower soil mobility means there will be higher herbicide concentration in the 0-2cm zone than further down the profile, so planting at ≥3cm depth typically reduces crop exposure. Additionally, where crops are planted IBS with knife points and press wheels, some herbicide treated soil will be removed from the planting furrow and into the interrow, further increasing crop safety.

For all herbicides (including Reflex® and Overwatch®), the risk of crop injury is greatest when there is a combination of additional stress on the emerging seedling (disease, other herbicide residues, slow emergence, poor conditions for metabolism, for example waterlogging).

Degradation and dissipation

As mentioned previously, the length of soil persistence is a factor of the initial rate of herbicide reaching the soil; the speed of breakdown of the herbicide; and the environmental conditions following application.

Reflex® and Overwatch® have relatively long persistence compared to many other herbicides. The published DT50 value (days of time for 50% of the herbicide to dissipate) for Reflex® is an average of 86 days, with a range across different soils tested of 59 to 112 days (see Pesticide Properties Database). For Overwatch®, the published values are 93 days (range 46-267) when not incorporated, or 179 days (range 37-446) if incorporated soon after application (see Public Release Summary on the evaluation of the new active bixlozone in the product Overwatch® Herbicide).

These relatively long DT50 values (or half-lives) will mean that extended plantbacks are required for sensitive crops. Closely follow label advice on plantback periods, or updated advice as provided by the manufacturer. Both FMC (Overwatch®) and Syngenta (Reflex®) provide additional information on their respective web pages.

For both herbicides, microbial degradation is the primary route for breakdown. Microbes attack herbicide residues to utilise the herbicide as an alternative food source (organic carbon). To ensure adequate levels of functioning soil microbial activity, there is a requirement for an ongoing food source (soil organic matter), available soil moisture and adequate soil temperature.

Highest levels of soil microbes are usually near the soil surface, as this is generally where the organic matter is concentrated. Soils with very low organic matter (that is, less than 1.5%) often have extended persistence of most residual herbicides.

Inversion tillage, that buries the soil surface containing the organic matter and microbes and replaces this with soil from depth that is low in organic matter and associated microbes, can be particularly problematic. Persistence of any residual herbicide is likely to be greatly extended in this situation, at least until organic matter levels can be rebuilt at the soil surface.

If the soil surface dries out, then no herbicide degradation will be occurring in this zone until the soil rewets. In southern farming systems, often with substantial dry periods over summer, this may result in an extension of time for herbicide degradation. For optimum herbicide degradation, consider the number of weeks of moist topsoil over the summer months, in addition to total amount of rainfall. Non-wetting sands can also result in uneven degradation within the soil profile, due to patches of wet and dry soil and resulting microbial activity.

Speed of microbial activity is also influenced by temperature. As soil temperature drops in winter, microbial activity slows. Therefore, soil moisture over the spring/summer months is typically more important for herbicide degradation than soil moisture during winter. In addition, soil microbes prefer a relatively neutral soil pH and no major soil constraints. Conditions outside of this may reduce the efficiency of microbial operation.

Due to the medium to long persistence of Reflex® and Overwatch®, it will be critical to ensure that label plantback advice is followed very closely. Where label plantback conditions have not been achieved, the most advisable strategy will be to switch planting intention to a more tolerant crop (that is, one with a shorter plantback period).

If labelled plantback conditions have only just been achieved, there may be benefit in conducting a soil bioassay in the field to be planted. A bioassay is where some seeds of the intended following crop are planted into soil in advance of the expected planting date and any herbicide symptoms observed on emerging seedlings. The Syngenta Reflex® web page provides information for appropriate bioassay protocols (https://www.syngenta.com.au/reflex)

Bioassays are best done in the field to be planted, as any herbicide remains in situ. However, this often means that test strips require regular watering if there is no rainfall to ensure the planted seeds have adequate conditions for emergence. Taking soil from the field to 'pot up' at home may be convenient to ensure pots can be easily watered, however runs the risk of mixing and diluting herbicide residues and may lead to false results.

Additionally, where possible, look for evidence of emerging weeds in autumn. If 'sensitive' weeds emerge without damage following the autumn break (for example, brassicas or sowthistle for Reflex®, lupins or sowthistle for Overwatch®), then users could expect an increased level of confidence that the majority of residues may have dissipated.

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ifarmwell.com.au

growing farmers' wellbeing

ifarmwell.com.au is a practical online tool kit to help Australian farmers manage life's challenges effectively and get the most out of every day.

MODULE 1: Taking stock of your current wellbeing and some practical strategies to get you started

MODULE 2: Thoughts are like bullies - how to spend less time 'in your head'

MODULE 3: Doing what matters - how to get the most out of a busy life

MODULE 4: Training your 'attention muscle' and focusing on the 'here and now' - a more pleasant, less exhausting place to be

MODULE 5: Putting it all together and moving forward

It has been designed based on
- what farmers want
- what research shows will help

- Created by farmers, for farmers
- Accessible from your computer, tablet or smart phone
- Relevant
- Confidential
- Free

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Australian Grain Technologies

Australia's largest plant breeding company, providing improved varieties of wheat, durum, barley, lupin and canola to Australian farmers.

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ADAMA Australia Company Profile

ADAMA Australia develops, manufactures and supplies, crop protection solutions for the Australian agricultural industry. At ADAMA Australia, we are committed to working with advisors, researchers, resellers and farmers to bring to market locally and globally developed solutions, addressing the crop protection issues faced by the industry.

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AGF Seeds and Smyth Seeds

AGF Seeds and Smyth Seeds have a well-established reputation for selling a comprehensive range of quality seed for cropping and pasture farming systems. As one of the leading seed production and marketing businesses in the country, we know the upmost importance of seed quality and invest heavily in continuous improvement and innovation to best serve farmers.

AGF Seeds represents more than 20 plant breeding companies from Australia and around the world. Our R&D team conducts independent, rigorous trials and evaluations to ensure that our customers have access not only to the best varieties for the Australian landscape, but the technical data required to make informed decisions. Combining our extensive trial program, farmer feedback, and decades of personal experience, our team is available to share their independent advice and expertise on the varieties that will best suit your clients, or your own, farming system and increase profitability.

Agriculture Victoria

Agriculture Victoria works with the agriculture industry on research, development, and extension to improve production, connect the sector with international markets, support development and maintain effective biosecurity controls.

Agriculture Victoria's CropSafe program collaborates with industry to actively conduct surveillance for exotic pests and diseases across the Victorian grain belt. Agriculture Victoria delivers the CropSafe program in collaboration with many major agribusiness companies, incorporating around 85% of Victoria's agronomists. This network is continually looking for pests and diseases giving farmers confidence that their grain crops are free of exotic threats.

AgVita Analytical

AgVita Analytical has been providing analytical services to clients nationally since 1984. We are recognised within agricultural industries as one of Australia's leading laboratories providing innovative plant, water and soil nutrient analysis. A key strength is our ability to provide 'real time' testing and analyses, which have a fit with today's advanced production systems, fertilisers and application technologies.

State of the art precision equipment run by dedicated staff guarantee rapid turn-around analyses, a service the Laboratory prides itself on. As well as providing a fast turn-around innovative analysis we also pride ourselves on our excellent customer service.

All test results are emailed to clients in user friendly, easy to use reports which enable consultants to further value-add when advising to their growers. We work closely with our clients to ensure they have the best information possible to assist them to understand the results issued.

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.

Envu

Envu was founded in 2022, a new company built on years of Bayer Environmental Science experience, for the sole purpose of advancing healthy environments for everyone, everywhere.

We offer dedicated services in: Vegetation Management; Turf & Ornamental Management; Professional Pest Management, Stored Grain and Termite Management.

Across each of our lines of business, we focus our work in chemistry and beyond, collaborating with our customers to come up with innovative solutions that will work today and well into the future.

For further information about Envu, please visit https://www.au.envu.com/about-us

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.

To learn more, visit www.fmccrop.com.au

GrainGrowers

GrainGrowers is a voice for Australian grain farmers with grower members across the country. We work to build a more profitable and sustainable grains industry for the benefit of Australian grain farmers, through our focus areas of policy and advocacy, grower engagement, thought leadership and active investment in future focused activities for all growers. Australian growers are at the heart of all that we do and the focus of our work. GrainGrowers membership is free for grain farmers and every voice counts.

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.

Pacific Seeds

Pacific Seeds was established in Central Queensland in 1962. Through technological innovations and collaboration with Australian growers, Pacific Seeds has grown to become the country's leading seed provider. Today, Pacific Seeds provides customers with the highest quality Canola, Field Corn, Grain Sorghum, Grazing Oats, Summer Forage and Wheat seed varieties. From technical guides to agronomic insights, Pacific Seeds also has the latest information and advice to give customers the best results.

Pioneer® Seeds

Pioneer® Seeds has been providing high performing hybrid seed and inoculants for Australian farmers for more than 40 years. All researched, produced and distributed in Australia by a Yates family-owned business, our products are backed by the Pioneer Seeds team with integrity, agronomic knowledge and localised support. www.pioneerseeds.com.au

WE LOVE TO GET YOUR FEEDBACK

Choose your preferred way to give feedback:

– access the digital form by scanning 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.

2023 Bendigo GRDC Grains Research Update Feedback

1. How would you describe your main role? *(choose one only)*

- ❑ Grower
- ❑ Agronomic adviser
- ❑ Farm business adviser
- ❑ Financial adviser
- ❑ Communications/extension
- ❑ Grain marketing
- ❑ Farm input/service provider
- ❑ Banking
- ❑ Accountant
- ❑ Researcher
- ❑ Student
- ❑ Other* (please specify)

Your feedback on the presentations

For each presentation you attended, please rate the content relevance and presentation quality on a scale of 0 to 10 by placing a number in the box **(10 = totally satisfactory, 0 = totally unsatisfactory).**

DAY 1

2. Classification – a pathway to market access. *Megan Sheehy*

Content relevance ☐ /10 Presentation quality ☐ /10

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

3. Revisiting the levers to maximise wheat yield – an international perspective: *Allan Mayfield*

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. 10:50 am	**Integrating new herbicides into the rotation** ***Chris Davey,*** *WeedSmart, YPAG Agriservices*	**Combatting septoria, rust and other battles** ***Grant Hollaway & Hari Dadu,*** *Agriculture Victoria*	**Emerging research on PGRs in high yielding environments and the photo thermal quotient.** ***Kenton Porker,*** *CSIRO*	**Canola disease management** ***Steve Marcroft,*** *Grains Pathology &* ***Kurt Lindbeck,*** *DPI NSW*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

5. 11:30 am	**A seasonal update on the hyper yielding crops project** *Darcy Warren, FAR Australia*	**Integrating new herbicides into the rotation** ***Chris Davey,*** *WeedSmart, YPAG Agriservices*	**Emerging powdery mildew challenges** ***Sam Trengove,*** *Trengove Consulting*	**Digging Deeper - agronomic fundamentals forum - Nitrogen budgeting** ***James Hunt,*** *University of Melbourne*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

6. 12:10 pm	**Combatting septoria, rust and other battles** ***Grant Hollaway & Hari Dadu,*** *Agriculture Victoria*	**Guidelines for batching and mixing new chemistry** ***Andrew Hewitt,*** *University of Queensland*	**The agronomics of pulses, implications of new varieties and herbicide tolerance traits.** ***Jason Brand,*** *Agriculture Victoria*	**Digging Deeper - agronomic fundamentals forum - Agronomic implications of crop growth stages** ***Dale Grey,*** *Agriculture Victoria*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

LUNCH

7. 1:50 pm	**Canola disease management** ***Steve Marcroft,*** *Grains Pathology & Kurt Lindbeck, DPI NSW*	**The development of a more effective zinc phosphide mouse bait** ***Steve Henry,*** *CSIRO*	**Emerging research on PGRs in high yielding environments and the photo thermal quotient.** ***Kenton Porker,*** *CSIRO*	**Testing the N Bank Theory across varying soil types** ***James Hunt,*** *University of Melbourne*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

8. 2:30 pm	**Emerging powdery mildew challenges** ***Sam Trengove,*** *Trengove Consulting*	**Guidelines for batching and mixing new chemistry** ***Andrew Hewitt,*** *University of Queensland*	**The development of a more effective zinc phosphide mouse bait** ***Steve Henry,*** *CSIRO*	**A seasonal update on the hyper yielding crops project** ***Darcy Warren,*** *FAR Australia*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

9. 3:10 pm	**Disease panel Q&A session:** ***Josh Fanning, Grant Hollaway, Sam Trengove***	**The agronomics of pulses, implications of new varieties and herbicide tolerance traits.** ***Jason Brand,*** *Agriculture Victoria*	**Tailoring subsoil amelioration to paddock zones** ***Daniel Hendrie,*** *Agriculture Victoria*	**Testing the N Bank Theory across varying soil types** ***James Hunt,*** *University of Melbourne*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

AFTERNOON TEA

10. The impact of subsoil water on soil constraints and crop growth. *Keshia Savage*

Content relevance ☐ /10 Presentation quality ☐ /10

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

11. Designing legume root ideotypes for SE Australia. *Spencer Fan*

Content relevance ☐ /10 Presentation quality ☐ /10

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

12. Maintaining a health mindset under pressure. *Kim Huckerby*

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	**Pulse disease wrap and fungicide resistance status** ***Josh Fanning,*** *Agriculture Victoria*	**A resistance update on broadleaf weeds.** ***Peter Boutsalis,*** *Plant Science Consulting*	**Novel seed traits – An update on recent R & D** ***Greg Rebetzke,*** *CSIRO*	**Emerging Strategies for Long Term Weather Forecasting** ***Dale Grey,*** *Agriculture Victoria*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

14. 9:40 am	**Key outputs and messages from the frost learning centre** *Mick Faulkner, Agrilink Agricultural Consultants*	**Benchmarking attitudes to pest management and results of IPM demos on RLEM control** *Paul Umina, CESAR*	**Reducing the reliance on artificial fertilisers** *Therese McBeath, CSIRO*	**Soil amelioration – where will it pay dividends?** *Roger Armstrong, Agriculture Victoria*	**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 pm	**Benchmarking attitudes to pest management and results of IPM demos on RLEM control** *Paul Umina, CESAR*	**Pulse disease wrap and fungicide resistance status** *Josh Fanning, Agriculture Victoria*	**Soil amelioration – where will it pay dividends?** *Roger Armstrong, Agriculture Victoria*	**Amelioration of sandy soils - the key profit levers** *Therese McBeath, CSIRO*	**None**

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

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

16. 11:30 pm	**Novel seed traits - An update on recent R & D** *Greg Rebetzke, CSIRO*	**Effectively mitigating yield losses following waterlogging** *Greta Duff, Southern Farming Systems*	**A resistance update on broadleaf weeds.** *Peter Boutsalis, Plant Science Consulting*	**Reducing the reliance on artificial fertilisers** *Therese McBeath, CSIRO*	**None**

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

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

17. 12:50 pm	**Emerging Strategies for Long Term Weather Forecasting** *Dale Grey, Agriculture Victoria*	**Effectively mitigating yield losses following waterlogging** *Greta Duff, Southern Farming Systems*	**Key outputs and messages from the frost learning centre** *Mick Faulkner, Agrilink Agricultural Consultants*	**Amelioration of sandy soils - the key profit levers** *Therese McBeath, CSIRO*	**None**

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

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

LUNCH

18. Can we survive without glyphosate? Lessons learned from Europe, Canada and Argentina.
Harm Van Rees

Content relevance ☐ /10 Presentation quality ☐ /10

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

19. The impact of soil characteristics and environmental factors on Reflex and Overwatch efficacy.
Mark Congreve

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.

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