DUBBO &
BARADINE, NSW

WEDNESDAY 28
FEBRUARY TO
FRIDAY 1 MARCH 2024

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

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GRDC 2024 Grains Research Update Welcome

Welcome to our summer series of northern GRDC Grains Research Updates for 2024.

We are pleased to bring growers and advisers another series of Grains Research Update events tailored to deliver the latest research, development and extension (RD&E) to enhance the profitability and reliance of grain production.

The past year has continued to present unique challenges and opportunities, building on our experiences from 2023 where we faced below-average rainfall in parts of Queensland and northern New South Wales and close to average rainfall in southern NSW. To date, we have seen higher than expected December and January rainfall in many regions despite an initial dryer than average outlook.

These conditions highlight the importance of our ongoing RD&E efforts in developing resilient and flexible farming practices, allowing growers to adapt to the diverse weather and climate changes we see in our region.

Sustainability within the profitable farming systems framework continues to be front of mind for our sector and an important consideration when it comes to future market access, government policy and community expectations. One quarter of GRDC's current RD&E investment portfolio has been identified as having direct environmental outcomes, with a significant portion contributing indirect environmental research outcomes. GRDC's Sustainability Initiative articulates our focus on emerging interests in sustaining and improving our soil resource and working to better understand and manage greenhouse gas emissions. We look forward to sharing further results from these investments at future Grains Research Updates.

2023 was a significant year for GRDC. After extensive consultation with growers and the grains industry we announced our RD&E 2023-28 plan and a commitment to invest more than a billion dollars in research, development and extension to deliver improved outcomes for Australian grain growers.

Across our regions, this strategic investment involves addressing critical concerns highlighted by growers and advisers through the National Grower Network (NGN) and RiskWi$e forums.

In the northern region, GRDC and NSW DPI have entered a strategic partnership *Unlocking Soil Potential* aimed at developing novel products to capture, store and use more soil water in grain production. Other major strategic investments include the National Risk Management Initiative, known as *RiskWi$e*, and work designed to quantify the response of deep phosphorus placement and means of improving phosphorus use efficiency, farming systems research comparing and improving crop sequence gross margins and of course our ongoing, extensive and well known National Variety Testing program.

These represent just a few of the investments designed to ensure the most pressing profitability and productivity questions are addressed from paddock to plate. GRDC places a high level of importance on grower and adviser engagement and we encourage you to look for opportunities to participate in regional NGN forums that capture insights for future RD&E.

While we're pleased to be able to facilitate plenty of face-to-face networking opportunities across this Updates series, we have also committed to continuing to livestream and record the main events for anyone who is unable to attend in person.

For more than a quarter of a century GRDC has been driving grains research capability and capacity with the understanding that high quality, effective RD&E is vital to the continued viability of our grains industry.

Sharing the results from this research is a key role of the annual GRDC Updates, which bring together some of Australia's leading grains research scientists and expert consultants. We trust they will help guide your on-farm decisions this season and into the future.

We would like to take this opportunity to thank our many research partners who have gone above and beyond this season to extend the significant outcomes their work has achieved for growers and advisers.

If you have concerns, questions or feedback please contact our team directly (details on the back of these proceedings) or email northern@grdc.com.au. Please enjoy the Update and we look forward to seeing you again next year.

Gillian Meppem
Senior Regional Manager – North

Day 1 Program: Thursday 29 February 2024

9am registration for a 10am start, finish at 5:05pm

Time	Topic	Speaker(s)
9:00 am	Registration, morning tea & trade displays	
10:00 am	Welcome	*GRDC*
10:30 am	The science under pinning farm gate greenhouse gas (GHG) footprint	***Warwick Badgery*** *(NSW DPI) p21*
11:05 am	GHG calculators for your grain farming business	***Ben White*** *(Kondinin Group) p26*
11:30 am	Securing access to nitrogen for food production, a GHG perspective	***Rob Norton*** *(Norton Agronomic) p27*
12:05 pm	Lunch	
1:05 pm	Concurrent session 1 – *See concurrent sessions for details*	
2:50 pm	Afternoon tea	
3:20 pm	Concurrent session 2 – *See concurrent sessions for details*	
5:05 pm	Close	
7:00 pm	Networking dinner & drinks at the at the Devil's Hollow Brewery 10 Commercial Ave, Blueridge Business Park Bus pick up for travel to Devils Hollow Brewery departs RSL at 6.30pm & 6.45pm, see route details in the proceedings. *Supported by AGT & Sumitomo Chemical Australia*	

Day 2 Program: Friday 1 March 2024

7:30–8:20am early risers session. Day sessions 8:30am start, finish by 3:05pm

Time	Topic	Speaker(s)
7:30 am	EARLY RISERS DISCUSSION SESSION The risk and reward of running a higher N budget (N banking)	***Jon Baird*** *(NSW DPI),* ***Matt Shephard*** *(IMAG)* ***& Rob Norton*** *(Norton Agronomic)*
8:30 am	Concurrent session 3 – *See concurrent sessions for details*	
10:15 am	Morning tea	
10:45 am	Concurrent session 4 – *See concurrent sessions for details*	
12:30 pm	Lunch	
1:30 pm	Being certain of uncertainty: getting the most from weather and climate forecasts. How different computer models work, resources available, why they may tell different stories, and interpreting forecasts for more effective decisions.	***Jonathan How*** *(BoM) p181*
2:05 pm	Novel weed control technologies under development in the US	***Mike Walsh*** *(University of WA) p188*
2:35 pm	Where AI adds value to agronomic and crop decision-making now, and where might this technology be in 5 years?	***Liam Ryan*** *(GRDC) p191*
3:05 pm	Close	

Location & Timing of Concurrent Sessions

	Theatrette	Starlite 1 & 2	Starlite 3
Day 1 – Session 1	Farming systems and aphids	Weeds	Barley net blotch, cereal rusts and sclerotinia in canola
Day 1 – Session 2	Farming systems and aphids	Weeds	Barley net blotch, cereal rusts and sclerotinia in canola
Day 2 – Session 3	Crown rot	Soils and technology	New tech and start-ups
Day 2 – Session 4	Crown rot	Soils and technology	New tech and start-ups

(Agenda subject to change)

Concurrent Sessions – DAY 1

Farming systems and aphids (Sessions 1 & 2, page 34)

Session Time		Topic and Speaker(s)
1	2	
1:05 pm	3:20 pm	Emerging aphid management issues - Russian wheat aphid distribution and management of faba bean aphid ***Zorica Duric*** *(NSW DPI)*
1:35 pm	3:50 pm	Farming systems impact on soil borne disease inoculum load and risks posed ***Steven Simpfendorfer*** *(NSW DPI)*
2:05 pm	4:20 pm	Farming system profit over time and risk - legumes & N & the risk/reward of high N strategies ***Jon Baird*** *(NSW DPI)*

Weeds (Sessions 1 & 2, page 64)

Session Time		Topic and Speaker(s)
1	2	
1:05 pm	3:20 pm	The residual efficacy of pre-em herbicides over time on problem weeds. An analysis of rainfall & efficacy on pre-em trials ***Richard Daniel*** *(Northern Grower Alliance)*
1:35 pm	3:50 pm	Resistance management strategies for glyphosate resistant weeds ***Chris Preston*** *(Uni of Adelaide)*
2:20 pm	4:35 pm	Consultant led discussion on integrated strategies for managing annual ryegrass in central western NSW. ***Richard Daniel*** *(NGA)*, ***Chris Preston*** *(Uni of Adelaide)*, ***Greg Condon*** *(WeedSmart)*, ***Mick Harris*** *(AGnVET)*, ***Glenn Shepherd*** *(IMAG)*

Barley net blotch, cereal rusts and sclerotinia in canola (Sessions 1 & 2, page 83)

Session Time		Topic and Speaker(s)
1	2	
1:05 pm	3:20 pm	Efficiently limiting yield loss from net-blotch in barley - a meta-analysis and an overview of decision support tools guiding the economics of fungicide use in cereals and canola ***Paul Melloy*** *(Uni of Qld)*
1:35 pm	3:50 pm	Rust management issues in 2024 ***Mumta Chhetri*** *(Uni of Sydney PBI)*
2:05 pm	4:20 pm	Sclerotinia in canola - its epidemiology and predicting when fungicide interventions are likely to be economic ***Kurt Lindbeck*** *(NSW DPI)*
2:20 pm	4:35 pm	Sclerotinia in canola - How well did the Sclerotinia CM App predict fungicide responses in central western NSW trials in recent wet seasons and were there common reasons for outliers? ***Maurie Street*** *(Grain Orana Alliance)*
2:35 pm	4:50 pm	Canola disease discussion

Concurrent Sessions – DAY 2

Crown rot (Sessions 3 & 4, page 103)

Session Time		Topic and Speaker(s)
3	4	
8:30 am	10:45 am	Strategies to reduce yield loss from crown rot – performance of Victrato®, strategies to reduce inoculum load and resistance and stewardship for Victrato ***Steven Simpfendorfer*** *(NSW DPI)*
9:00 am	11:15 am	Wheat yield and quality impacts of crown-rot with different sowing rates, nitrogen rates and varieties in a water limited year ***Ben O'Brien*** *(Grain Orana Alliance)*
9:30 am	11:45 am	A foe in the fallow: what happens with crown rot between seasons? ***Toni Petronaitis*** *(NSW DPI)*
10:00 am	12:15 pm	Consultant led panel session - managing inoculum load over time

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Soil and technology (Sessions 3 & 4, page 137)

Session Time		Topic and Speaker(s)
3	4	
8:30 am	10:45 am	The economic response of long-term soil amelioration strategies. Testing for aggregate stability & diagnosis: creating an amelioration plan: the economics of amelioration ***Chris Guppy*** *(UNE)*
9:00 am	11:15 am	Mapping soil constraints in 3D for more informed decisions on crop inputs and soil amelioration – a new decision support tool ***Ned Skehan*** *(Optisoil)*
9:30 am	11:45 am	Sensors, automation, data and Ag Tech – setting the farm up for the future ***Tim Neale*** *(DataFarming)*
10:00 am	12:15 pm	Predicting, mapping and understanding the drivers of grain protein variability using John Deere's Harvestlab 3000 Grain Sensing System (PhD presentation) ***Mikaela Tilse*** *(University of Sydney)*

New tech and start-ups (Session 3 & 4, page 161)

Session Time		Topic and Speaker(s)
3	4	
8:30 am	10:45 am	Integrating soil moisture sensors on sowing equipment to optimise seeding depth and establishment ***David Finlay*** *(MPT)*
8:51 am	11:06 am	A handheld lab for better infield decision making ***Peter Johnston*** *(Hone Ag)*
9:12 am	11:27 am	Robust remote area connectivity solutions ***Rob Lansdown*** *(Zetify)*
9:33 am	11:48 am	Automated agricultural disease detection ***Karla Gartshore*** *(BioScout)*
9:54 am	12:09 pm	Manage environmental data such as soil tests for fertiliser budgets, or developing carbon offset projects ***Sam Duncan*** *(Farmlab)*

BARADINE
GRDC Grains Research Update
Wednesday 28 February 2024

Baradine Hall, Narren Street, Baradine NSW 2396
Registration: 8:30 AM for a 9:00 AM start, finish 3:05 PM

AGENDA Time	Topic	Speaker(s)
9:00 AM	**GRDC welcome**	*GRDC*
9:10 AM	**Farming systems profitability and risk in wet and dry seasons** with a dive into nitrogen and pulse impacts on system risk and profit over time	*Jon Baird* *(NSW DPI)* *(Paper page 50)*
9:50 AM	**The economics and practicalities of dual purpose crops in Central/Northern NSW**	*David Harbison* *(DR Agriculture)* *(Paper page 58)*
10:30 AM	**MORNING TEA**	
11:00 AM	**Finding profit in the face of increasing input costs, interest and land value and the value of water use efficiency as a benchmark tool**	*Simon Fritsch* *(Agripath)* *(Notes page: 63)*
11:45 AM	**Soil constraints project -** an update on the economic response of long term soil amelioration strategies.	*Chris Guppy* *(UNE)* *(Paper page: 137)*
12:20 PM	**LUNCH**	
1:10 PM	**Resistance management strategies for glyphosate resistant weeds**	*Chris Preston* *(Uni of Adelaide)* *(Paper page 71)*
1:50 PM	**Management strategies to reduce losses from crown rot -** performance of Victrato and management strategies of inoculum load for 2024 and beyond. Resistance and stewardship for Victrato	*Steven Simpfendorfer* *(NSW DPI)* *(Papers from page 103)*
2:15 PM	**Discussion on grower strategies to manage crown rot - what's important?**	*Tony Single* *(Grower, Tigah Pty Ltd)*
2:30 PM	**The science behind farm gate GHG footprint**	*Warwick Badgery* *(NSW DPI)* *(Paper page: 21)*
3:05 PM	**CLOSE**	

Contents

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General Plenary - Day 1

Reducing GHG emissions in cropping systems – responding to drivers for change

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Key words

greenhouse gas footprint, emission reduction, emission intensity, management change

Take home message

- There are things that you can do now as a grain producer to start a journey towards a low GHG emissions future. These include, understanding the data requirements to calculating a C footprint and choosing a suitable tool for the calculations.
- Once you understand the C footprint of your business, you can assess the options available to reduce GHG emissions. This will include the expected GHG reduction of a practice change and any effects on production and profitability.
- If considering sequestration in soil and trees to offset emissions, understand that this is often initially higher than the long-term rates and will need to be maintained permanently. This comes with risk in a variable and changing climate.
- There is risk associated with doing nothing, given the expected link between C footprints and price in the future. Initiatives funded by state and federal governments are available to help, so get involved.

Introduction

The need to reduce greenhouse gas (GHG) emissions to meet international climate targets has resulted in many corporations setting GHG emissions reduction targets. These targets have been set to demonstrate a commitment to climate action to their customers and investors in order to retain their social licence to operate and help maintain market share. The frameworks used to set these targets generally require corporations to include the GHG emissions associated with their entire supply chain, including the GHG emissions associated with their suppliers. Corporations that use grains in their business will seek to purchase grain with lower GHG emissions to meet their GHG emissions reduction target. It is anticipated that the Australian grains sector will need to reduce the GHG emissions associated with production to remain competitive in global markets.

The drive for low GHG emission commodities is generating uncertainty in many agricultural sectors. Producers are not only uncertain about which management changes are likely to reduce GHG emissions but also how they demonstrate their GHG emissions intensity (*i.e.* kilogram of GHG per tonne of commodity) to the supply chain. Whilst these changes may be new for a large proportion of grain producers, what is not well known and may provide some assurances is that growers have been managing this process for several years already. In 2009, legislation was introduced that required any biofuel feedstocks imported into the EU to have a GHG emissions intensity 50–65% lower than that of conventional fuels. The EU biofuel market is a key trade outlet for WA canola growers, so they have been estimating and reporting the GHG emissions intensity of their canola production to meet market requirements for several years now. In addition, the process of demonstrating the emissions intensity of grain production is likely to be relatively simple with existing calculators (e.g. Cool Farms, CSIRO FarmPrint, PICCC Grains-GAF) able to tap into existing farm management record software with grower consent to automatically generate the emissions intensity.

GHG emissions

There are several GHGs that contribute to grain farming emissions, including carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). These gases have different contributions to global warming and different residence times in the atmosphere. The global warming potential (GWP) or CO_2 equivalent (CO_2-e) of these gases is given a standardised value for the impact they have on the environment over a 100-year period. These values have changed over time, as the method for estimating the impact of GHG's on global warming has been refined. In the Intergovernmental Panel for Climate Change (IPCC) Fifth Assessment Report the GWP values for N_2O and CH_4 are 265 and 28 CO2-e's respectively, while CO_2 is one.

Baseline emissions

The first step in reducing the GHG emissions associated with grain production is to understand the source of GHG emissions. Sevenster *et al.* (2022) assessed the GHG emissions for the Australian grains sector (Figure 1) and showed that, on a CO_2-e basis, on-farm GHG emissions ("Scope 1") comprise 61% of emissions and are dominated by nitrogen (N) fertiliser and lime emissions (26%), residue emissions (i.e. N loss from decomposing plant residue; ~20%) and fuel use (11%). Off-farm GHG emissions ("Scope 3") are dominated by emissions associated with fertiliser (22.5%) and crop protection chemical (11%) production. These emission sources can be summed for any given season or year to estimate the total GHG emissions of a paddock, farm, or the sector. However, many corporations use emissions intensity or GHG footprint (the GHG emissions for a unit of product) not the total emissions to determine purchases. Currently, the GHG emission intensity of Australian grain production is 315 kg CO_2-e/tonne grain, which is relatively low compared to other grain production countries (Sevenster *et al.,* 2022). However, the Australian grains sector needs to have a pro-active stance and work towards low GHG emissions intensity to ensure any market advantage is maintained.

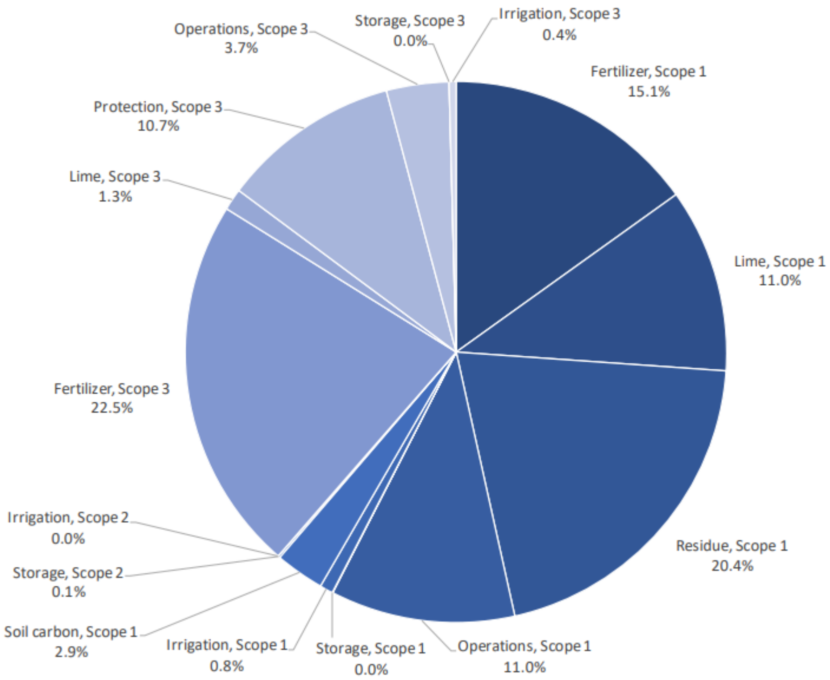

Figure 1. Contribution of emissions sources for the Australian grain sector (From Sevenster *et al.,* 2022). Scope 1 - Direct emissions from the company's operations; Scope 2 - Indirect energy emissions; and Scope 3 – Other indirect emissions.

The above assessment of GHG emissions sources is for all crops across Australia. The GHG emissions intensity of a crop will differ for each farm business and producers can estimate the GHG emissions intensity of their grains using one of a number of existing GHG calculators that are compliant with the Australian GHG accounts (see previous examples). These calculators can be used to undertake a simple analysis of an individual paddock or a few paddocks prior to making an investment decision. Governments at the state and federal level are investing in training to assist producers to baseline GHG emissions and to plan management changes to reduce GHG emissions. Interested producers should consider participating in the Carbon Farming Outreach program, a federal government funded program to educate producers on GHG accounts, that will be rolled out in 2024.

Assessing changes to grain production systems to reduce GHG emissions

It is critical that grain producers examine potential management changes through the same lens as they currently make business decisions and ensure that risk and profit impacts are well-understood and appropriately managed. Some examples of what grain producers need to consider when assessing whether management changes to reduce GHG emissions are compatible with their current system are listed below.

- *Check if claims for GHG emissions reductions or carbon sequestration are supported by credible scientific evidence*. Claims of unrealistic GHG emissions reductions, for example inflated estimates of soil organic carbon sequestration, are prevalent and grain producers need to ensure that any estimates of GHG emissions reductions are well proven, realistic and persist into the future. The most reliable peer-reviewed information will come from state-based agencies, reputable industry bodies or universities.

- *Prioritise avoidance of GHG emissions over C sequestration*. There is a high degree of certainty that implementing a strategy to avoid emissions (e.g. improve N use efficiency to reduce N_2O emissions) will result in a reduction of GHG emissions. Sequestration, in soil particularly, is higher risk because it must be maintained permanently and there is a high chance of reversal with a variable and changing climate.

- *Potential impacts on productivity*. Perhaps the most critical consideration is the impacts of management changes to reduce GHG emissions on the long-term productivity and profitability of the farm business. For example, reducing N inputs into the system can reduce the GHG emissions intensity of grain production yet doing so has the potential to not only reduce yields and profit but also increase reliance on N mineralised from soil organic matter that will result in a decline in fertility and a loss of soil organic carbon. Similarly, cutting back on lime applications where soil acidity limits production will also have long-term negative impacts on productivity.
- *Are carbon credits needed?* Carbon credits are not required for a GHG footprint. Further, if carbon credits are generated and sold to someone else then they cannot be used to offset emissions within the business, which may be required to maintain market access in the future.
- *Assess direct and indirect costs*. There is a direct cost associated with changing management to reduce GHG emissions however the indirect costs associated with a management change may be more critical to assess (e.g. yield reductions with lower N levels). There can also be indirect benefits, (e.g. pastures phases improving organic matter, mineral N supply and soil physical properties) associated with management changes. It is important to assess costs on a \$/t CO_2-e basis (i.e. marginal abatement cost).

Some of the main GHG emission reduction strategies are outlined in Table 1, along with the potential for GHG avoidance and sequestration.

Conclusion

Changing management to reduce GHG emissions intensity requires a strategic approach to ensure the change is a good fit for the system. The first step in this process is to establish an emissions baseline for your business then assess the options available to reduce GHG emissions including the expected GHG reduction of a practice change and any direct or indirect effects on production and profitability. An assessment of changes needs to take a long-term view, as issues like a gradual rundown in soil fertility may be masked by short-term seasonal variability. There are initiatives funded by state and federal governments and industry to baseline GHG emissions and plan management changes to reduce GHG emissions that producers can take part in.

Table 1. Summary of management options to avoid GHG emissions or to sequester C in a grain farming system.

Management strategy	Avoidance	Sequestration	Comments
N fertiliser efficiency	Yes	Possible	Applying N fertiliser efficiently (e.g. variable rate, split applications, not in waterlogged conditions) to optimise crop yield and replace N removal. Excess N fertiliser above crop removal rates increases the risk of N losses and N_2O production, higher fertiliser (balanced for NPKS) may lead to higher soil C[1].
N fertiliser coating	Yes	No	Using enhanced efficiency fertilisers (EEFs; e.g. N inhibitors) can reduce N_2O emissions by up to 80% but generally do not increase yield to offset the higher price[1,2]
N fertiliser production	Yes	No	Green ammonia[1] can reduce scope 3 emissions from production. Possible modular production available on-farm[2].
Lime use efficiency	Yes	No	Lime neutralises acid soils but also omits CO_2. Improve the efficiency of lime by using precision application. Consider lime alternatives.
Legumes in rotation	Possible	Possible	Legume N may reduce N fertiliser needs and the emissions associated with production. Higher N may also be associated with higher soil C.
Biochar	Yes	Yes	Biochar can neutralise soil acidity reducing the use of lime. It also has a negative priming effect that can stimulate additional soil C storage. Currently it is not viable in extensive grain production systems.
Increasing pasture phases	Yes	Yes	Soil C often continues to decrease with cropping, but pasture phases increase soil C and N, and increase mineralisation of N for subsequent crops.
Cover crops and reducing fallows	Uncertain	Uncertain	Legume cover crops may supply additional N to subsequent crops but also increase the N fertiliser needs in the short-term as N is used from fallows. Cover crops and reducing fallows may increase soil C in some situations.
Revegetation with trees	No	Yes	Revegetation with trees can sequester C but removes land used for cropping from production.

[1] Further detail on N strategies to reduce GHG emission in: *Norton R, Gourley C, Grace P, Kraak J (2024) Securing access to nitrogen for food production, a GHG perspective. GRDC Updates*.

[2] Not to be confused with green urea, which is a coated fertiliser product to reduce N_2O emissions.

Reference and further reading

GAF tools - https://piccc.org.au/resources/Tools.html

Sevenster M, Bell L, Anderson B, Jamali H, Horan H, Simmons A, Cowie A, Hochman Z. (2022) Australian Grains Baseline and Mitigation Assessment. Main Report, CSIRO, https://publications.csiro.au/publications/publication/PIcsiro:EP2022-0163.

Norton R, Gourley C, Grace P, Kraak J (2024) Securing access to nitrogen for food production, a GHG perspective. GRDC Updates.

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GHG calculators for your grain farming business

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Notes

Securing access to nitrogen for food production, a greenhouse gas (GHG) perspective

Rob Norton[1], Cameron Gourley[2], Peter Grace[3], Jeff Kraak[4], Graeme Sandral[5]

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Key words

nitrogen fertilisers, greenhouse gas, nitrous oxide, nitrogen use efficiency, GHG

Take home message

- The challenge is to know the nitrogen removal to use ratio – you cannot manage what you cannot measure. Growers are encouraged to make field scale N input and removal (NUE) estimates using the best tools available.
- Adopt N management strategies that provide 'just enough' nitrate in the rootzone to meet crop demand, such as N budgeting, enhanced efficiency fertilisers, zoned nutrient management, split applications, fixed N from legumes and in-soil N placement.
- The production of 'green ammonia' as feedstock will significantly reduce GHG footprint of N fertiliser.

As N cycles from the air to soil and into plant products, ammonia (NH_3) volatilisation, nitrate (NO_3^-) leaching and nitrification/denitrification can result in environmental impacts. Denitrification is the principal process where NO_3^- is biologically reduced by removing one or more of its oxygen atoms to create N_2, NO or N_2O, depending on soil conditions. Gaseous NH_3 and N_2O emissions can be derived from all N sources, including manures, composts, crop residues, biological fixation and fertilisers (Figure 1).

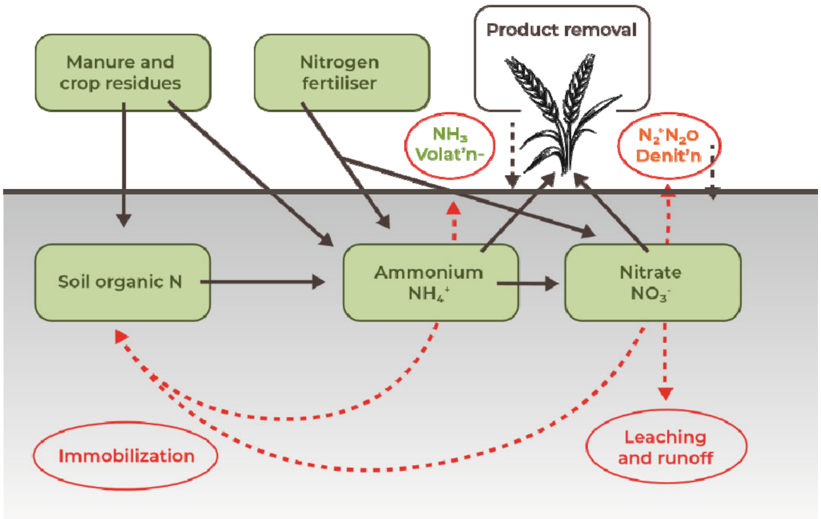

Figure 1. A simplified nitrogen cycle showing the inputs and pools of nitrogen, along with loss and transfer pathways in red dashed lines (International Plant Nutrition Institute). (Volat'n = volatilisation; Denit'n = denitrification). Gaseous N can redeposit.

Nitrous oxide (N_2O) is one of the main greenhouse gases associated with N fertilisers. Agriculture produces around 15% of Australia's greenhouse gas emissions, and N_2O represents about 15% of the emissions from agriculture or 8.1 Mt carbon dioxide equivalent (CO_2e). Direct (Scope 1) N_2O emissions from agriculture are derived from fertilisers (30%), decomposition of crop residues and organic materials (30%), the direct deposition of dung and urine (35%), and where animal manure is stored, and land applied (5%) (Figure 2).

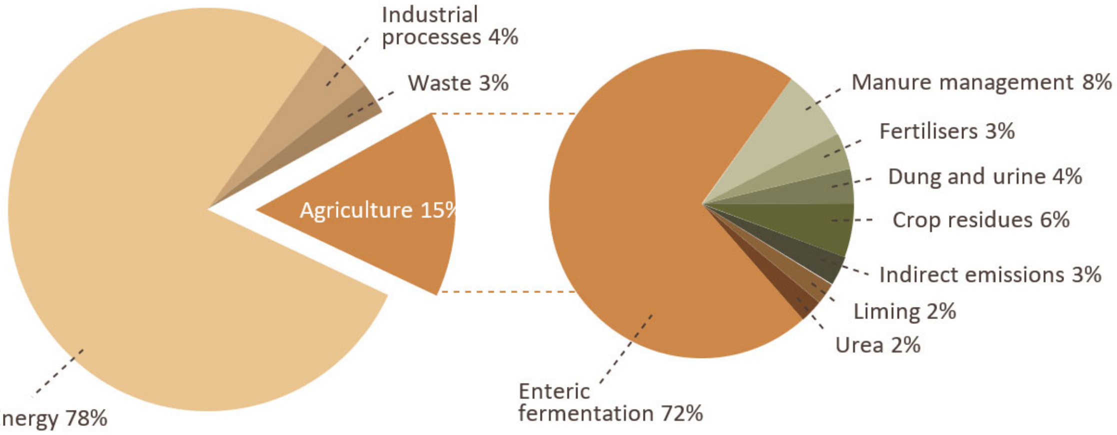

Figure 2. Total greenhouse gas (GHG) emissions for Australia by United Nations Framework Convention on Climate Change, net of Land Use, Land Use Change and Forestry sector (left) and the breakdown of agricultural emissions by IPCC source.

There are additional Scope 1 greenhouse gas (GHG) emissions from urea fertilisers due to the 20% carbon content, released as CO_2, not N_2O. The GHG inventory estimates this adds 1.76 Mt CO_2e. Significant GHG emissions are embedded in the production of N fertilisers, although the amount varies depending on the place of manufacture and the different N sources. For example, when urea fertiliser was produced in Australia, it had a GHG 'cost' of 3.3 t CO_2e per tonne N, while urea produced in China, using coal-derived energy, has twice this GHG 'cost'.

The production of N_2O is intimately connected to the levels of NO_3^- and the presence of warm, wet or waterlogged soils. The amount of N_2O produced is indexed against the amount of N fertiliser supplied by the 'emission factor' (EF). Australian research (Grace P *et al.,* 2023) has measured an average EF for all N sources of 0.57%, ranging from 0.17% (non-irrigated pastures) to 1.77% (sugar cane). Emission factors were independent of topsoil organic carbon content, soil bulk density and pH, but increased with rainfall for every 100 mm over 300 mm. Emission factors were not always linearly related to N input, with some farming systems showing a two component EF model with linear and exponential components.

What is the issue?

Options to reduce GHG emissions is a focus across many industrial activities and agriculture is no exception. The National Farmers Federation 2030 Roadmap identified that low GHG emissions credentials are important to keep our commodities in export markets. Methods to assess GHG footprints are being developed and refined, along with management strategies where emissions can be reduced to guide towards a low emissions future.

The challenge is that as N fertiliser use in Australia increases to meet the demands of high and more sustainable production, the increase in production is somewhat greater, proportionately, than the increase in N – with the result that emission intensity (kg CO_2-e per tonne of grain) declines. The Sevenster *et al.*, 2022 report suggests that the 2005 GHG emission intensity for cereal production was 315 kg CO_2e/tonne grain and suggested that fertiliser manufacture and use contributed 40% of the total emissions. Estimated GHG levels for individual farms can now be calculated using tools like:

- Cool Farms (https://coolfarm.org),
- CSIRO FarmPrint (https://www.csiro.au/en/research/environmental-impacts/sustainability/FarmPrint)
- PICCC Grains-GAF (https://www.piccc.org.au/resources/Tools).

It is useful for growers or their advisors to go through this analysis to establish a benchmark along with an understanding of how they compare to others in the industry so measures can be taken to reduce emissions intensity.

In addition to meeting our national emissions targets, it is clear that other countries are undertaking GHG assessments for their own production systems, but also considering international emissions transfers through commodity trading – termed Carbon Border Adjustment Mechanisms (CBAM). The European Union (EU) was the first jurisdiction to announce a program for implementing a CBAM. The mechanism is designed to reduce carbon leakage and create a level playing field for domestic producers in industries that pay a carbon price as part of the EU emissions trading scheme (EU ETS) (European Parliament, 2022). Other countries, in response, have similarly announced consideration of adopting similar policies (Deloitte Access Economics, 2023).

Significance of Australia's N use to GHG

Australia uses less than 1.5% of the total elemental fertiliser N consumed globally and is the 17th largest consumer of 117 countries reporting N use. Domestic N fertiliser use has increased 9-fold since 1960 to almost 2 Mt N, but represents <1.5% of global use. Legume species also supplement fertiliser N supply, but N fixation is challenged by a decline in land area, lower biomass and weak symbiosis (Peoples et al., 2001). The relatively low N fertiliser rates predominately used for extensive cropping, at around 30–70 kg N per ha, is compensated by the large area of cropped land and makes up around 66% of all N fertiliser used. Compared to other countries, our rates of use and removal are modest (Figure 3) with average NUE for wheat, other cereals, canola, cotton, and sugarcane, of 0.82, 0.68, 0.88, 0.48 and 0.44, respectively (Norton *et al.,* 2023). Of note is that substantial cropped areas have N use efficiency (NUE) >1, effectively drawing down soil N and organic matter.

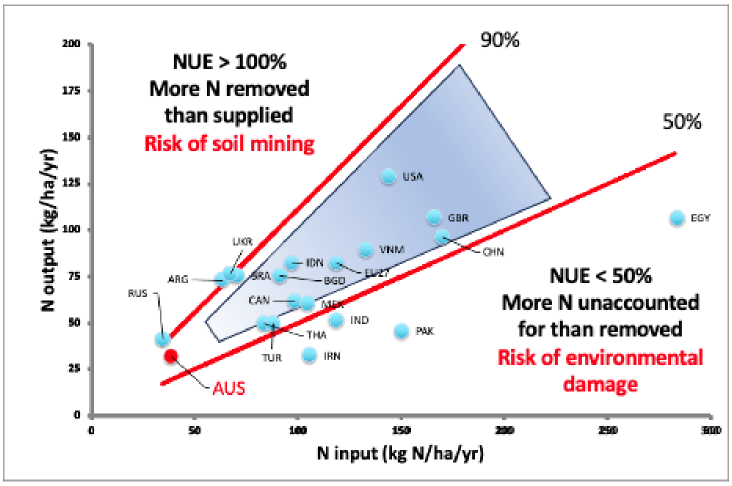

Figure 3. NUE (partial nutrient balance for N) for cereals, graphed as the output (removal) of N against the fertiliser input N. The thick red lines show values of NUE according to the relation between inputs and outputs. Biological N fixation and manure use are not considered in this example. The 'safe' operating area as proposed by the EU Expert Panel is shaded. Each circle represents a country indicated by UN Country 3 letter code.

What to do?

It is an old saying that you cannot manage what you cannot measure, and so the first step in managing N and GHG fertiliser emissions is to know the nitrogen use efficiency (NUE). NUE in its simplest form is the nutrient removal to use ratio, which is the efficiency of a recovery of N in the produce. NUE is more correctly termed the partial nutrient balance (PNB) of N and in much of the literature this simple measure of NUE is used because it is scalable from field to farm to region to national and even global. It can also be estimated as repeated measures over time, and most importantly, informs management.

NUE (%) = (sum of outputs / sum of inputs) * 100

Where the **sum of outputs** (kg N/ha) = (grain yield (t/ha) * protein (%) * 10) / 5.7

e.g., 4 t/ha * 12% protein * 10 / 5.7 = 84 kg N/ha,

and the **sum of inputs** (kg N/ha) = (urea rate (kg/ha) * 0.46) + (MAP rate * 0.10)

e.g., 140 (kg urea/ha) * 0.46 (% N in urea) + 60 kg MAP * 0.10 (% N in MAP) = 70 kg N/ha.

NUE is 84 / 70 = 120% which means 120 kg N /ha is exported for every 100 kg N applied. The Australian wide average NUE/PNB value for cereals for 2018 was reported as 83% (Norton et al. 2023).

In a balanced system, the NUE would be 100%, with all the N supplied being removed in the produce. Nitrogen use efficiency, as used here, does not describe any N transformations within a system, nor is it a direct quantitative assessment of N loss from the system. Nitrogen supplied but not removed in the plant products might remain on site and accumulate in the soil. However, over the long term, low NUE (e.g. <0.7) will usually mean N is being lost to the system, with adverse economic outcomes for growers and poor environmental outcomes. Conversely, if the NUE is high over time (e.g., >1.4), soil resources are being exploited and long-term soil fertility will decline ultimately adversely affecting the sustainability of productivity. A direct consequence of high NUE is most obviously a decline in soil organic matter, which supplies the N demand not met by mineral N.

Within any cropping system, NUE varies from paddock to paddock and year to year, and so N input and removal estimates for a paddock need to be developed over 4 or 5 years to assess whether N is in deficit or in surplus. Consideration of N loss through grain, residue removal, leaching, erosion and denitrification are balanced against fertiliser addition (see examples calculations above) and N fixation (Biomass dry weight at 30% podding * 19.5 = Net N contribution in kg N/ha, see Brill et al 2023). Further refinements can be applied where farm machinery permits the development of N removal maps [(grain yield (t/ha) * protein (%) * 10) / 5.7] on a 3 ha or so grid basis and N supply delivered on the same grind basis. This allows PNB for N to be estimated on the 3 ha grid so checks can be applied to areas that maybe outside the ideal range of 0.8 to 1.2.

General initiatives to reduce GHG intensity.

- Where there are large differences between water limited potential yield and achievable yield, check for production limiting factors and apply remedies.
- Most approaches that improve water use efficiency will reduce GHG intensity as efficiency of the conversion of inputs to outputs is improved.

Initiatives to reduce the GHG footprint of fertilizer N

It's important to recognise that management options to improve NUE and reduce N_2O emissions are complementary strategies.

- Best practice guides such as the Fertcare® series covering various industry sectors incorporate the 4R (right rate, right source, right placement, and right timing) nutrient stewardship principles.
  - ‘**Right rate**’, use appropriate N budgeting strategies aided by soil testing and tissue testing to improve the ‘right rate’ as part of nutrient stewardship.

    N budgeting based on yield estimates from Harries et al. (2022), Sadras and Rodriguez (2007) and French and Schultz J (1984) indicate water limited potential yield (WLPY) as:

    Wheat = (WU – 75)*25 / 1000 = t/ha

    Barley = (WU – 80)*24 / 1000 = t/ha

    Canola = (WU – 110)*15 / 1000 = t/ha

    Where WU (mm) = (0.20*Nov–Mar rain) + Apr–Oct rain

    Economic yield (EY) is estimated by WLPY * 0.8

    Therefore, for wheat where WU is 280 mm the WLPY is 5.1 t/ha and EY is 4.1 t/ha.

    Crop N demand for EY is calculated as 4.1 t/ha (EY) x 40 kg N/t of grain production providing a total of 164 kg N/ha. From this pre-sowing soil N is subtracted (say 60 kg of pre-sowing soil N/ha) leaving the amount of N to be supplied from fertiliser, in this example 104 kg N/ha of fertiliser N is required. Converting to urea the 104 kg N/ha is divided by 0.46 to provide the urea application rate (e.g., 226 kg urea/ha). In the case of canola 80 kg N/t of grain production is used.

    Note that the above calculations assume no other yield limiting factors. It is common for paddocks or parts of paddocks to be yield limited by nutrient deficiencies other than N, soil acidity, soil sodicity, low infiltration rates leading to surface water flow, or poor soil water holding capacity. Where one or more of these or other factors limits yield then a revised potential yield (RPY) needs to be estimated and replaces the water limited potential yield (WLPY) value in the calculations provided above. These insights are particularly important in avoiding any over fertilisation with N which increases the risk of GHG emissions.
  - ‘**Right timing**’, use split applications of N fertilisers to address the ‘right timing’ as part of nutrient stewardship. This approach reduces the nitrate spike in the soils and increases the efficiency of use by plants, leaving less N to be lost to the atmosphere, leaching or potential denitrification. This ‘right time’ approach ensures an improved matching between plant N demand and N fertiliser supply. In cereals N demand increases significantly from the commencement of stem elongation.

    As part of the ‘**right timing**’ approach, avoid applying N under waterlogged conditions and improvements in soil drainage will significantly reduce GHG emissions. Low soil oxygen combined with the high soil nitrate favours the conversion of NO_3^- to N_2O and N_2 gas. While denitrification rates are generally low, if these conditions occur in conjunction with warm soil temperatures the denitrification losses can be extreme. Split N applications are particularly suited to sites that may be prone to temporary waterlogging or leaching.
  - ‘**Right source**’, gaseous N losses as N_2O can often be reduced by up to 80% by using nitrogen stabilisers such as nitrification inhibitors (NI). The gains in productivity from the use of NI products can be small, suggesting that the adoption of these enhanced efficiency fertilisers will likely need to be incentivised.
  - ‘**Right source**’, incorporate legume N from crops or pastures in the crop sequence to provide organic N. The advantage of organic N is that in this form it is not subject to losses and will

  only mineralise to nitrate (NO_3) at significant rates when soil moisture and temperature conditions are favourable for plant growth.
  - Manage cropping soils with minimum tillage and retain residues to slow organic matter breakdown.
    - Tillage often causes a spike in N mineralisation and microbial growth increasing CO_2 emissions from microbes as they consume soil carbon. It also increases the risk of nitrate exposure to loss pathways (e.g., release of N_2O and N gas) at a time of no or low plant demand for N.
    - Burning residues releases CO_2 and retaining residues allows a proportion of the stubble to be incorporated into the soil carbon pool.
  - '**Right place**', where possible, place N in the soil rather than on the surface. This can reduce losses from ammonia as products like urea are first converted to ammonium and from ammonium are converted to either ammonia or nitrate. Urea placed in the soil allows for any ammonia to be re-converted to ammonium as the ammonia moves away from the high pH of the urea granule and encounters a lower pH soil environment. The high pH around the urea granule is a temporary spike caused by hydrolysis of the urea. Typically, in acid soils there is a low risk of ammonia loss.
  - '**Right place**', precision placement of N using protein maps, N offtake, N sensors and other Precision Agriculture tools is helpful in avoiding over supply of N that also increases the risk of N losses and GHG emissions.
- Decarbonising N fertiliser manufacture: Urea is the main N source used in cropping systems and as discussed earlier it has significant Scope 3 carbon emissions embedded in its manufacture. There are technologies to produce ammonia - the feedstock to urea production - by using renewable energy (wind, solar, geothermal) to power traditional Haber-Bosch synthesis, as well as the development of electrolytic processes to generate hydrogen from water rather than deriving it from fossil fuels (methane). There are also options for carbon capture and sequestration (CCS) to offset carbon generated through the Haber-Bosch process, and this is termed 'blue" ammonia. The shift towards the production of 'green' and 'blue' ammonia will reduce the Scope 3 emissions embedded in N fertilisers. New and modular production facilities that can be deployed for N fertiliser production represent a significant disruptive technology for the fertiliser industry.

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This paper is a brief summary of parts of the 2023 commissioned publication 'Nitrogen fertiliser use and greenhouse gases - An Australian assessment: Challenges and Opportunities.' by Norton RM, Gourley C, Grace P. Fertilizer Australia, Canberra. 69 pp. Copies can be obtained from https://fertilizer.org.au/about-fertilizer-australia/our-priorities-and-initiatives/fertiliser-issues/environment

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Concurrent session - Aphids & farming systems

Emerging aphid management issues – Russian wheat aphid distribution in northern NSW and management options for faba bean aphid

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Key words

Diuraphis noxia, *Megoura crassicauda*, aphids, wild grass, seed treatment, foliar insecticide, efficacy

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Take home message

- The Russian wheat aphid (*Diuraphis noxia*) has been recorded to northern New South Wales in August 2023, and its presence has been verified on wild grasses throughout the summer. Gurley (NSW) marks the northernmost location where it has been detected. Wheat, barley, barley grass, phalaris grass, and prairie grass are among the crops and grasses where Russian wheat aphid has been identified.
- The presence of the faba bean aphid (*Megoura crassicauda*) has been documented in Queensland, New South Wales, and Victoria. Typically, infestations occur in late winter, but in 2022, it made an unwelcome early appearance, impacting volunteer and early established faba bean crops.
- The application of tested chemicals in field conditions reduced faba bean aphid numbers compared to the control group, where intensive damage was observed along with the presence of predators and parasitoids. Both foliar treatments tested, pirimicarb and pymetrozine, were highly effective and the imidacloprid seed treatment significantly reduced aphid numbers in emerged faba beans, particularly when combined with foliar treatments.
- Typically, effective aphid management involves addressing the green bridge and volunteer plants before the season begins, monitoring both pests and beneficial insects throughout the season, and applying insecticides when aphid pressure becomes high.

Background

The **Russian wheat aphid** (RWA – *Diuraphis noxia*), a significant pest affecting cereal crops globally, was first reported in South Australia in 2016. It has since spread to the key grain growing regions of South Australia, Victoria, New South Wales, Tasmania, and Western Australia, but remains absent in Queensland. As of 2019, the northernmost confirmed presence of the Russian wheat aphid in Australia was at Tamworth (NSW). However, there were no samples positively identified as RWA in north-west NSW that would indicate the presence of the aphid in the years 2020, 2021, and 2022. The decrease in the Russian wheat aphid population during this period may be attributed to the hot and dry summer of 2019, along with the absence of an over-summer green bridge which suppressed the population prior to the wet seasons that followed. Notably, during this same period, RWA occurrences were recorded in central and southern NSW. However, in August 2023, RWA was identified in multiple locations across the northern NSW.

The initial recording of the **faba bean aphid** (FBA – *Megoura crassicauda*) in Australia dates to 2016 in Sydney, and it was later discovered in a faba bean crop in north-west NSW in 2017. Despite conducting a distribution survey, the aphid was not observed again until 2020. Subsequently, since 2020, the FBA has been consistently identified in NSW. The aphid's presence extended to

Queensland in October 2021, and by 2022 outbreaks were reported in Victoria. Notably, sightings of the aphid were documented on the citizen science platform iNaturalist in late November 2020 in Victoria, preceding its confirmed spread in 2022.

Update on Russian wheat aphid activity, environmental drivers and distribution in northern NSW in 2023

While the CLIMEX model, developed by Avila *et al.* (2019), indicates the potential for the RWA to be established in all major Australian grain regions, its success as an invasive species depends heavily on environmental factors. Spring and autumn rainfall appear to be crucial influences on RWA population growth. The aphid is abundant in relatively warm, dry climates with summer rainfall ranging from 300 to 400 mm. Mean temperatures exceeding 20°C create an unfavourable environment for RWA and reduce survival (GRDC, 2017). However, once established in an area, the RWA is highly adaptable to environmental changes. This resilience allows it to survive at low numbers for extended periods and experience sudden population outbreaks in new areas when favorable environmental conditions are met.

Winter cereal crops typically experience infestations of RWA during warm autumn conditions, when aphids move from grasses to early planted cereals. However, in autumn 2023 in northern NSW this did not occur, with various locations, including Tamworth, experiencing significantly higher than average total rainfall. This increased precipitation may have delayed RWA movement. A further delay in the main infestation likely occurred when warm and dry conditions emerged.

By August 2023, RWA was officially detected in several areas in the north of NSW. The first confirmation of RWA's presence for the season was documented at Tambar Springs, followed by positive samples identified in different locations. These encompassed reports received and the examination of crops and samples from commercially cultivated cereals in the Liverpool Plains, Trangie, and Moree Plains regions (Figure 1). The recorded RWA infestation has extended approximately 180 km compared to the 2019 record, reaching Gurley with no observed or reported positive findings further north.

Low numbers of RWA (1-2% of tillers infested) were detected in the crops examined in August 2023. The infestations have been detected in wheat and barley, both with and without insecticide seed treatment. Characteristic symptoms of RWA feeding were evident on the cereals, including long streaks, ranging from whitish to yellowish and longitudinal rolled leaves where the aphids were sheltered. The growth stage of the crops was approximately GS 30-32 at the time of initial infestation and inspection, except the crops in Moree Plains, which were at heading and flowering growth stages. In 2023, a total of 130 samples were inspected. Apart from the cereal hosts during the winter season, positive samples were also collected from barley grass (*Hordeum leporinum*), phalaris (*Phalaris aquatica*), prairie grass (*Bromus catharticus*) and regrowth of wheat and barley during summer.

Wheat, barley and durum wheat are known as primary and viable hosts for RWA for a significant part of the year. Nevertheless, the host range of RWA includes over 140 species (GRDC, 2017), suggesting the potential for RWA to sustain its population using alternative hosts such as oat, triticale, sorghum, and a diverse range of wild grasses (Duric, 2021). As the winter season concludes and temperatures rise, RWA migrates towards alternative hosts.

Wild grasses and volunteer cereals play a crucial role in maintaining RWA populations during the summer, acting as a ‘green bridge’ for infesting cereal crops in the autumn. This is because RWA relies heavily on the existence of alternative hosts, particularly barley grass, and especially in areas with relatively consistent summer watering. Other preferred alternate hosts are brome grasses, wild oat grasses, and sporadically phalaris and dactylis grasses (Pirtle *et al.,* 2019).

Effectively managing this green bridge is crucial for controlling RWA populations. Successful control also involves monitoring cereal crops at growth stage 30 and using the developed Russian wheat aphid action threshold calculator to determine the need for intervention. By taking these proactive steps, growers can prevent RWA outbreaks and protect their crops from significant damage in later, more sensitive growth stages.

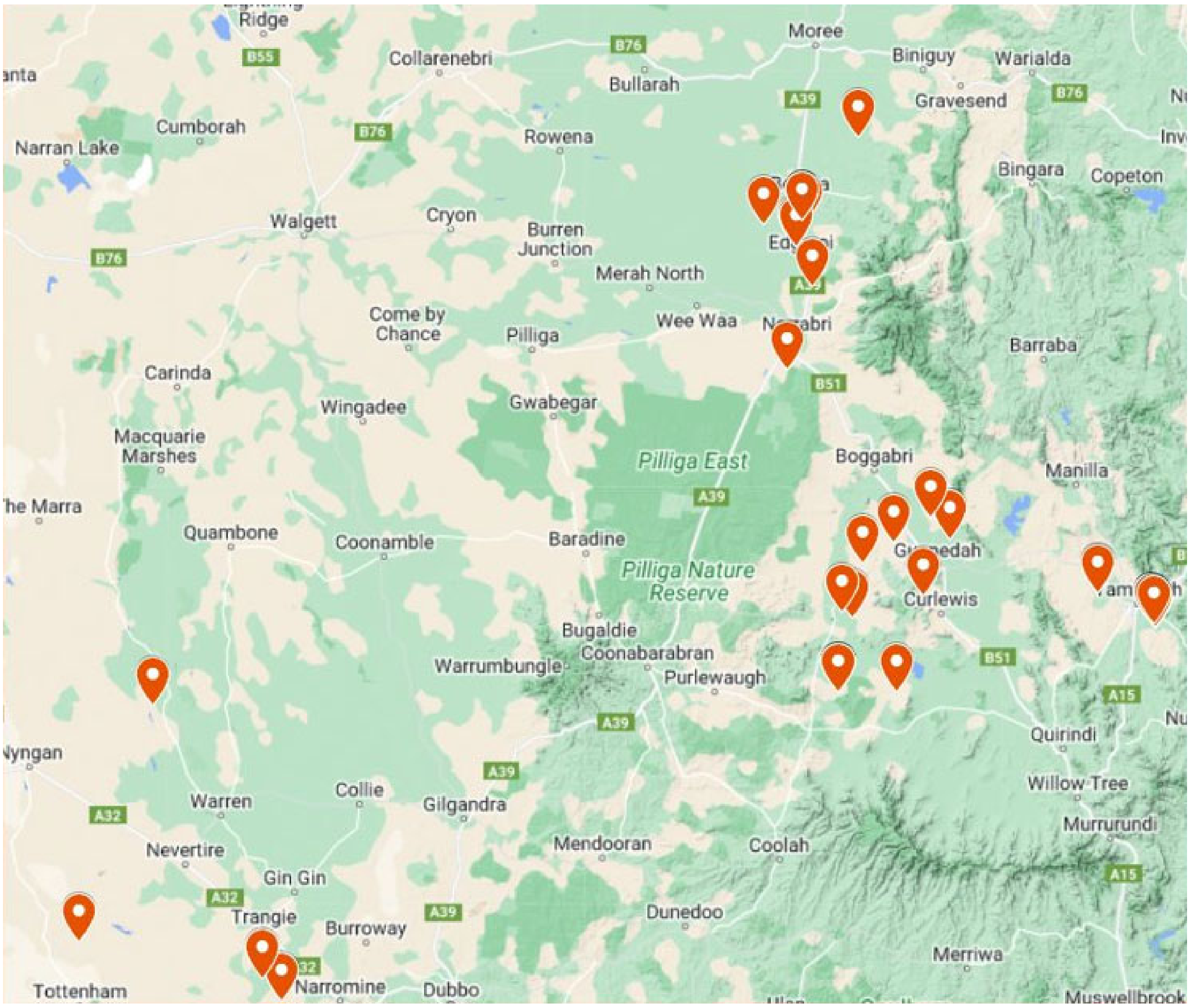

Figure 1. RWA positive samples collected in 2023 in northern NSW

Field study on faba bean aphid management

Observations from previous studies show FBA's predisposition to form hot spots within crops, primarily faba bean and common vetch (Duric *et al.*, 2022). These hosts facilitate the aphid's rapid reproduction, while field peas, lentils, and to a lesser extent, lucerne and subclover offer additional survival and reproductive opportunities. Notably, intensive feeding by FBA can induce damaging symptoms including necrosis, wilting, stunting, and defoliation. Furthermore, previous research demonstrates FBA's ability to vector both *Bean leaf roll mosaic virus* (BLRV) *and Pea seed-borne mosaic virus* (PSbMV), suggesting a wider potential for persistent and non-persistent virus transmission.

Previously, FBA infestations were primarily associated with late winter. However, 2022 observations in north-west NSW revealed early aphid presence in both volunteer and early established faba bean crops (Duric *et al.,* 2023). FBA may be leveraging alternative pasture legumes as a 'green bridge' to connect the gap between seasons and colonise winter crops earlier. Recognising the significant challenge posed by FBA's year-round survival and migration capabilities, we conducted a field trial to assess and compare the effectiveness of various chemical control options. This initiative provides valuable insights for effective FBA control throughout the year, ensuring crop protection and minimising future losses.

Methods

This study assessed the effectiveness of various chemical products against FBA in faba beans. Faba bean seeds (WardaⓅ) were treated with imidacloprid before planting. Both treated and untreated faba bean seeds were planted on April 17, 2023 and plants germinated on May 1, 2023. Additional foliar insecticide treatements (pirimicarb or pymetrozine) were applied later, after aphids had established. Six treatment groups in total were compared: untreated control (Con), imidacloprid seed treatment only (Imi), pirimicarb foliar spray (Pir), pymetrozine foliar spray (Pym), combined imidacloprid seed treatment and pirimicarb spray (Imi/Pir), and combined imidacloprid seed treatment and pymetrozine spray (Imi/Pym). The experimental design was a randomised complete block with four replicates. The rates used are given in grams of active ingredient (g a.i.) applied per ha (Table 1).

Table 1. Descriptions of insecticides used in the experiment and application rate in field conditions

Active ingredient (a.i.)	Formulation	Application rate	Recommended field rate	Type of pesticide	Critical use comments
Imidacloprid	600 g/L	120 mL/100 kg of faba bean seed		4A group Insecticide	Do not graze or cut for stock feed within 16 weeks of sowing.
Pirimicarb	800 g/kg	128 g a.i./ha	160–190 g/ha	1A group Insecticide/ Aphicide	Minimum retreatment intervals 14 days. Do not apply more than 2 applications per crop. Withholding Period: Do not harvest, graze or cut for stock food for 21 days after application.
Pymetrozine[1]	500 g/kg	100 g a.i./ha	200 g/ha for faba bean aphid	9B group Insecticide	Minimum retreatment interval 14 days. Withholding Period: Harvest: Not required when used as directed. Grazing: Do not graze or cut for stock food for 21 days after application Do not apply after BBCH 70 Do not apply more than 2 applications per crop. Do not apply consecutive applications.

[1] Permit no PER85363 allows minor use of pymetrozine in faba beans until 31 August 2026 for control of specified aphid species. The permit is valid in all states and territories except Victoria.

Prior to the field experiment, FBA colonies were multiplied in insect cages under controlled glasshouse conditions. When faba bean plants emerged and reached the ‘three pairs of unfolded leaves’ growth stage, repeated infestations were carried out to establish aphid colonies on them.

Ten randomly chosen plants were used within each plot to count live adults and nymphs (Day 0). Foliar insecticides were then applied on the same day. Subsequently, the same labelled plants were monitored on days 2, 7, 14, and 27 after foliar treatment (except for imidacloprid seed treatments, where data refer to days after infestation).

To investigate the impact of insecticide treatment on both aphid survival and their offspring production, a linear mixed-effects model (LMM) was employed. To identify specific treatment groups with significant differences in aphid survival and progeny production, pairwise Least Significant Difference (LSD) tests with Bonferroni adjustment were conducted. Additionally, Henderson-Tilton's formula was used to calculate the percentage efficacy of the treatments against FBA adults:

$$\%\ \text{efficacy} = \left(1 - \frac{\text{n in Co starting population} \times \text{n in T 2, 7, 14, 27 DAT}}{\text{n in Co 2, 7, 14, 27 DAT} \times \text{n in T starting population}}\right) \times 100$$

n = adult aphid numbers, T = treated, Co = untreated, DAT = days after foliar treatment (for imidacloprid seed treatments, data refer to days after infestation).

Results and discussion

Aphid colonisation and establishment on imidacloprid seed-treated plants was less than on seed-untreated plants at day 0 (Figures 2 and 3), however there was no significant difference in their initial levels across the treatments. All insecticide treatments, including imidacloprid seed treatments, resulted in consistent reductions in aphid populations on days 2, 7, 14, and 27. Significant differences were evident in all insecticide treatments within each pairwise comparison of FBA adults (Figure 2) and nymphs (Figure 3), except on day 2, where the pymetrozine treatment was not significantly different to the untreated control for both adults and nymphs. In contrast to all treatments, populations in the control treatments either remained stable in adult counts or gradually increased in nymph counts until the final observation on day 27, with a slight decrease on day 14 likely attributed to environmental conditions.

Control plots suffered severe damage, with honeydew, necrosis, and stunted growth. Notably, a new symptom was observed: a curving of the stalk's top part where aphid colonies flourished (Figure 4). While beneficial predators like white collared ladybirds (*Hippodamia variegate*) were found on these large control colonies, no such presence was noted in the insecticide-treated plots. Moreover, mummified FBA were identified for the first time, a valuable discovery given the limited knowledge about FBA predation and parasitism (Figure 5).

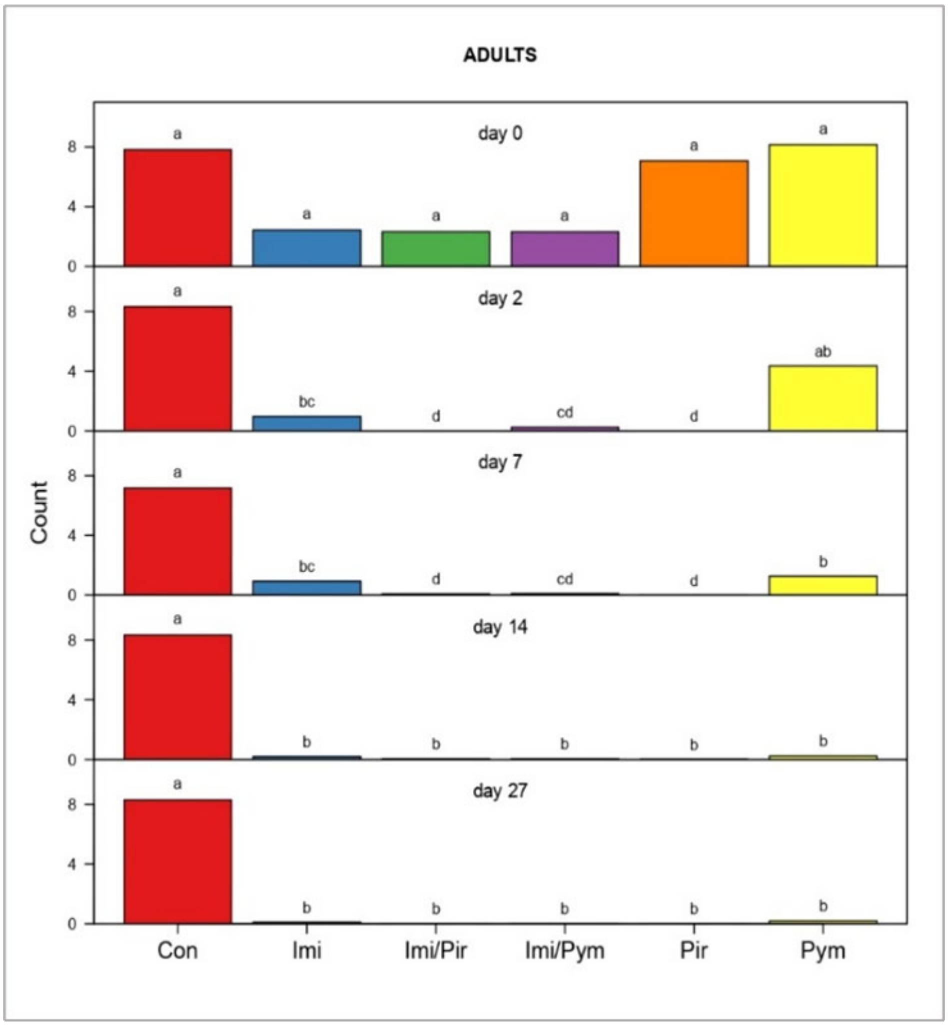

Figure 2. Pairwise comparisons of faba bean aphid adult survival following insecticide treatments. Data represents survival observed on Day 0 and Days 2, 7, 14, and 27 after foliar treatment (for seed treatments with 'imidacloprid' data refers to days after infestation).
The model treated 'day' and 'treatment' as fixed effects, and 'repetitions' as a random effect. Data within rows marked by the same lower case letter did not differ significantly at the 5% level of significance.

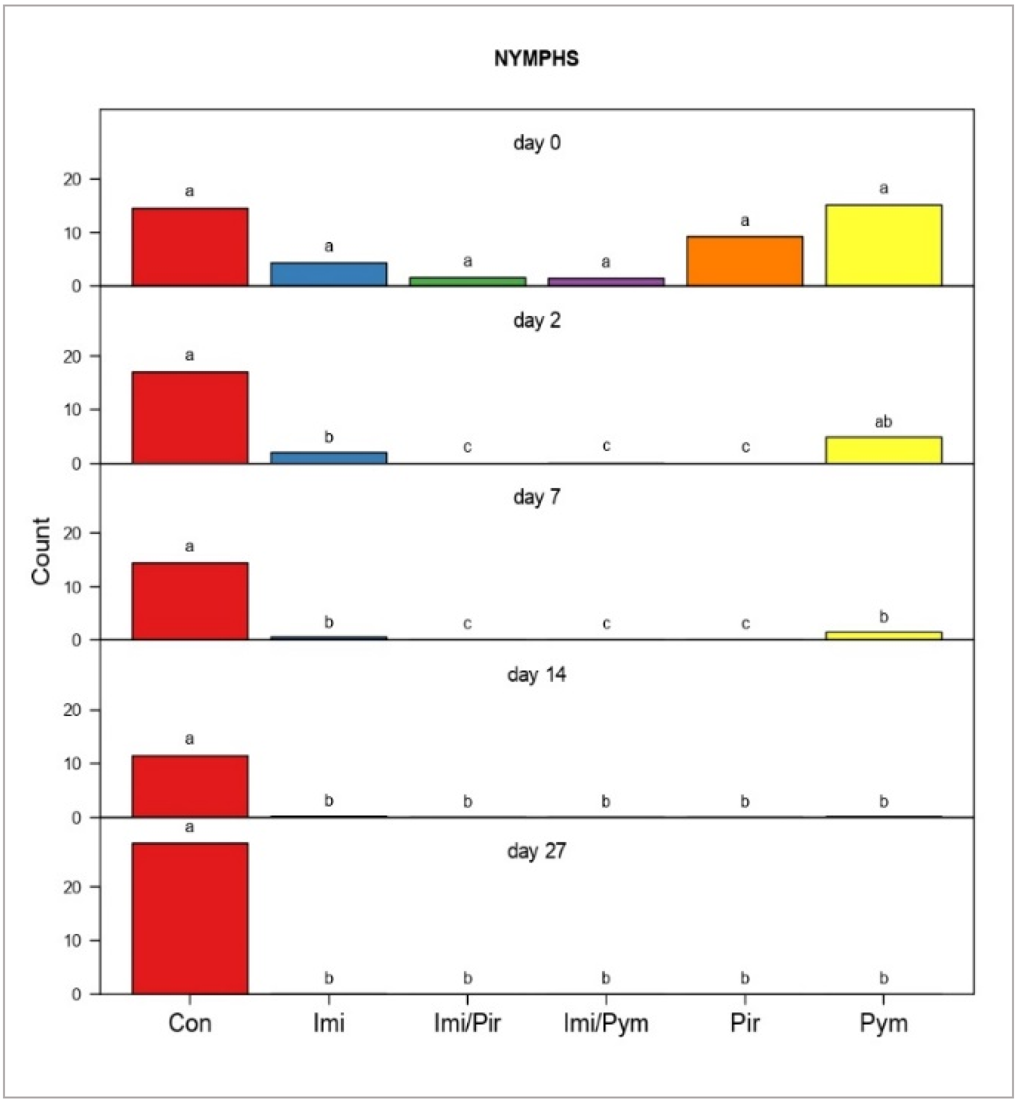

Figure 3. Pairwise comparisons of faba bean aphid nymph production following insecticide treatments. Data represents production observed on Day 0 and Days 2, 7, 14, and 27 after foliar treatment (for seed treatments with 'imidacloprid' data refers to days after infestation).

The model treated 'day' and 'treatment' as fixed effects, and 'repetitions' as a random effect. Data within rows marked by the same lower case letter did not differ significantly at the 5% level of significance.

Figure 4. Faba bean plant infested with aphids, causing curving of the stalk.

Figure 5. Mummified aphid found in faba bean aphid colony.

The low aphid population established on Day 0 likely explains the moderate efficacy of imidacloprid seed treatment at Day 2 (68.9% for adults, 63.8% for nymphs). However, its efficacy increased by Day 14, five weeks after the germination of faba beans, reaching 87.4% for adults and 97.9% for nymphs (Figure 6). This delayed but potent suppression, supported by our previous glasshouse experiments (Duric *et al.*, 2023), highlights the potential of imidacloprid to prevent early infestations and effectively control FBA aphid populations at the beginning of the winter season.

Data analysis confirmed that all foliar and combined foliar-imidacloprid seed treatments effectively suppressed FBA populations, preventing re-infestation in later observations. As observed in our previous study (Duric *et al.,* 2023), pirimicarb demonstrated exceptional efficacy, averaging 99.9% for adults and 100% for nymphs, with similar results in the pirimicarb-imidacloprid combination (Figure 6). This aligns with our past findings and highlights its effectiveness. However, it is crucial to acknowledge that new research (Knapp *et al.,* 2023) raises concerns about pirimicarb's toxicity to beneficial insects like parasitoid wasps, key biological control agents for aphids.

Compared to our previous observations of slower action in glasshouse experiements (Duric *et al.,* 2023), in this field trial, pymetrozine demonstrated an increase in efficacy by Day 2 (47.4% for adults, 68.9% for nymphs). This rapid onset could be attributed to environmental factors in the field setting. The insecticide maintained its potency throughout the study, reaching 97% and 99.8% control for adults and nymphs, respectively, by Day 27. Combined with seed treatment, its average efficacy remained consistently high at 93.9% for adults and 98.7% for nymphs.

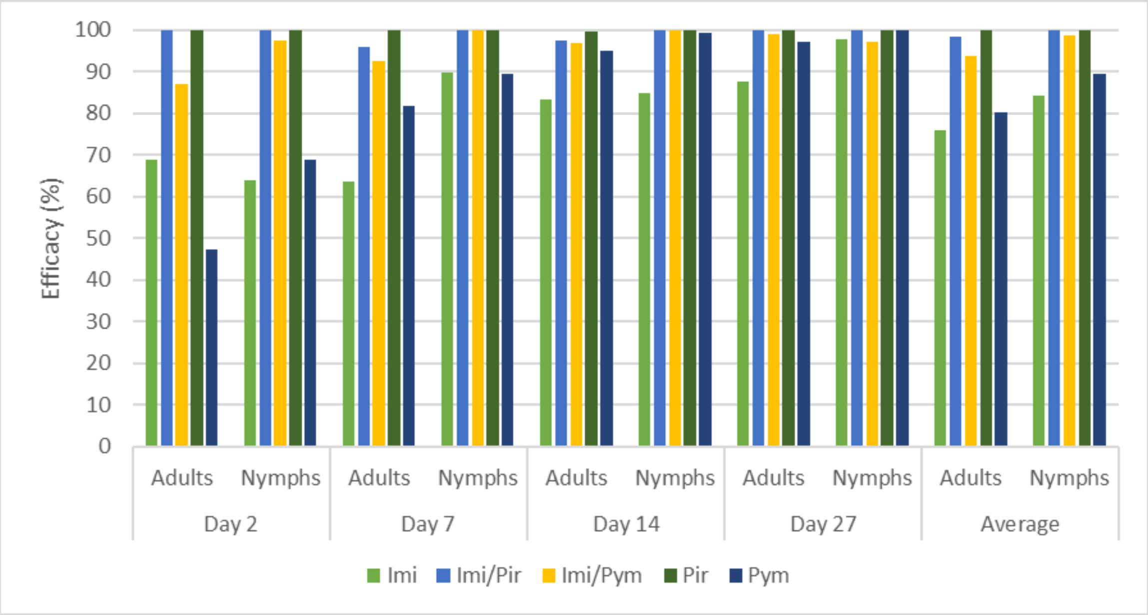

Figure 6. Efficacy (%) of insecticides on faba bean aphid adults and nymphs 2, 7, 14 and 27 days after foliar treatment (for seed treatments with 'imidacloprid' data refers to days after infestation).

Conclusion

RWA is present in the northern region and has not been detected north of the Moree plains. Late winter surveys confirmed RWA presence on cereal crops exhibiting characteristic symptoms. Following its spring migration, RWA has also been found on volunteer cereals and wild grasses like barley grass, phalaris, and prairie grass during the late spring and summer months. To effectively manage RWA, controlling volunteer cereals and the wild grasses before autumn planting is crucial to prevent early infestations. Additionally, monitoring RWA populations in cereals during early growth stages allows time for implementing control measures if necessary.

The results of the field study on the most effective insecticide treatments for managing FBA correlate well with our previous glasshouse study. Both imidacloprid seed and foliar insecticides, pirimicarb and pymetrozine, alone and combined treatments, reduced aphid populations with significant differences except for the pymetrozine treatment on day 2. No re-infestation occurred in any treatment during the experiment, while the colony was increasing in the control treatment. The presence of predatory species and parasitised aphids was recorded in control treatments.

Generally, effective aphid management should involve managing the green bridge and volunteer plants before the season begins, monitoring both pests and beneficial insects during the growing season, and applying insecticides based on economic thresholds whenever feasible. It is crucial to implement a rotation of chemicals throughout the growing season, opting for products with diverse modes of action, and considering options with less impact on beneficials when available.

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Russian wheat aphid action threshold calculator

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Fusarium crown rot in central and northern cropping systems: it’s all a numbers game

Steven Simpfendorfer, NSW DPI Tamworth

Keywords

yield loss, crop rotation, canola, pulse, summer crop, double-break

GRDC codes

DPI2207-004RTX: Integrated management of Fusarium crown rot in Northern and Southern Regions
DPI2207-002RTX: Disease surveillance and related diagnostics for the Australian grains industry

Take home message

- Yield loss from Fusarium crown rot (FCR) is a function of the percentage of plants which get infected within a paddock
- The increased frequency of winter cereal crops within a rotation sequence elevated the probability of having much higher levels of FCR infection
- Rotation to non-host break crops such as canola and pulses does not fully eliminate FCR in all paddocks but considerably reduces the probability of having high levels of infection
- A two-year break may be required in paddocks with high FCR inoculum levels
- Rotation history remains a good indicator of likely FCR risk within individual paddocks but there is still some variability in actual levels of infection
- PreDicta®B or cereal stubble testing are useful tools to further refine crop rotation and other integrated disease management decisions to limit losses from FCR.

Background

Fusarium crown rot (FCR), caused predominantly by the fungus *Fusarium pseudograminearum* (*Fp*), remains a major constraint to winter cereal production across the central and northern grain production region. The causal fungus is stubble-borne with inoculum surviving between seasons as mycelium (cottony-growth) inside retained winter cereal stubble and/or grass weed residues. Crop rotation to non-host break crops such as canola and pulses (e.g. chickpea, lupin or faba bean) or summer crops (e.g. cotton, sorghum or mung bean) remain a key management strategy for FCR. However, the process revolves around decomposition of *Fp* infected cereal stubble during these break crop and fallow phases which is in turn dependent on moisture availability and time. Consequently, the season in which a break crop is grown influences its effectiveness at facilitating decomposition of cereal stubble and reducing FCR inoculum levels. Conversely, recent research has highlighted when relative humidity is >92.5% that *Fp* can colonise vertically up retained standing cereal stubble in a process termed ‘saprotrophic growth’. At 100% relative humidity this saprotrophic growth can occur at a maximum rate of 1 cm per day (Petronaitis *et al.,* 2020). The FCR fungus can therefore saprotrophically grow to the cut height of the cereal stubble under prolonged or accumulated periods of rainfall, effectively increasing inoculum loads. This can then result in FCR infected cereal stubble being spread out the back of the header during the harvest of lower stature break crops such as chickpeas, increasing FCR risk for the next cereal crop (Petronaitis *et al.,* 2022).

This dynamic between cereal stubble decomposition and saprotrophic growth appears to complicate the management of FCR within farming systems but what are real grower paddocks across the region telling us?

What did we do?

Under a co-investment with GRDC, NSWDPI has been providing a 'free' cereal stubble testing service to growers and advisors over the past two seasons. These samples are collected either during late grain filling or post-harvest from individual paddocks across central NSW, northern NSW and southern Qld, along with background information including the previous two crops within the rotation. Winter cereal stubble samples (bread wheat, durum, barley or oats) are trimmed and plated on laboratory media to determine the incidence of FCR based on distinctive growth of *Fp* in culture. Infection levels are then categorised as being either low (≤10% FCR), medium (11–25% FCR), high (26–50% FCR) or very high (≥51% FCR). This data provides an unbiased snapshot of FCR infection levels in winter cereal crops across the region under varying crop rotations over the last two seasons. But why is the level of FCR infection so important? It is simple, yield loss only occurs in cereal plants infected with FCR, with the actual extent of yield loss strongly dependent on the extent of moisture and temperature stress during grain filling. Growers may not have much influence over seasonal conditions and stress during this critical period, but they can influence the percentage of plants infected with FCR. Reduce FCR infection levels and you reduce the risk of yield loss by that same level. As a rough rule of thumb, 100% FCR infection can result in 80% yield loss in durum wheat, 60% in bread wheat and 40% in barley if prolonged hot and dry conditions occur during grain filling. Granted that these are worst case scenario values from replicated and inoculated field trials across seasons in this region, but even halving FCR infection levels to 50% reduces potential yield loss to 40% in durum, 30% in bread wheat and 20% in barley if the season turns to #%^&.

What did we find?

Seasonal effects

In total, 617 winter cereal stubble samples were processed from the 2022 and 2023 harvest which consisted of 507 bread wheat, 59 barley and 51 durum wheat crops (data not shown). There were 289 cereal crops sampled in 2022 and 328 in 2023 (Figure 1). The levels of FCR infection have risen within the central and northern cropping region from 2022 to 2023 with the proportion of paddocks with very high levels (≥51% FCR) rising from 20% to 36%. Over the same period the proportion of paddocks with high levels of infection (26–50% FCR) have also risen from 23% in 2022 up to 31% in 2023 (Figure 1).

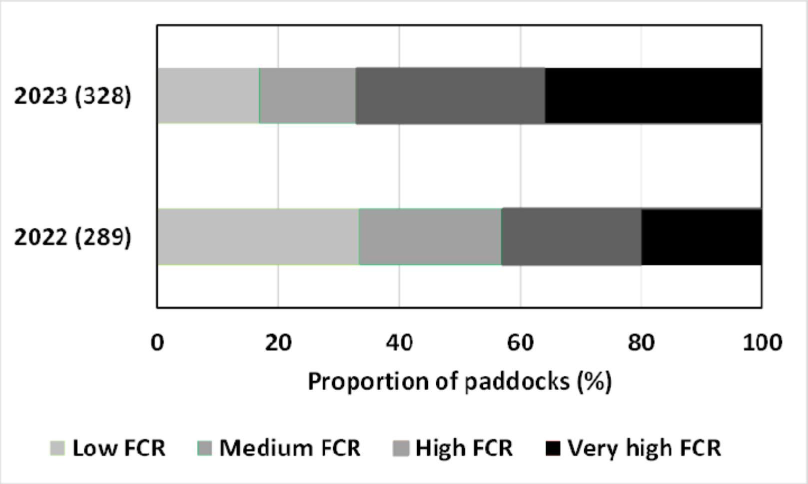

Figure 1. Proportion of winter cereal paddocks with varying levels of Fusarium crown rot (FCR) infection in 2022 and 2023.
Number in brackets (Y-axis) is the number of paddocks sampled in each year.
Low = ≤10% FCR, medium = 11–25% FCR, high = 26–50% FCR, very high = ≥51% FCR

FCR inoculum levels are a function of the percentage of plants infected and the quantity of stubble produced within a season. FCR infection is favoured by wet conditions which also generally increase biomass (i.e. stubble) production and yield of cereal crops. Consequently, larger inputs of FCR inoculum occur in wetter seasons such as 2021 and 2022 even though these conditions may not favour expression of FCR as whiteheads and yield loss from this disease. This data supports random crop disease surveys, conducted by NSWDPI with co-investment from GRDC, which have been showing a progressive build-up of FCR inoculum levels in this region from 2020 onwards. Milder temperatures and frequent rainfall during grain filling in 2021 and 2022 reduced FCR expression in these seasons. This was not the situation in 2023, with a return to warmer and drier conditions during spring which unfortunately also coincided with elevated FCR infection levels within central and northern cropping systems (Figure 1).

Sub-region levels of FCR

In total, 93 samples were from southern Qld, 163 from north-west NSW, 173 from north-east NSW, 131 from central-west NSW and 57 from central-east NSW (Figure 2). FCR infection levels in the last two cereal crops have been highest in southern Qld (SQld), north-west NSW (NWNSW) and north-east NSW (NENSW) with the proportion of paddocks with very high levels (≥51% FCR) at 38%, 33% and 32%, respectively. The proportion of paddocks in this highest category of FCR infection level was lower at 18% in central-west NSW (CWNSW) and 14% in central-east NSW (CENSW; Figure 2). However, all regions had relatively high FCR levels (≥26% FCR in high or very high categories) ranging from 44% of paddocks in CENSW up to 62% in NENSW (Figure 2).

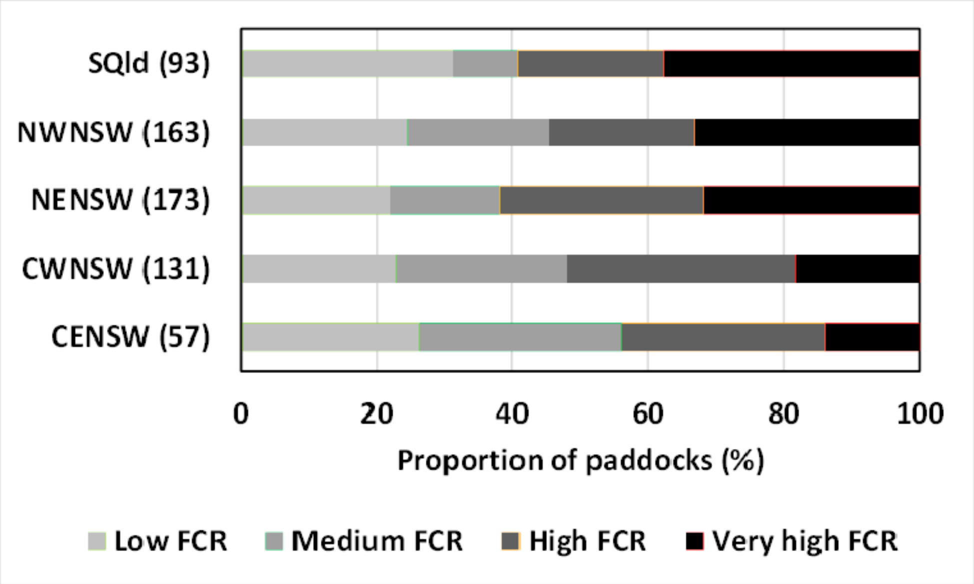

Figure 2. Proportion of winter cereal paddocks in 2022 and 2023 with varying levels of Fusarium crown rot (FCR) infection across southern Qld, central NSW and northern NSW.
Number in brackets (Y-axis) is the number of paddocks sampled from each sub-region.
Low = ≤10% FCR, medium = 11–25% FCR, high = 26–50% FCR, very high = ≥51% FCR

Influence of a single break – what do the numbers say?

Adopt a cereal-cereal-cereal ‘rotation’ and there is a 50% chance that you will have very high (≥51%) FCR infection (Figure 3). If the preceding crop was a summer break crop or fallow then this risk of very high FCR infection in the 2022 or 2023 winter cereal crop was reduced to 41% and 33%, respectively. If the preceding crop was a winter pulse or canola break crop then this risk of very high FCR in the 2022 or 2023 cereal crop was reduced further to 14% and 12%, respectively (Figure 3).

In terms of pulse break crops, faba bean (14% high FCR and 7% very high FCR in 29 paddocks) was more effective than chickpea (22% high FCR and 20% very high FCR in 51 paddocks; data not shown). In terms of summer break crops, cotton (22% high FCR and 39% very high FCR in 18 paddocks) was potentially slightly better than sorghum (40% high FCR and 34% very high FCR in 35 paddocks; data not shown).

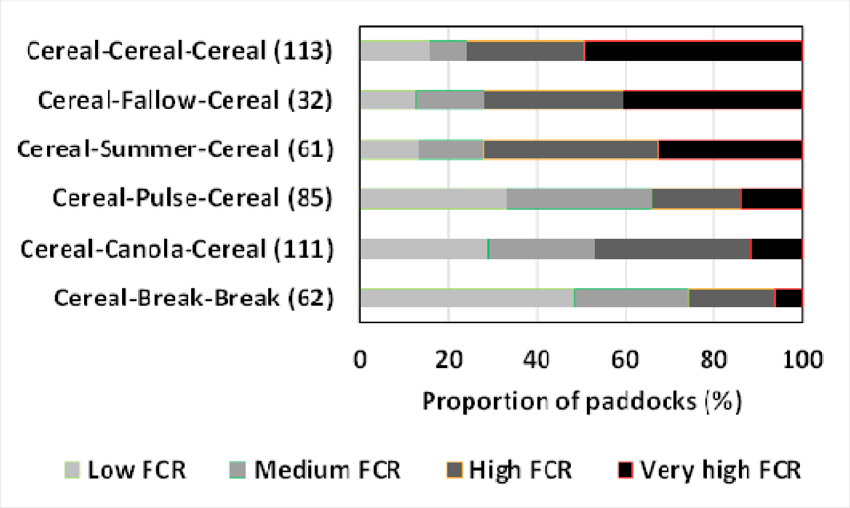

Figure 3. Proportion of winter cereal paddocks in 2022 and 2023 with varying levels of Fusarium crown rot (FCR) infection under different crop rotations.

Number in brackets (Y-axis) is the number of paddocks sampled from each rotation sequence.

Low = ≤10% FCR, medium = 11–25% FCR, high = 26–50% FCR, very high = ≥51% FCR

There are a number of potential variables such as FCR infection levels in cereal crops two years ago, stubble management (e.g. burning or cultivation), seed source (e.g. Fusarium grain infection from 2022 FHB epidemic), grass weed management, inter-row sowing, harvest height) which could also underly this data and introduce variability. Clearly non-host crop or fallow periods reduce the probability of higher FCR infection levels and consequently yield loss from this disease so playing the rotation numbers still works. However, a one-year break may not be sufficient under higher FCR infection levels. A two-year break further reduced the probability of high and very high FCR infection levels in 2022 or 2023 cereal crops which dropped to 19% and 6%, respectively (Figure 3).

Can I get away with a break only once in three years?

Alright, let’s try presenting differently and having a ‘glass half full’ approach. Assume low and medium FCR infection levels result in <25% whiteheads in a season conducive to disease expression, so does not trigger the ‘I told you not to sow another cereal crop in that paddock’ argument with your agronomist. In a three-year consecutive cereal situation, there is a 24% probability of this happening. This increased to 38% if the paddock was in fallow two years ago and 30% if it was a pulse crop two years ago. However, the likelihood of this outcome reduced to 23% if it was canola and 21% if it was a summer crop two years ago (Figure 4). Some may like these probabilities and continue to roll the dice whilst others may be swayed more by the probabilities around the second wheat crop having high or very high FCR infection levels (Figure 4).

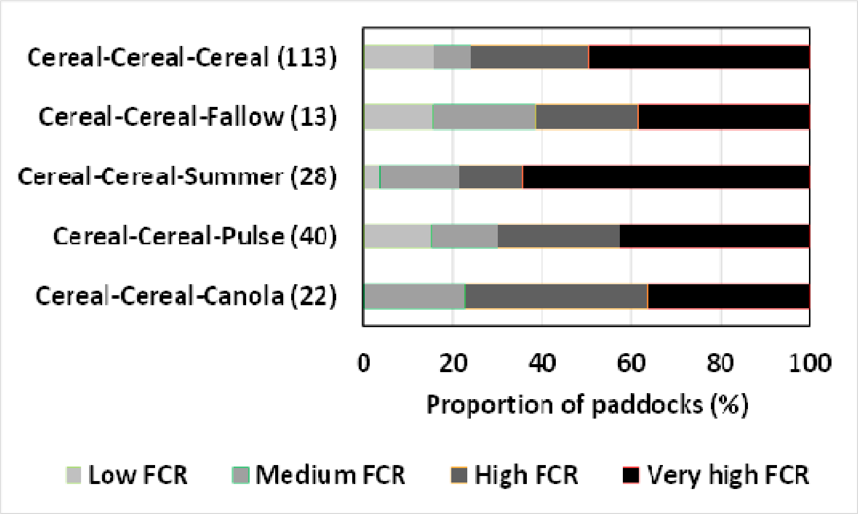

Figure 4. Proportion of winter cereal paddocks in 2022/23 with varying levels of Fusarium crown rot (FCR) infection under different crop rotations.
Number in brackets (Y-axis) is the number of paddocks sampled from each rotation sequence.
Low = ≤10% FCR, medium = 11–25% FCR, high = 26–50% FCR, very high = ≥51% FCR

Conclusions

Recent crop history within individual paddocks is a useful guide to the likely risk of FCR infection. However, not all paddocks and underlying crop management are the same so there is variability in the actual numbers, but the rotation sequence clearly drives the probability of having higher or lower levels of FCR infection. This further highlights the value of testing to establish actual FCR infection levels within a paddock using PreDicta®B or cereal stubble plating to further guide crop rotation and other integrated disease management decisions.

References and further resources

PreDicta®B procedure - Sampling_protocol_PreDicta_B_Northern_regions.pdf (pir.sa.gov.au)

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Economic performance of modified farming systems in Central West NSW

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Key words

system gross margin, pasture phase, legume frequency

GRDC code

CSA00050, DAQ00192

Take home message

- Ley (Lucerne) pasture based farming systems provided the best gross margins during the moderate and dry seasons at Trangie. Grain crops post pasture phase performed well compared to cropping only systems
- Incorporating more legumes (+50%) in a cropping sequence recorded the highest gross margins during the wetter seasons (2020–2022)
- Ley pasture systems reduced farming system input costs during the drier seasons, decreasing economic risk, while achieving high relative system income.

Introduction

Central West NSW is a highly valuable agricultural producing region. The region is home to a range of industries, both irrigated and rain fed. It contains a variety of soil types and characteristics, that along with changing climatic conditions can impact agricultural production.

Growers face challenges from declining soil fertility, increasing herbicide resistance, and increasing soil-borne pathogens in their farming systems. To meet these challenges and to maintain farming system productivity and profitability the Queensland Department of Agriculture and Fisheries (DAF), New South Wales Department of Primary Industries (NSW DPI) and Commonwealth Scientific and Industrial Research Organisation (CSIRO) are collaborating to conduct an extensive field-based research program. The research is focused on developing farming systems to better use the available rainfall to increase productivity and profitability, aiming to answer the question:

"Can systems performance be improved by modifying farming systems in the northern region?"

In 2014 research began in consultation with local growers and agronomists to:

- Identify the key limitations, consequences, and economic drivers of farming systems in the northern region;
- Assess farming systems and crop sequences that can meet the emerging challenges; and
- Develop the systems with the most potential for use across the northern region.

Experiments were established at seven locations, including a large factorial experiment managed by CSIRO at Pampas near Toowoomba, and locally relevant systems being studied at six regional centres at Emerald, Billa Billa, Mungindi, Spring Ridge, Narrabri and Trangie (two sites characterised by either a red or grey soil type).

This report focuses on the economic performance of the modified systems at Trangie situated at the NSW DPI Trangie Agricultural Research Centre located in Central West NSW. The region is known for its high-performance winter crops and variable soil types suit a diversity of systems including dual purpose crops and grazing pastures alongside broadacre cropping. There are two experimental sites at Trangie, one on a hard setting red soil and the other on a self-mulching grey clay (soil characteristics in Table 1).

Trangie farming system modifications and descriptions

The key system modifications under examination involve changes to:

- Crop intensity – the proportion of time that crops are growing which impacts on the proportion of rainfall captured and transpired by crops and fallow efficiency. This is being altered by changing soil water thresholds that trigger planting opportunities. Moderate intensity systems (*Baseline* which represents common practice) have a moderate soil water threshold of 50% full profile. The lower intensity systems require a profile >80% full before a crop is sown and higher value crops are used when possible.
- Increased legume frequency – crop sequence whereby every second crop is a legume, with the aim of reducing fertiliser N inputs and to improve long-term soil fertility.
- Increased crop diversity – crop choice aims to select 50% of crops that are resistant to root lesion nematodes (preferably two crops in succession) and crops with similar in-crop herbicide mode of action cannot be grown consecutively. The aim is to test systems where the mix and sequence of crops are altered to manage soil-borne pathogens and weeds in the cropping system.
- Nutrient supply strategy – by increasing the fertiliser allocation to achieve 90% of yield potential for that crop compared with 50% of yield potential. The aim is to boost background soil fertility, increase N cycling and maximise yield in favourable years.
- Ley pasture – Lucerne was specifically selected as the ley pasture system at the Trangie sites as the system is representative of the mixed grain/livestock enterprise of many farm businesses in central NSW.

System gross margin analysis

Economic analysis was undertaken to compare systems at both sites, using actual input rates for fertiliser and pesticides, which were costed at standardised prices. The ten-year median port prices less freight and grading/bagging cost where appropriate (i.e. pulses) for the various crops were wheat = $265, barley = $266, chickpea = $644, faba bean = $433, canola = $568 and field pea = $368 per tonne.

The pasture margins were valued as cattle live weight gain, with 50% pasture utilisation and 10 to 1 as fed feed conversion for stocking rate calculations. Long-term Meat Livestock Australia (MLA) annual prices were used to determine income at $6.10 per kg cwt, a dressing percentage of 50% with variable production costs equal to $75 per beast.

Site characteristics

The red soil site is hard-setting chromosol containing ~60% sand, 20% clay and ~15% silt. The pH is slightly acidic with low organic carbon (Table 1).

The second site is based on a self-mulching grey vertosol, containing 50% clay, 35% sand and 15% silt. The soil contains 0.3% more organic matter than the red soil and is slightly alkaline in pH.

Table 1. Trangie soil characteristics at the Red and Grey soil sites.

Site	Depth (cm)	BD (g/cm^3)	OC (%)	Colwell-P (mg/kg)	BSES-P (mg/kg)	Colwell-K (mg/kg)	Sulphur (mg/kg)	EC (dS/m)	pH$_{Ca}$	pH$_w$
Red	0–10	1.58	1.02	30	53	427	7.3	0.035	5.3	6.2
	10–30	1.61	0.43	9	15	268	5.0	0.021	6.0	6.8
Grey	0–10	1.42	1.48	50	62	506	10	0.09	7.6	8.4
	10–30	1.47	0.70	6	10	235	16	0.11	7.7	8.6

System cropping sequence

Due to the system planting triggers and rules, cropping sequences have diversified over the last 7 years. The grower's practice (*Baseline*) systems contained wheat and barley as pillar crop choices, with canola and chickpea as the break crops. A consideration for all systems was the dry seasons leading up to the 2018/2019 drought, where crop productivity was limited and below average. Once the drought broke in 2020, crop choice and intensity increased for all systems (Table 2). Field peas, canola and faba beans were sown within the modified systems.

Table 2. Trangie Red soil and Grey soil sites cropping sequence

	2016	2017	2018	2019	2020	2021	2022
Red soil							
Baseline	wheat	wheat	barley	canola	wheat	barley	chickpea
Higher nutrient	wheat	wheat	barley	canola	wheat	barley	chickpea
Higher legume	wheat	chickpea	barley	field pea	wheat	chickpea	wheat
Higher diversity	wheat	chickpea	field pea	wheat	canola	barley	chickpea
Lower intensity	wheat	fallow	barley	fallow	canola	wheat	chickpea
Ley pasture	lucerne	lucerne	lucerne	fallow	wheat	canola	wheat
Grey soil							
Baseline	wheat	wheat	barley	fallow	canola	wheat	barley
Higher nutrient	wheat	wheat	barley	fallow	canola	wheat	barley
Higher legume	wheat	chickpea	barley	fallow	faba bean	wheat	chickpea
Higher diversity	wheat	chickpea	field pea	fallow	wheat	canola	chickpea
Lower intensity	wheat	fallow	barley	fallow	canola	wheat	chickpea
Ley pasture	lucerne	lucerne	fallow	fallow	wheat	canola	wheat

Results

System performance

Of the five systems containing only a cropping sequence, the *Baseline, Higher nutrient* and *Higher legume* systems recorded the highest yield and gross margin across the seven years of research

(Table 3). While there are benefits to selecting systems based on cropping diversity, smaller breeding programs may limit yield potential when directly compared to mainstream crop choices. As the project continues and disease and weed legacies develop, the *Higher diversity* system goal is to have greater sustainability and higher yield potential than low-diversity (monoculture) farming systems.

Ley pasture systems accumulated high system gross margins on both soil types. The economic performance of the pasture systems was valued using cattle live weight gain over the duration of the pasture. The pasture phase for both sites occurred during 2016–2019 the driest recorded period. During this period, it produced the highest gross margins for both sites compared to systems with only crops. On average, the pasture systems were $696/ha better than the next best performing system over this period, which struggled to produce grain crops consistently in the dry conditions. The economic advantage continued throughout the drought and into the cropping phase from 2020 to 2022 (Figure 1).

Table 3. Productivity and gross margins of the Trangie farming systems for 7 seasons, 2016–2022.

	Red soil		**Grey soil**	
System	**System yield (t/ha)**	**System GM ($/ha)**	**System yield (t/ha)**	**System GM ($/ha)**
Baseline	19.3	4272	20.1	4782
Higher nutrient	21.1	4840	18.4	3908
Higher legume	20.5	5311	17.2	4955
Higher diversity	14.6	3263	11.6	3467
Lower intensity	15.2	3954	12.9	3229
Ley pasture*	12.7	5379	11.6	5312

Note: *Ley pasture system yield values are only grain yields and do not include 7.9 t/ha of lucerne on the Red soil and 4.3 t/ha of lucerne on the Grey soil

Economic evaluation

Implementing various system rules resulted in a range for the total cropping costs of $1,369/ha at the Red soil site and $808/ha at the Grey soil site (Table 4). Input costs such as herbicides and sowing seed were big outliers for the *Higher diversity* and *Higher legume* systems compared to the other systems. The implication with systems containing high value grains and niche crops is input costs can be high compared to a cereal based sequence. Growers need to account for these costs and any risks that crops may have in variable conditions.

System modifications such as applying higher amounts of fertiliser as in the *Higher nutrient* system result in greater cropping costs, at Trangie Red a ~$330/ha increase in fertiliser costs has resulted in ~$900/ha additional income, however at Trangie Grey we have not seen the same positive response. Other changes such as reducing cropping intensity and/or implementing a ley pasture phase reduced long term system costs. Lowering costs is particularly beneficial in drier seasons where productivity is limited. Reducing system costs during drier seasons lowered the economic risk for the farming system.

Table 4. Farming system costs at Trangie Red soil and Grey soil sites (2016–2022)

Site	**System**	**Expenses ($/ha)**			
		Total system	**Herbicides**	**Seed**	**Fertiliser**
Red soil	***Baseline***	1862	630	288	452
	Higher nutrient	2212	666	282	782
	Higher legume	2133	674	401	359
	Higher diversity	2567	914	516	246
	Lower intensity	1959	872	270	305
	Ley pasture	1198	290	208	353
Grey soil	***Baseline***	1509	635	185	285
	Higher nutrient	1742	671	179	501
	Higher legume	1521	606	294	212
	Higher diversity	1478	492	280	178
	Lower intensity	1189	609	130	148
	Ley pasture	934	265	193	154

System performance in wet and dry seasons

Seasonal conditions in the northern grains region are highly variable and improving system performance across various conditions improves long-term sustainability. There were two distinct phases of economic returns for the project. A drier period between 2015 and 2019, where systems averaged ~$400/ha per year (Figure 1), largely made up of good returns from 2016's winter crop. As the seasons improved between 2020 and 2022, system returns increased to ~$1000/ha per year. When the *Ley pasture* system returned to a cropping phase the system successfully produced high value crops, allowing it to maintain its advantage during the drier seasons.

One system that showed variance in the dry and wetter seasons, was the *Higher legume* system. The system had moderate gross margins during the dry phase, but once rainfall increased it became one of the better performing systems. Between 2020 and 2023, the *Higher legume* accumulated the greatest system gross margin on both soil types at Trangie. The higher grain value of legumes and high grain yields resulted in high system performance.

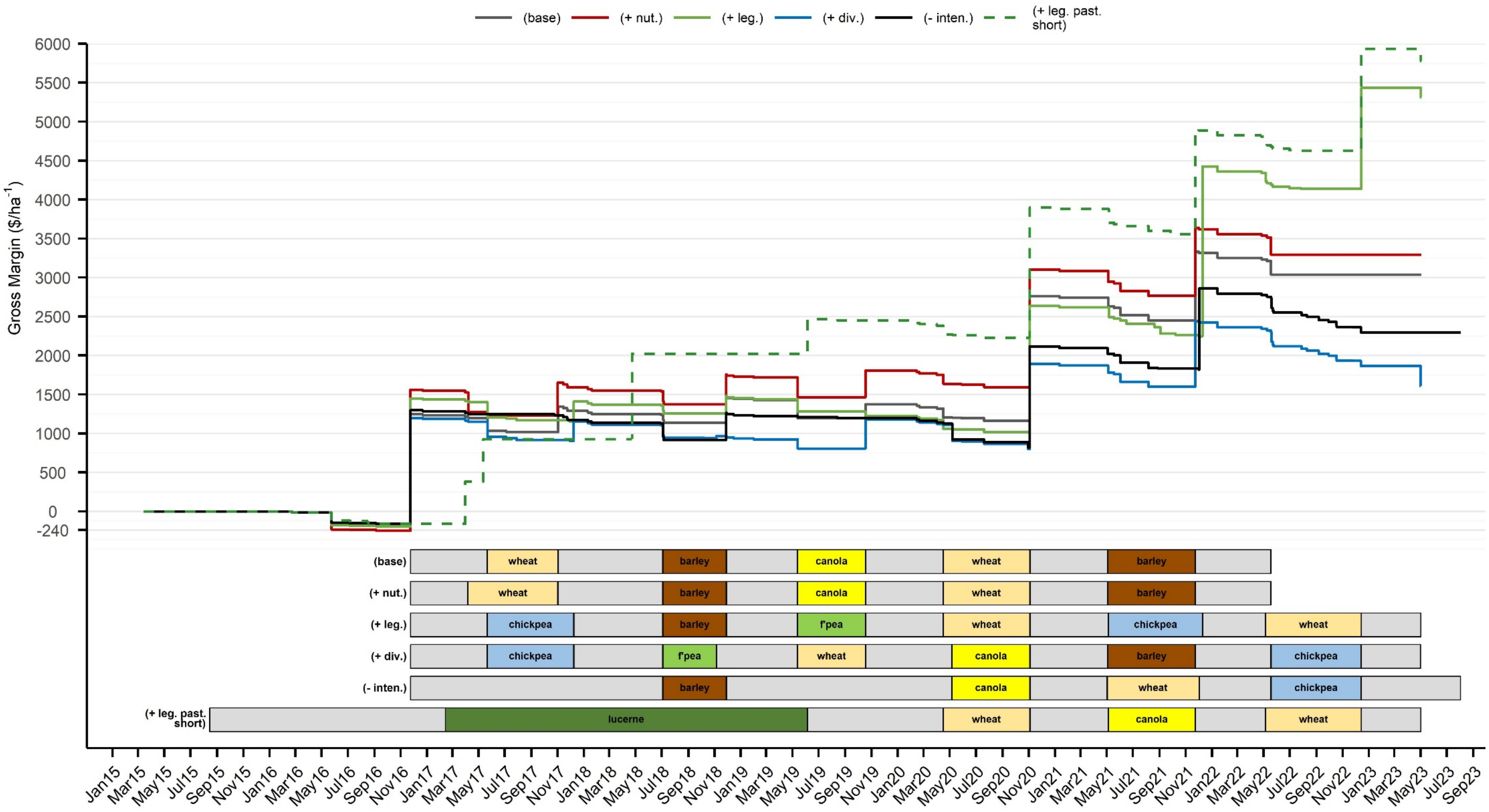

Figure 1. Trangie Red soil site time course system gross margin.

Base = Baseline, + nut = Higher nutrient, + leg = Higher legume, + div = Higher diversity, - inten = Lower intensity and + leg. Past. Short = Ley pasture.

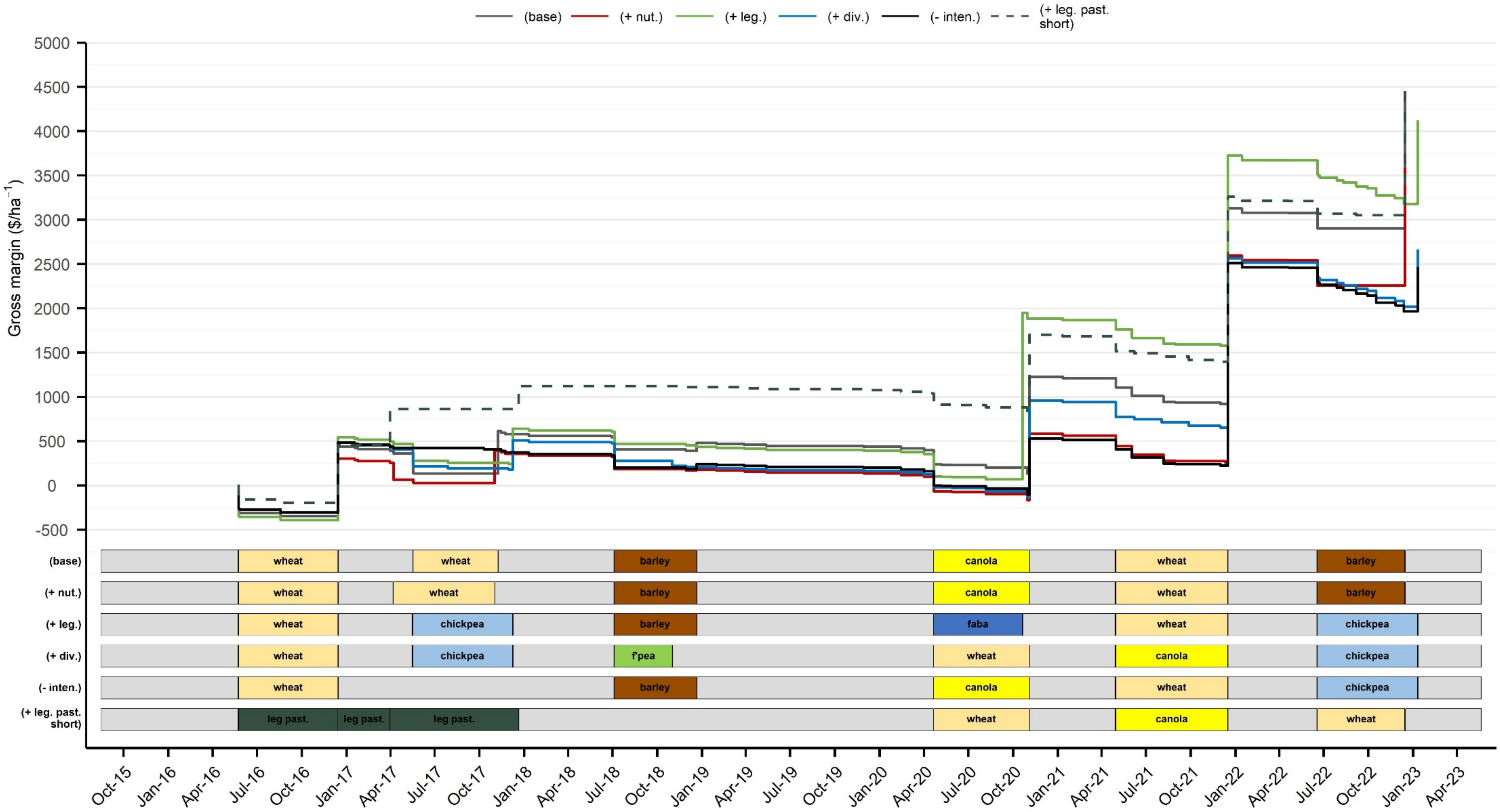

Figure 2. Trangie Grey soil site time course system gross margin.

Base = Baseline, + nut = Higher nutrient, + leg = Higher legume, + div = Higher diversity, - inten = Lower intensity, and + leg. past. short = Ley pasture.

Conclusion

The project showed that modifying farming systems led to economic benefits for growers located in central west NSW. The systems containing a short-term pasture phase had the highest gross margin returns with relatively low input costs. The Ley pasture system also performed well when phased back into cropping production at the Red and Grey soil sites. Applying this system as part of the rotation would allow growers to maintain cashflow during extended dry periods where achieving profitable grain production is challenging. Further studies will continue to investigate other system legacies over the next two seasons.

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The economics and practicalities of dual purpose crops in central/northern NSW

David Harbison, D R Agriculture Pty Ltd

Key words

rainfall pattern, stored water, timely sowing, dual purpose crops, grazing management

Take home message

- Fallow management and stored water are critical for grazing dual purpose crops and improve the likelihood of early sowing
- Timely sowing creates 'grazing days'
- Maximising grazing efficiency, stocking rates, land area and class of stock increases the probability of greater profits
- Increased profitability per hectare gross margin by comparison to grain only situations.

Introduction

Dual-purpose cropping in northern NSW, and the more northern areas of central NSW is more challenging than in southern NSW due to reliance on summer rainfall which typically experiences greater variability in distribution and higher evaporation rates. However, research conducted to evaluate farming systems within the northern region showed that the potential gross margin returns can be increased up to $400/ha for mixed systems comprised of grain and grazing compared to grain only systems (Bell, 2016). Driving the 'top end' of such returns are dependent on making the right agronomic decisions including but not limited to sowing date, selection of dual purpose or long season cultivar, plant nutrition, grazing management (both stock density and timing) and 'lock up date'.

In addition to the potential individual paddock gross margin benefits, there are wider whole-farm benefits offered by dual purpose crops. These include risk management, widening of the sowing window, providing high quality late autumn/winter dry matter crop flexibility (grazing out or conservation as hay or grain production), and 'rest', or the option of deferring the grazing of grass/legume based pastures areas while stock are on crop. With an increase in the size of cropping machinery over the last 20–30 years to benefit the productivity of the grains' operations (including labour efficiency), much of the livestock infrastructure has been reduced or removed. So, what limitations does this place on the uptake of dual purpose crops by grain growers for livestock production? In short, many paddocks are now too large for 'best practice' grazing. Water points are often minimal and provide an insufficient amount of quality water suitable for livestock, or alternatively the number of stock required to provide efficient grazing would be very large thereby creating its own sub-set of management issues in terms of infrastructure and labour (Harbison, 2020).

Practicalities

The maximum paddock size for grazing and cropping is largely dependent on the practicalities of providing adequate water for livestock and an acceptable level of crop utilisation. Growers with paddocks less than 40 ha in area have found it is far easier to adjust grazing management to maximise dry matter utilisation over a shorter period of time, whilst leaving sufficient residual biomass so as not to impede re-growth and crop yield (Kirkegaard *et al.* 2022; Sprague *et al.* 2016).

When selecting which dual purpose cultivar to use, it is important to consider the potential grain value at harvest as well as the likely dry matter production available for grazing. Sowing early, or ‘earlier’ than common practice, is driven largely by fallow efficiency, stored water and the ‘likelihood’ of a sowing opportunity. Bell (2016) provides modelled data from Walgett NSW, with two approaches to a ‘sowing opportunity’. The first is when the rain received exceeds the potential evaporation over 7 days, and the second is based on a threshold of 15 mm of rain occurring over a 7-day period (Figure 1). The analysis here using the first approach shows that sowing any earlier than 1 May is likely to result in a false break (i.e. % of years which incur a false break is greater than the sowing opportunity), whilst the second approach shows that planting could occur as early as 1 March and consequently has much earlier sowing opportunities, but likely greater risk.

In an approach to limit the risk of a false break, conserving fallow rainfall is critical. The Coonamble long-term rainfall pattern (Figure 2) shows the importance of capturing summer rainfall to generate an early sowing opportunity. If the second ‘opportunity to sow’ approach is combined with an adequate amount of stored moisture (e.g., plant available water (PAW) greater than 150 mm), the potential success of dual-purpose crops increases significantly.

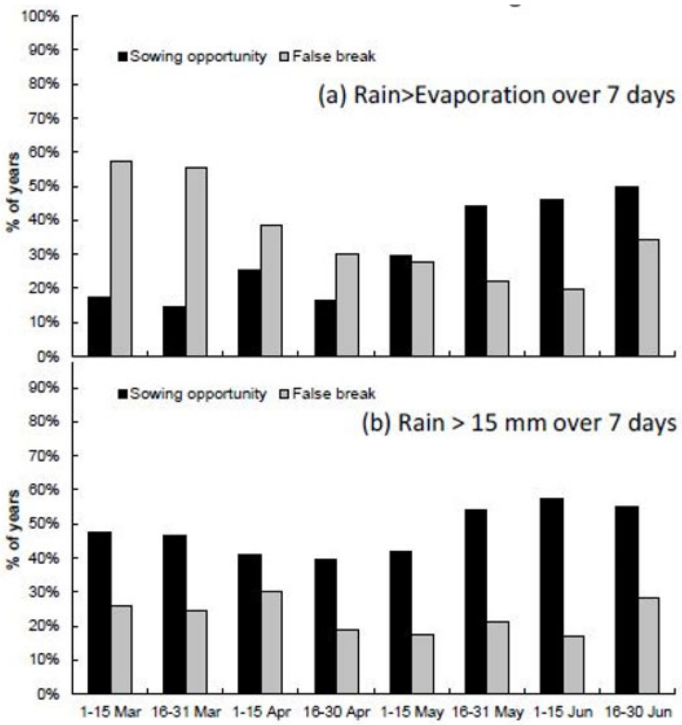

Figure 1. Frequency of a sowing opportunity in fortnightly windows from 1 March to 30 June at Walgett. Sowing opportunities were calculated as the % of years when either (a) rainfall exceeded potential evaporation over a 7-day period or (b) 15 mm of rainfall over a 7-day period.
Source; Bell 2016

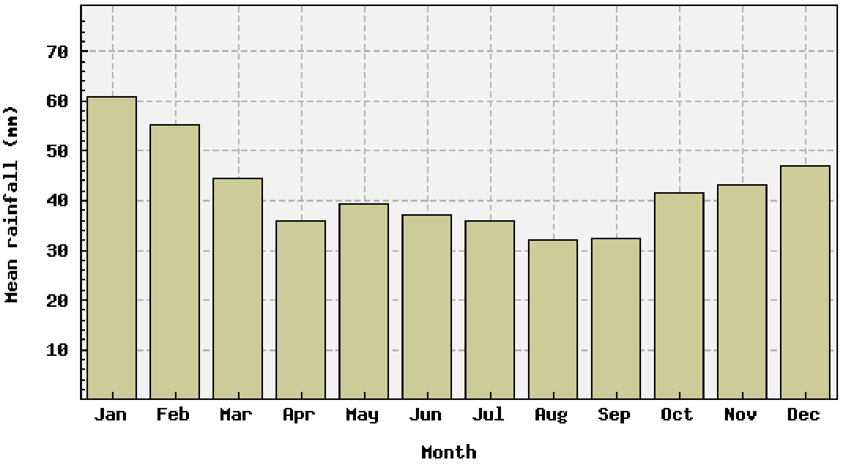

Figure 2. Coonamble long term (1878 – 2010) average monthly rainfall.
Source; BOM 2024

The early dry matter produced varies with species and cultivar, soil health and fertility. Managing both ensures the best grazing opportunity. While seasonal dry matter data varies significantly each year, anticipated dry matter at the commencement of grazing would generally range from 1500 – 2500 kg DM/ha. Much of the research (Kirkegaard *et al.* 2016, Sprague *et al.* 2016) reports dry matter yield in 'grazing days', thus determining how many livestock, of what class (or DSE equivalent), for how long can be difficult. How likely is a second graze? Assumptions are made to convert dry matter yield into red meat. The decision when to 'close the gate' or 'shut up' should be driven by the physiology of the plant and stage of growth and residual biomass, and not by a date on a calendar. If maximising grain yield is a key target, it is imperative to get this destocking decision right. Managing all these challenges is critical to achieve the best grazing efficiency and grain yield which in turn maximises the economic return.

Summary

The grazing window for dual purpose wheat is between the period where the wheat plant is well anchored in the soil and DC31, which is the commencement of stem elongation. Later grazing than DC31 increases the risk of the wheat head being grazed whilst it emerges from the plant base. If grazing young developing wheat heads, there is a significant risk in northern grain belt areas of grain yield penalties. Wheat dry matter will accumulate at 30 to 60 kg/day and early sowing permits maximum dry matter to be accumulated and available for grazing during this window. Crop recovery is important and to facilitate this at least 1500 kg/ha of wheat dry matter should be left after grazing. Good stored soil water, early sowing, and timely removal of livestock stock are key to the biological success of dual purpose crops for good grain yields.

Economics

Market prices of all inputs/outputs determine financial outcomes and the economics of each decision and of the whole farming system. When assessing the economic performance of a mixed farming operation, the grazing component including the 'value' of dual purpose crops must be considered. The costs of sowing a crop, be it for grazing and grain, or just straight grain, will be similar. One variable that is likely to change, from a grazing perspective, is nitrogen (N) management. Providing sufficient N 'up front' (pre-plant) to maximise dry matter production will contribute to the potential carrying capacity. Whilst not all the ingested N in plant tissue is used for livestock growth, with varying amounts of N returned to the soil as manure and urine, additional N is likely to be needed post destocking to achieve grain yield and protein targets.

Animal liveweight gains on grazing crops for sheep (lamb) and cattle (steer) are regularly quoted at >0.25 kg/day and >1.5 kg/day respectively. There are many cases of improved animal performance when mineral supplementation occurs with grazing cereals, (particularly wheat), and more so in cattle. Cattle can have an 'adaption' or 'lag phase' period as they are introduced to grazing crops, particularly canola, but once 'adapted' perform well. McCormick *et al.,* (2021) report cattle average daily gains of 1.75 kg over the entire grazing period despite a period of 'adaptation'.

Putting all the above numbers into perspective, if upwards of 30–50 grazing days are achieved and grazing utilisation is at 60%, using stocking rates of 2.5–3 steers/ha can see gross grazing returns of $330–470/ha (at steer pricing of $2.50/kg liveweight). Lamb calculations work out very similar.

Conclusions

The incorporation of dual purpose crops to support livestock for mixed operations can contribute very positively to whole farm income including the central and northern NSW regions. Important to the success of dual purpose crops is making the right agronomic decisions which creates the opportunity to sow 'early', with the chosen species/cultivar, grazing efficiently (driven by stock density and paddock size) with the right class of livestock, having access to good quality and quantities of water, making timely destocking/closing the gate decisions and utilising efficient livestock infrastructure all make small steps towards a significant grazing return. As Kirkegaard *et al.,* (2016) highlight, "not leaving enough residual biomass after the last grazing is very damaging in terms of grain recovery". Do not overgraze, we need to get it right.

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Finding profit in the face of increasing input costs, interest and land value and the value of water use efficiency as a benchmark tool

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Notes

Concurrent session – Weeds

Impact of application interval and total rainfall on residual herbicide efficacy

Linda Bailey, Rachel Norton, Denielle Smith, Lawrie Price, Richard Daniel, Northern Grower Alliance

Key words

residual herbicides, rainfall, timing

GRDC codes

NGA00003, NGA00004 and NGA2009-001RTX

Take home message

- Multi-year data sets were analysed to examine the residual efficacy of key herbicides on common sowthistle or feathertop Rhodes grass
- Efficacy patterns clearly varied by herbicide and weed species
- The efficacy patterns observed could assist to refine herbicide management choices on the basis of seasonal forecasts.

Background

Validation of the benefit and fit of residual herbicides in the northern farming system has been an important aspect of Northern Grower Alliance (NGA) project activity over many seasons. Individual projects always have a specific research question and focus with the key outcomes being determined generally over a one to two season period.

However, after generating large numbers of efficacy data sets, questions were raised whether additional insights into the use and performance of residual herbicides could be gained by analysing these multi-year data packages.

Summaries were prepared of all NGA trials (in both crop and fallow situations) using residual herbicides to manage three major weed issues: common sowthistle, feathertop Rhodes grass and flaxleaf fleabane. Weed control was expressed as a % of untreated to allow summaries across trials. Data sets were sorted on the basis of the interval from application to assessment and also the total rainfall amount from application to assessment. The intention was to examine the relative impact of application interval and rainfall on herbicide efficacy.

During analysis it was evident that the number of residual flaxleaf fleabane trials (9 trials over 5 cropping seasons) was too small to allow evaluation of application interval or total rainfall impacts.

Key limitation

- **Simple comparisons of herbicide efficacy on a product to product basis are not valid** due to the wide range of trials and situations evaluated e.g. could be comparing efficacy in summer fallows to winter in-crop.
- **Key focus should be on the impact of time from spray application to weed assessment or total rainfall on the performance of the individual herbicide and comparison of those patterns between herbicides.**

Common sowthistle (*Sonchus oleraceus*)

Trials were conducted in a maximum of 16 cropping seasons (8 in both ‘winter’ and ‘summer’). Summaries prepared from a maximum of 35 individual trials (24 in fallow and 11 in chickpeas). Additional efficacy assessments were conducted in 4 fallow trials on multiple weed cohorts.

Table 1. Key herbicides with registrations for residual control of common sowthistle in-crop or fallow that have been included in the data sets following

Herbicide	**Crop registrations**	**Fallow# registration for ‘residual’ use patterns**
Isoxaflutole 750g/kg (Balance®)	Post sow pre-emergent (PSPE): chickpeas 100g/ha	100 g/ha
Terbuthylazine 850g/kg (Terbyne® Xtreme®)	Pre sowing: chickpeas, field peas, faba beans, lupins 0.86-1.2 kg/ha PSPE: chickpeas, field peas, faba beans 0.6-0.86 kg/ha	0.86-1.2 kg/ha
Flumioxazin 500g/kg (Valor®)	Incorporated by sowing (IBS): chickpeas, field peas, faba beans 180 g/ha (Suppression only) IBS: wheat (not durum) 120 g/ha (suppression only) Pre sowing: soybeans, peanuts 210-280 g/ha PSPE: soybeans, peanuts 210 g/ha >1 month pre-sowing: pigeon pea, maize, sorghum, navybean 210-280 g/ha >2 months pre-sowing: cotton, sunflower, mungbeans 210-280 g/ha	210-280 g/ha
Saflufenacil 250g/L + trifludimoxazin 125g/L (Voraxor®)	IBS to 7 days pre-sowing: chickpeas, field peas, faba beans, wheat, barley, durum, oats, triticale 200 mL/ha 7-21 days pre-sowing: wheat, barley, durum, oats or triticale 240 mL/ha	Fallow claims on label are only for knockdown
Fomesafen 240g/L (Reflex®)	IBS: chickpeas, field peas, faba beans, narrow leaf lupins, vetch 750-1500 mL/ha PSPE: chickpeas, field peas, faba beans, narrow leaf lupins 500-1250 mL/ha	n/a

Observe plantback requirements for following crops when used in fallow   n/a - no registration for use

Figure 1 shows the impact of the time from spray application to weed assessment on common sowthistle control. Efficacy data was initially grouped in intervals of <10 weeks, 10-14 weeks, 14-18 weeks and >18 weeks (not shown). However, grouping in periods of <14 weeks and >14 weeks showed very similar efficacy patterns but ensured larger data sets in each category.

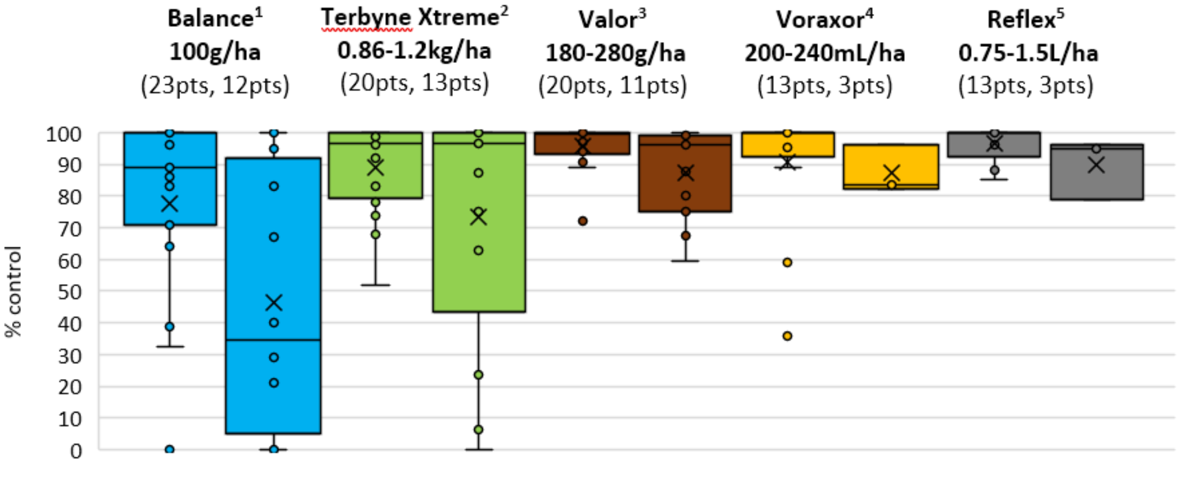

Figure 1. Box and whisker analysis showing the impact of application interval on residual control of common sowthistle.

For each herbicide, the left-hand column shows efficacy in assessments with <14 week intervals, right-hand >14 weeks from application
Text under the herbicide shows the number of data points for each application interval scenario e.g. 23 observations for Isoxaflutole (Balance) <14 weeks, 12 observations >14 weeks
Where herbicide rate ranges are shown, no clear rate differences were evident in the data sets
Limited data exists for saflufenacil+ trifludimoxazin (Voraxor) and fomesafen (Reflex) with evaluation only commencing summer 2021/22. Take care with interpretation as these herbicides may not have been compared across the same range of environmental conditions.
Horizontal line in each box shows the median result with 'X' showing the mean. Where the median line is well above the mean, it indicates a distribution with skewed frequency to higher levels of control e.g. terbuthylazine (Terbyne Xtreme) at >14 weeks. Where the median line is well below the mean, it indicates a distribution with skewed frequency to lower levels of control e.g. isoxaflutole (Balance) >14 weeks. Range is shown by whiskers with outliers as individual dots.
[1] 750g/kg isoxaflutole, [2] 875g/kg terbuthylazine, [3] 500g/kg flumioxazin, [4] 250g/L saflufenacil, + 125g/L trifludimoxazin, [5] 240g/L fomesafe

Figure 2 shows the impact of the total rainfall between application and assessment on common sowthistle efficacy. The efficacy data is grouped in three scenarios; <150mm rainfall between application and assessment, 150-300mm rainfall and >300mm rainfall. NB analysis was only possible on the total amount of rainfall received as there were insufficient trials to assess the impact of different rainfall distributions.

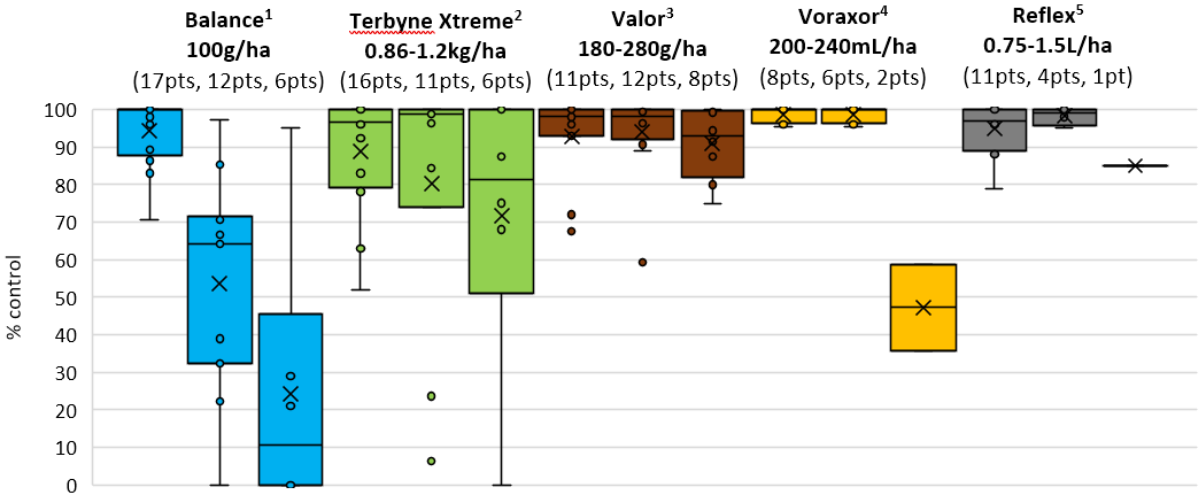

Figure 2. Box and whisker analysis showing the impact of total rainfall on residual control of common sowthistle.

For each herbicide the left-hand column shows efficacy in assessments with <150mm rainfall, centre 150-300mm and right-hand >300mm. The text under the herbicide shows the number of data points for each rainfall scenario e.g. 17 observations for Balance <150mm, 12 observations with 150-300mm and 6 observations with >300mm.

Where herbicide rate ranges are shown, no clear rate differences were evident in the data sets.

Limited data for saflufenacil+ trifludimoxazin (Voraxor) and fomesafen (Reflex) with evaluation only commencing summer 2021/22. Take care with interpretation as these herbicides may not have been compared across the same range of environmental conditions

Horizontal line in box shows the median result with 'X' showing the mean. Where the median line is well above the mean, it indicates a distribution with skewed frequency to higher levels of control e.g.. terbuthylazine (Terbyne Xtreme) at 150-300mm. Where the median line is well below the mean, it indicates a distribution with skewed frequency to lower levels of control e.g. isoxaflutole (Balance) >300mm.

Range is shown by whiskers with outliers as individual dots.

[1] 750g/kg isoxaflutole, [2] 875g/kg terbuthylazine, [3] 500g/kg flumioxazin, [4] 250g/L saflufenacil, + 125g/L trifludimoxazin, [5] 240g/L fomesafe

Key points - common sowthistle efficacy

Isoxaflutole (Balance) efficacy appeared more impacted by rainfall amount than application interval. High levels of control at <150mm rainfall but generally dropped dramatically in trials with >150mm of rainfall. The most sensitive herbicide to rainfall amount in these data sets.

Terbuthylazine (Terbyne Xtreme) efficacy was generally good but with some results that were unexplained by application interval or rainfall amount alone e.g. 99-100% control was still achieved in 50% of trials >14 weeks after application or >150mm rainfall, however in other situations there had been almost full degradation. Soil type, pH, organic matter and history of triazine herbicide use are other factors also known to influence degradation, however these were not evaluated in this review.

Flumioxazin (Valor) efficacy was generally maintained in both long application intervals or increased rainfall situations, although there was evidence of some degradation at the longest intervals or heavier rainfalls. No clear rate responses. Strong option to consider particularly in fallow when a wet season is forecast.

Saflufenacil+trifludimoxazin (Voraxor) and fomesafen (Reflex) limited data sets but very encouraging results from both herbicides for duration and consistency of control, even in situations with up to 150-300mm.

Feathertop Rhodes grass *(Chloris virgata)*

Trials were conducted across a maximum of 10 cropping seasons (3 in 'winter' and 7 in 'summer'). Summaries prepared from a maximum of 20 individual trials (18 in fallow and 2 in chickpeas). Additional efficacy assessments were conducted in 6 fallow and 2 chickpea trials on multiple weed cohorts.

Table 2. Key herbicides with registrations for residual control of feathertop Rhodes grass in-crop or fallow that have been included in the data sets following

Herbicide	Crop registrations	Fallow# registration for 'residual' use patterns
Isoxaflutole 750g/kg (Balance)	n/a	100 g/ha
s-metolachlor 960g/L (Dual Gold®)	Pre sowing: maize, mungbeans, peanuts, soybeans, sunflowers, sorghum 1-2 L/ha Pre sowing: cotton 1L/ha Pre sowing: green bean, navybean 1.5-2 L/ha	1-2 L/ha
Flumioxazin 500g/kg (Valor)	Pre sowing: soybeans, peanuts 210-280 g/ha PSPE: soybeans, peanuts 210 g/ha>1 month pre-sowing: pigeon pea, maize, sorghum, navybean 210-280 g/ha >2 months pre-sowing: cotton, sunflower, mungbeans 210-280 g/ha	210-280 g/ha

Observe plantback requirements for following crops when used in fallow   n/a - no registration for use

Figure 3 shows the impact of the time from spray application to weed assessment on feathertop Rhodes grass efficacy. Efficacy data was initially grouped in intervals of <10 weeks, 10-14 weeks, 14-18 weeks and >18 weeks (not shown). However, grouping in periods of <14 weeks and >14 weeks showed very similar efficacy patterns but ensured larger data sets in each category.

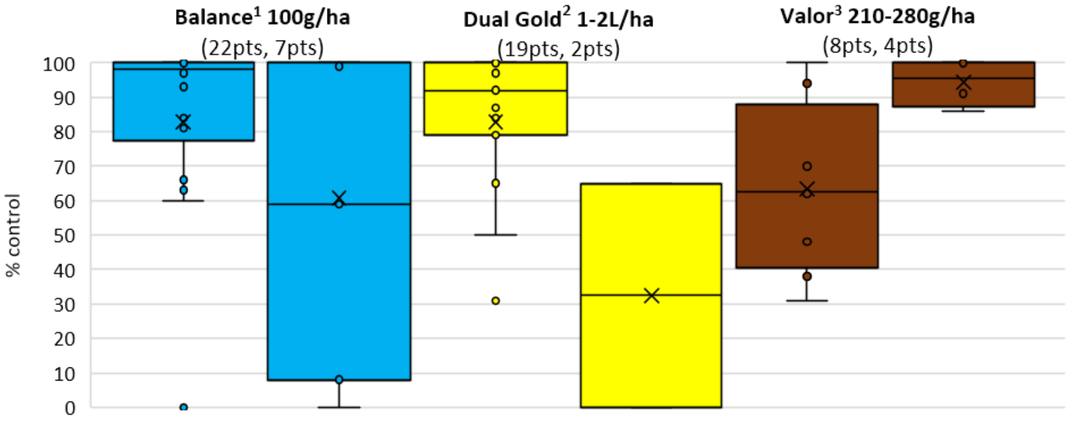

Figure 3. Box and whisker analysis showing the impact of application interval on residual control of feathertop Rhodes grass.

For each herbicide, the left-hand column shows efficacy in assessments with <14 week intervals, right-hand >14 weeks from application. Text under the herbicide shows the number of data points for each application interval scenario e.g. 22 observations for isoxaflutole (Balance) <14 weeks, 7 observations >14 weeks.

Where herbicide rate ranges are shown, no clear rate differences were evident in the data sets.

Horizontal line in box shows the median result with 'X' showing the mean. Where the median line is well above the mean, it indicates a distribution with skewed frequency to higher levels of control e.g. isoxaflutole (Balance) at <14 weeks (>99% control in 11 of 22 situations). Where the median line is well below the mean, it indicates a distribution with skewed frequency to lower levels of control. Range is shown by whiskers with outliers as individual dots.

[1] 750g/kg isoxaflutole, [2] s-metolachlor 960g/L, [3] 500g/kg flumioxazin

Figure 4 shows the impact of the total rainfall between application and assessment on feathertop Rhodes grass efficacy. The efficacy data is grouped in three scenarios; <150mm rainfall between application and assessment, 150-300mm rainfall and >300mm rainfall. NB analysis was only possible on the total amount of rainfall received as there were insufficient trials to assess the impact of different rainfall distributions.

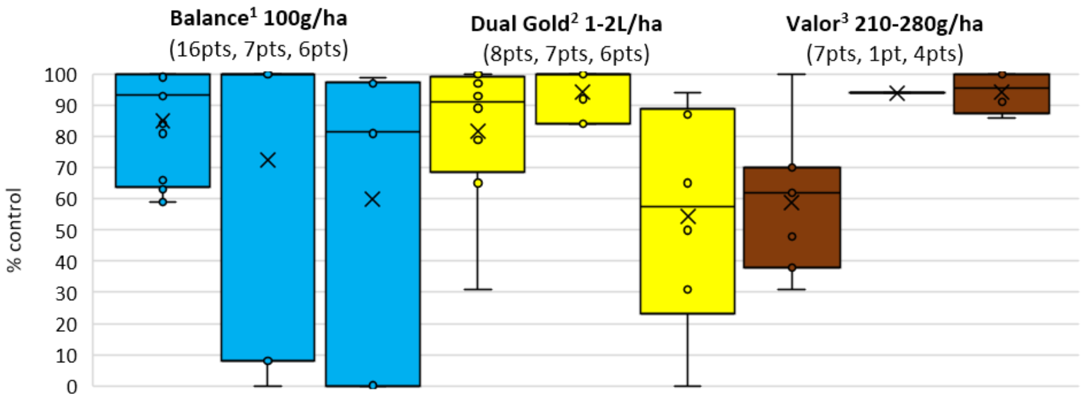

Figure 4. Box and whisker analysis showing the impact of total rainfall on residual control of feathertop Rhodes grass.

For each herbicide the left-hand column shows efficacy in assessments with <150mm rainfall, centre 150-300mm and right-hand >300mm. The text under the herbicide shows the number of data points for each rainfall scenario e.g. 16 observations for Balance <150mm, 7 observations with 150-300mm and 6 observations with >300mm.

Where herbicide rate ranges are shown, no clear rate differences were evident in the data sets.

Horizontal line in box shows the median result with 'X' showing the mean. Where the median line is well above the mean, it indicates a distribution with skewed frequency to higher levels of control e.g isoxaflutole (Balance) at 150-300mm (100% control in 5 of 7 situations). Where the median line is well below the mean, it indicates a distribution with skewed frequency to lower levels of control. Range is shown by whiskers with probable outliers as individual dots.

[1] 750g/kg isoxaflutole, [2] s-metolachlor 960g/L, [3] 500g/kg flumioxazin

Key points – feathertop Rhodes grass efficacy

Isoxaflutole (Balance) provided effective control in situations with <150mm rainfall or up to 14 weeks from application. Efficacy was generally good even in situations with 150-300mm rainfall (100% control in 5 of 7 trials, but very poor in 2 trials). Feathertop Rhodes grass efficacy appeared less sensitive to rainfall quantity than common sowthistle.

s-metolachlor (Dual Gold) patterns of control were similar to isoxaflutole (Balance) with good efficacy at <14 week intervals. Results in 150-300m rainfall situations were surprisingly good (100% control in 4 of 7 sites).

Flumioxazin (Valor) showed some variability in control at sites that wasn't explained by application interval or rainfall amount. There was little apparent reduction in efficacy at sites with >150mm rainfall.

Conclusions

The availability of these large data sets allowed evaluation of the impact of the interval between application and assessment, or the amount of rainfall received up to assessment. The interval between application and assessment alone was generally a poor indicator of the residual herbicide efficacy. Amount of rainfall received provided a better indication of herbicide performance but was strongly associated with the individual herbicide and the weed target.

Differences in herbicide performance under varied application intervals or amounts of rainfall could assist growers to better match herbicide choice to the situation of use e.g. modifying management choice on the basis of timing of fallow spraying or on the basis of the season forecast.

Further analysis of trials where variability in efficacy appeared unrelated to either application interval or amount of rainfall is also likely to improve our understanding of how to achieve improved management.

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Resistance management strategies for glyphosate resistant weeds, finessing pre-emergent herbicides, and getting the early post-emergent space right

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Key words

glyphosate resistance, pre-emergent herbicides, double knock

GRDC code

UOA2007-007RTX

Take home message

- Glyphosate resistance is increasing in incidence in Australia in both summer growing and winter growing weeds
- Management strategies that do not include glyphosate can be better than the double knock in managing glyphosate resistant populations
- Choosing the right pre-emergent herbicide strategy for the situation improves annual ryegrass control.

Glyphosate resistance

Recent weed resistance surveys are indicating an increase in glyphosate resistant weeds. This includes annual ryegrass, as well as summer growing weed species (Table 1). While the double knock has been the main management tactic for glyphosate resistant weeds it has sometimes been difficult to institute and other tactics, such as glyphosate mixtures, have been used instead. Management is further complicated by the evolution of paraquat resistance in both annual ryegrass and flaxleaf fleabane.

Table 1. Extent of resistance to glyphosate in various weed species collected in a random survey of cropping fields across Australia in 2020/2021. Samples were considered resistant if more than 20% of the individuals survived herbicide treatment. Annual ryegrass and common sowthistle were collected across Australia, while the other species were only collected in northern NSW and Queensland.

Weed species	Samples tested	Resistance to glyphosate (% of samples)
Annual ryegrass	1354	19
Common sowthistle	517	0.2
Flaxleaf fleabane	104	59
Feathertop Rhodes grass	128	97
Awnless barnyard grass	75	28
Sweet summer grass	26	58

The mechanism of resistance to glyphosate may also influence the results of management strategies. There are three main mechanisms of glyphosate resistance that have been identified in weeds in Australia: target site mutations; reduced glyphosate translocation through vacuolar sequestration;

and gene amplification. Recently, it was found that applying glyphosate to glyphosate resistant barley grass increased the level of glyphosate resistance through increasing the number of copies of the EPSPS gene in the plants (Figure 1).

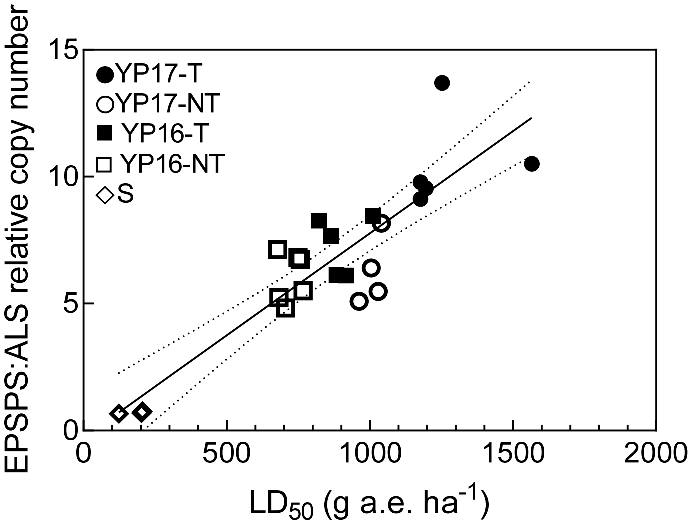

Figure 1. Increase of LD_{50} and EPSPS gene copy number in the progeny of glyphosate-resistant barley grass clones from 2 populations treated or not treated with glyphosate. Individual plants were divided into 2 clones. One clone from each individual was treated with 405 g ha^{-1} glyphosate and the other clone was untreated. Seed was collected from each clone. The LD_{50} was calculated from a dose response of progeny from each clone. The copy number of EPSPS for each set of progeny was determined by qPCR. Open symbols are progeny from clones not treated with glyphosate and closed symbols are progeny of clones treated with glyphosate.

This result suggests that management strategies using glyphosate will result in higher levels of resistance in weeds with the gene amplification mechanism. Other weeds with this resistance mechanism are windmill grass and brome grass. Flaxleaf fleabane, feathertop Rhodes grass, common sowthistle, barnyard grass and annual ryegrass all have populations with target site resistance and are likely to respond differently. Most glyphosate-resistant annual ryegrass plants have reduced translocation of glyphosate.

Managing glyphosate resistant weed populations

Experiments have been established exploring different management strategies on populations of glyphosate resistant weeds. Preliminary results for common sowthistle (Table 2) and feathertop Rhodes grass (Table 3) show that double knocks are better than using glyphosate alone; however, using herbicides other than glyphosate is better at keeping glyphosate resistant populations low. For barley grass, a double knock is better than glyphosate mixtures with Group 14 herbicides.

Table 2. Survival (%) of two glyphosate-resistant common sowthistle populations after herbicide treatment in the second year of the trial at Hermitage Research Facility, Warwick QLD. Populations containing 30% resistant individuals were sown and treated over 2 consecutive seasons with the same herbicide strategies. fb = followed by.

Herbicide strategy	Survival (%)	
	ST white	ST yellow
Double knock alternative – 2,4-D fb paraquat + diquat (Spray.Seed®)	1.1	0
Double knock – glyphosate fb paraquat + diquat (Spray.Seed®)	0.1	0.6
Single knock – glyphosate applied morning	8	7
Single knock – glyphosate applied midday	20	13
Residual herbicide – Balance®	0	0

Table 3. Survival of feathertop Rhodes grass with different mutations in EPSPS after herbicide treatment in the second year of the trial at Hermitage Research Facility QLD. Populations containing 30% resistant individuals were sown and treated over 2 consecutive seasons with the same herbicide strategies. fb = followed by.

Herbicide strategy	Mutation		
	Pro 196 Leu	Pro 196 Ser	Pro 196 Thr
Double knock alternative – haloxyfop fb paraquat	16	55	0
Double knock – glyphosate fb paraquat	92	59	51
Single knock – glyphosate	80	54	71
Residual herbicide – s-metolachlor (Dual Gold®)	0	0	0

A challenge for the management of glyphosate and paraquat resistant annual ryegrass is that neither herbicide in the double knock will be effective on its own. An alternative approach to manage glyphosate resistant annual ryegrass when the seasonal conditions are appropriate is to dry sow and use pre-emergent herbicides and crop competition. However, with dry sowing it is important to choose the pre-emergent herbicides wisely. For dry sowing, more persistent herbicides are better than using less persistent herbicides, such as s-metolachlor + prosulfocarb (Boxer Gold®) (Table 4). Including an early post-emergent application of s-metolachlor + prosulfocarb (Boxer Gold), prosulfocarb (Arcade®) or aclonifen+diflufenican+pyroxasulfone (Mateno® Complete) can provide better control of annual ryegrass and provide insurance against poor control of weeds by pre-emergent herbicides due to seasonal conditions (Table 4).

Table 4. Annual ryegrass control in a dry sown wheat trial at Concordia, SA in 2023. Weed counts were made 49 days after sowing. fb = followed by, early post-emergent herbicide products applied 21 days after sowing.

Herbicide active(s)	**Trade name**	**Formulation(s)**	**Rate(s)**	**Annual ryegrass (plants m^{-2})**
Nil	Nil			76.8 a
Trifluralin	TriflurX®	480 g/L	2 L/ha	24.9 b
Pyroxasulfone	Sakura® Flow	480 g/L	210 mL/ha	13.2 bc
Prosulfocarb + S-metolachlor	Boxer Gold	800 g/L + 120 g/L	2.5 L/ha	37.6 ab
Cinmethylin	Luximax®	750 g/L	0.5 L/ha	15.2 bc
Aclonifen+ Pyroxasulfone+ Diflufenican	Mateno Complete	400 g/L 100 g/L 66 g/L	0.75 L/ha	24.0 b
Aclonifen+ Pyroxasulfone+ Diflufenican	Mateno Complete	400 g/L 100 g/L 66 g/L	1 L/ha	15.2 bc
Bixlozone	Overwatch®	400 g/L	1.25 L/ha	14.2 bc
Trifluralin fb (Aclonifen+ Pyroxasulfone+ Diflufenican)	TriflurX fb Mateno Complete	480 g/L fb (400 g/L 100 g/L 66 g/L)	2 L/ha fb 0.75 L/ha	14.7 bc
Trifluralin fb (Aclonifen+ Pyroxasulfone+ Diflufenican)	TriflurX fb Mateno Complete	480 g/L fb (400 g/L 100 g/L 66 g/L)	2 L/ha fb 1 L/ha	6.8 bc
Bixlozone fb (Aclonifen+ Pyroxasulfone+ Diflufenican)	Overwatch fb Mateno Complete	400 g/L fb (400 g/L 100 g/L 66 g/L)	1.25 L/ha fb 1 L/ha	0.5 c
Trifluralin fb (Prosulfocarb + S-metolachlor)	TriflurX fb Boxer Gold	480 g/L fb (800 g/L + 120 g/L)	2 L/ha fb 3 L/ha	8.3 bc
	P			0.0004

Getting better control of annual ryegrass with pre-emergent and early post-emergent herbicides

There are four main causes for pre-emergent herbicides to fail to control weeds: herbicide resistance in weeds; too little herbicide persistence; too much rainfall that moves the herbicide below the weed root zone; or too little rainfall to properly activate the herbicide.

There is relatively little resistance to pre-emergent herbicides present in NSW, with some resistance to trifluralin, prosulfocarb and s-metolachlor + prosulfocarb (Boxer Gold) in annual ryegrass. If resistance to these herbicides is known to be present, alternative products should be chosen.

Too little persistence is a problem for products such as s-metolachlor + prosulfocarb (Boxer Gold), prosulfocarb (e.g. Arcade®) and metazachlor (Tenet®), where the efficacy of the herbicide declines rapidly after application. This allows later emerging weeds to avoid the herbicide. This is also more likely to be a problem in higher rainfall zones or in longer seasons. The solution is to use longer persistence products and mixtures of pre-emergent herbicides.

Loss of herbicide out of the root zone of the germinating weeds mostly occurs with the more soluble herbicides, such as metazachlor (Tenet®) and cinmethylin (Luximax) and generally on lighter soil types. However, this can be a problem for many herbicides with sufficient rainfall. In higher rainfall regions, using herbicides with lower water solubility will manage this problem.

Too little rainfall after application of the herbicide is normally a problem for the less soluble products, such as pyroxasulfone (Sakura), propyzamide and aclonifen+diflufenican+pyroxasulfone (Mateno® Complete). This typically occurs where there has been good rainfall prior to application of the herbicide that causes annual ryegrass to germinate. Without sufficient follow-up rainfall after herbicide application, the herbicides are not activated in time to control the weeds. Mixtures with herbicides that have different properties can overcome this problem. Useful mixtures have been pyroxasulfone (Sakura) plus tri-allate (Avadex® Xtra) and pyroxasulfone (Sakura) plus trifluralin.

An early post-emergent application of s-metolachlor + prosulfocarb (Boxer Gold), prosulfocarb (Arcade) or aclonifen+diflufenican+pyroxasulfone (Mateno® Complete)can be used in combination with the pre-emergent herbicide to manage the potential issues with pre-emergent herbicides. All of these herbicides require rainfall after application to activate them. S-metolachlor + prosulfocarb (Boxer Gold)is the most water-soluble product, requiring the least amount of rainfall, followed by prosulfocarb (Arcade), whereas aclonifen+diflufenican+pyroxasulfone (Mateno® Complete)is much less water soluble. S-metolachlor + prosulfocarb (Boxer Gold)and prosulfocarb (Arcade) are best applied when annual ryegrass is at the 1 to 2-leaf stage. Aclonifen+diflufenican+pyroxasulfone (Mateno® Complete), because of the higher rainfall requirement, is best applied as a strategic application rather than for salvage and at the 2-leaf stage of the crop, preferably before additional annual ryegrass has emerged. Aclonifen+diflufenican+pyroxasulfone (Mateno® Complete) will control new emergence of annual ryegrass after rainfall has occurred but will not control larger annual ryegrass plants.

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Herbicide resistance status of weed species across the cropping regions of New South Wales and Queensland

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Key words

herbicide resistance, ryegrass, wild oats, sowthistle

GRDC code

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Take home message

- Resistance to post-emergence herbicides including glyphosate is widespread in the northern grain cropping region with the greatest frequency in southern NSW
- Resistance in ryegrass was only recorded to two pre-emergent herbicides (trifluralin and prosulfocarb + S-metolachlor) and at lower frequency than resistance in ryegrass collected from other Australian states
- Wild oat resistance is more common in NSW and Qld than in populations from other states
- Widespread sulfonylurea resistance was identified in sowthistle populations

Background

Herbicide resistance surveys have been conducted across the Australian grain cropping region for many years with the initial surveys in WA, NSW and Vic conducted to determine the extent of resistance in annual ryegrass in the early 1990's (Gill 1993; Pratley *et al.,* 1995; Henskens 1997). Subsequently surveys were conducted to determine the level of resistance in wild oats (Pratley *et al.,* 1996; Nietschke 1997). Since then, surveys have been conducted across many sections of the cropping regions at regular intervals looking at many different weed species (Llewellyn and Powles 2001; Walsh *et al.,* 2001; Owen *et al.,* 2007; Broster *et al.,* 2011, 2012; Boutsalis *et al.,* 2014; Owen *et al.,* 2014, 2015a, 2015b). However, it was not until 2016 that every region of the Australian cropping region had been surveyed at least once (Broster *et al.,* 2018).

While all the cropping regions had been surveyed by 2020 each of the organisations undertaking the surveys had used different methods for sample collection, preparation, chemical application, assessment and reporting. In some states, parts of the state were surveyed and screened each year, while in others the entire state was surveyed in a single year with the resistance screening occurring in subsequent years.

The 2020 survey was the first national survey to use a consistent methodology across all these criteria for each species, to the extent that each individual species is screened for resistance at a single location, not at different locations.

This paper presents the results from the winter cropping weed samples obtained from NSW and Qld paddocks during the random field surveys for herbicide resistance conducted in 2020 and 2021 and compares them to the overall survey findings from across Australia.

Results

Samples collected Australia wide

Across Australia 3053 paddocks were visited during the most recent round of surveys, 2688 paddocks with winter crop and 465 (all in NSW or Qld) with summer crop or fallow (Figure 1). From these paddocks the following seed samples were collected; 1486 ryegrass, 677 wild oats, 272 barley grass, 383 brome grass, 581 sowthistle, 136 wild radish, 35 Indian hedge mustard, 124 fleabane, 144 feathertop Rhodes grass, 111 awnless barnyard grass and 27 sweet summer grass.

Samples collected NSW and Qld

From the 878 winter crop paddocks (33% of all winter crop paddocks across Australia) surveyed in NSW (634) and Qld (244) (Figure 1), 337 (23% of total samples) ryegrass samples were collected along with 345 (51%) wild oats, 55 (20%) barley grass, 34 (11%) brome grass, 387 (67%) sowthistle and 27 (20%) wild radish samples. As all of the summer cropping or fallow paddocks surveyed were from NSW or Qld, all of the feathertop Rhodes grass, awnless barnyard grass and sweet summer grass samples collected nationally came from these states. All but two populations of fleabane were from Qld and NSW with two collected from WA as part of their winter survey.

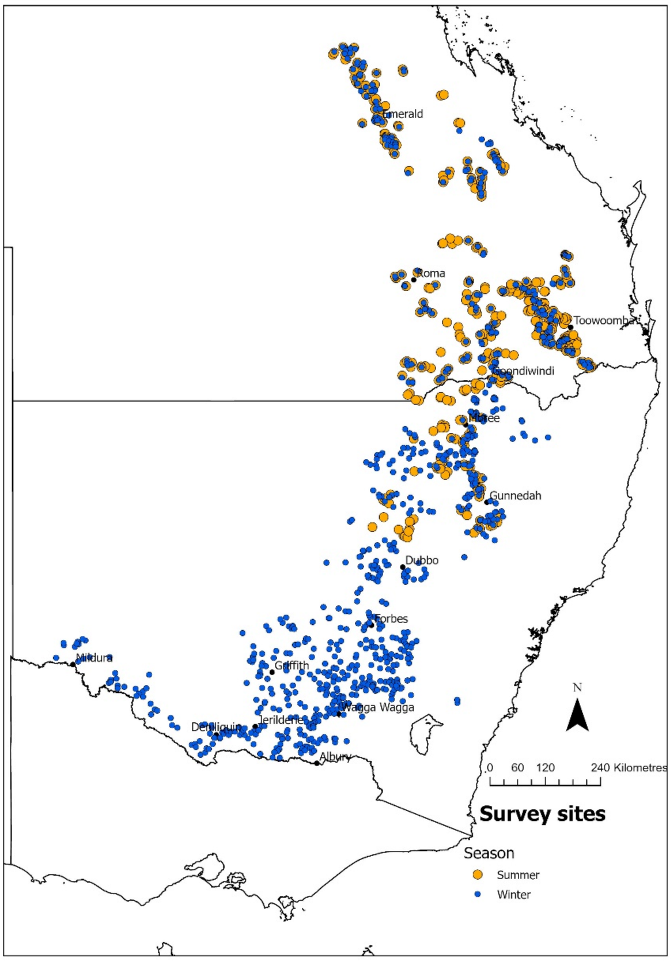

Figure 1. Winter and summer survey sites

Ryegrass

Ryegrass was only found in NSW paddocks with the majority of the samples collected south of Dubbo (southern NSW). Due to previous surveys across Australia finding that 90% plus of samples from most regions were resistant to Group 1 'fop' herbicides, this herbicide sub-group was not tested in samples collected during this survey. While the percentage of samples from southern NSW resistant to each of the post-emergent herbicides was similar to the overall survey findings, the extent of resistance for northern (north of Dubbo) NSW was lower for all herbicides (Table 1). Over 70% of samples from southern NSW were resistant to Group 1 'den' and Group 2 'SU' and 'Imi' herbicides compared with less than 50% from northern NSW. About 20% of southern NSW samples were resistant to clethodim (Group 1 'dim') and glyphosate (Group 9) compared with 10% for northern NSW (Table 1).

Resistance to the pre-emergent herbicides was much lower with resistance recorded for only trifluralin (Group 3) and prosulfocarb + S-metolachlor (Group 15) in southern NSW only, and at a lower level than the overall survey (Table 1).

Table 1. Percentage of ryegrass samples from NSW resistant (>20% survivors) to different herbicides compared with the overall survey.

Herbicide	Group	Northern NSW	Southern NSW	Australia (including NSW)
Clethodim	1 'dim'	6	19	23
Pinoxaden	1 'den'	26	79	71
Iodosulfuron	2 'SU'	44	91	91
Imazamox + Imazapyr	2 'Imi'	24	73	79
Glyphosate	9	14	24	16
Paraquat	22	0	0	0
Trifluralin	3	0	2	12
Prosulfocarb + S-metolachlor	15	0	1	2
Pyroxasulfone	15	0	0	0
Propyzamide	3	0	0	0
Cinmethylin	30	0	0	0
Bixlozone	13	0	0	0

Only 6% of the southern NSW ryegrass samples were susceptible to all herbicides, the same as for the overall survey, much lower than the 47% of northern NSW ryegrass samples susceptible to all herbicides (Figure 2).

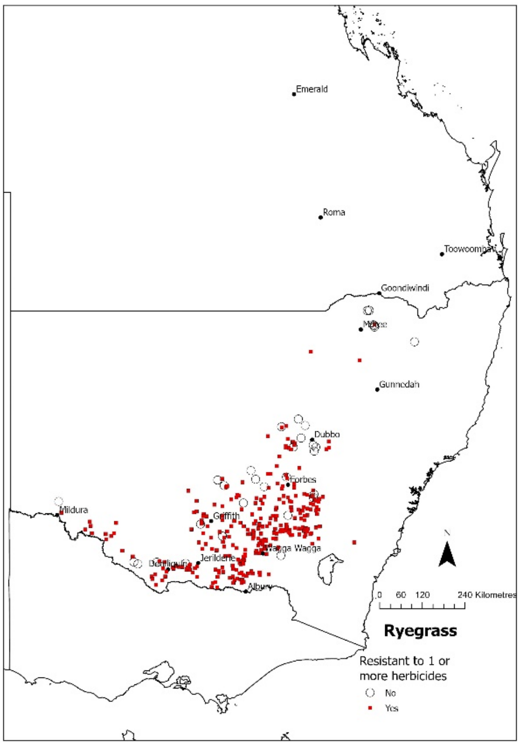

Figure 2. Ryegrass populations susceptible to all tested herbicides (open circles) or resistant to one or more herbicides (red/darker squares)

Wild oats

Wild oats were found evenly across the entire area surveyed in NSW and Qld and at a greater frequency than in the other states. Fifty percent of national wild oat samples were collected in NSW and Qld from only 33% of all winter crop paddocks visited.

The wild oat resistance to the Group 1 and 0 herbicides was higher in northern NSW than southern NSW, Qld and the overall survey (Table 2). For both southern NSW and Qld the level of resistance for these herbicide groups, while lower than in northern NSW, was also either higher, or similar, to the overall national survey. A significant percentage of the samples from all regions were classed as developing resistance, that is they had plants that survived the herbicide application but at less than 20% (Table 2).

No samples were considered to be resistant (i.e. greater than 20% survivors) to triallate but the seed from some 'developing resistance' populations that had surviving plants have been collected for re-testing to see if they survived due to resistance or other reasons.

Table 2. Percentage of wild oat samples from NSW and Qld resistant (>20% survivors) or developing resistance (in brackets; 5-20% surviving plants) to different herbicides compared with the overall survey.

Herbicide	Group	Northern NSW	Southern NSW	Queensland	Australia (including NSW & Qld)
Clodinafop	1 'fop'	27 (10)	25 (20)	21 (15)	16 (15)
Clethodim	1 'dim'	2 (0)	0 (3)	0 (3)	0 (1)
Pinoxaden	1 'den'	14 (8)	9 (22)	5 (14)	5 (12)
Mesosulfuron	2 'SU'	0 (9)	0 (10)	2 (3)	1(8)
Flamprop	0	11 (9)	6 (23)	8 (18)	7 (25)
Triallate	15	0 (25)	0 (19)	0 (16)	0 (15)

Thirty three percent of northern NSW wild oat samples were resistant to one or more herbicide groups compared with 29% of southern NSW and 26% of Qld samples (Figure 3). This is higher than the 20% for the overall survey.

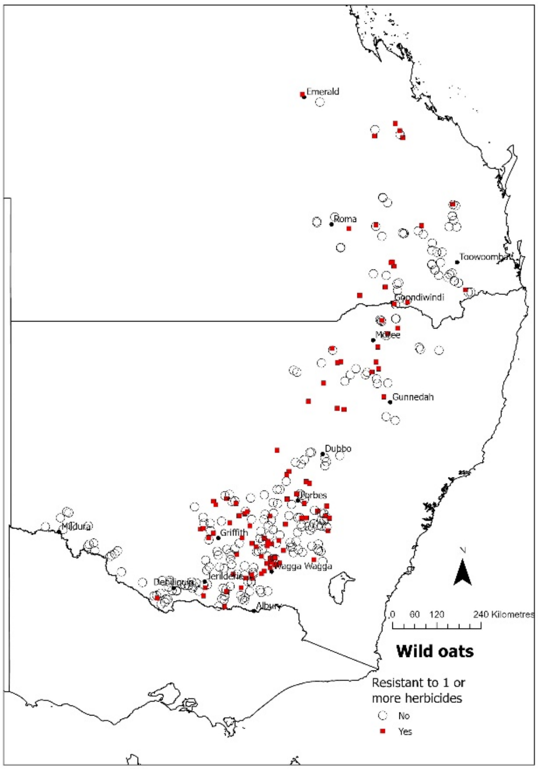

Figure 3. Wild oat populations susceptible to all tested herbicides (open circles) or resistant to one or more herbicides (red/darker squares)

Sowthistle

Sowthistle was collected in 387 paddocks across NSW and Qld with 111 of these populations collected during the summer survey from 465 paddocks. The highest incidence of resistance to the sulfonylurea herbicides was in southern NSW with 87% of samples confirmed resistant, compared with 75% in northern NSW, 67% in Qld, and 73% for the whole survey. However, 2,4-D resistance was highest in Qld at 8% of samples compared to 3% in NSW and Australia overall (Table 3). At 5% of populations when combined across the region, this is the first reported incidence of 2,4-D resistance in sowthistle from northern surveys. Of additional concern, a further 33% of populations were rated as developing resistance (1-19% survivors). In this survey no samples were found to be resistant to glyphosate, however a previous 2016-18 survey (Broster *et al.,* 2023) identified 8% glyphosate resistance across the northern region. Further investigations into this are on-going.

Table 3. Percentage of sowthistle samples from NSW and Qld resistant (>20% survivors) to different herbicides compared with the overall survey

Herbicide	Group	Northern NSW	Southern NSW	Queensland	Australia (including NSW & Qld)
Chlorsulfuron	2 ‘SU’	75	87	67	73
2,4-D amine	4	3	3	8	3
Glyphosate	9	0	0	0	0

Note: chlorsulfuron is not registered for control of sowthistle. Chlorsulfuron was included in this screen to check current resistance levels to SU herbicides.

Other species

A small number of other species (barley grass, brome grass and wild radish) were collected from NSW and Qld (wild radish only) during the survey.

All the barley grass and brome grass samples from NSW were susceptible to quizalofop, clethodim, glyphosate, imazamox + imazapyr and paraquat (barley grass only). While all barley grass samples were susceptible to sulfosulfuron, 27% of brome grass populations were resistant to that herbicide. For both paraquat and sulfosulfuron there was one barley grass population with some surviving plants (developing resistance) and three populations (7%) of brome grass were classed as developing resistance to sulfosulfuron.

No wild radish populations from NSW or Qld were resistant to diflufenican (Group 12) although populations from NSW were classed as developing resistance (4 out of 15). Populations from NSW were resistant to chlorsulfuron (5/16) and imazamox + imazapyr (3/14) and developing resistance to 2,4-D amine (6/21) and chlorsulfuron (1/16) while samples from Qld were resistant to 2,4-D amine (1/5) and imazamox + imazapyr (3/4) and developing resistance to 2,4-D amine (3/5) and chlorsulfuron (3/4). Due to limited seed, not all samples were tested to all herbicides.

Future work

Screening of some wild oat populations that required seed increase to have sufficient volume of seed for testing is continuing, as are investigations into glyphosate resistance in sowthistle. A number of wild oat populations with varying levels of survival to clodinafop are also being screened to haloxyfop to check on any similarities or differences in resistance status between Group 1 ‘fop’ herbicides.

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Concurrent session - Barley net blotch, cereal rusts and sclerotinia in canola

Efficiently limiting yield loss from net-blotch in barley – a meta-analysis

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Key words

net-blotch; spot-form; net-form; *Pyrenophora teres f. teres*; *Pyrenophora teres f. maculata*; network meta-analysis, decision support tools

GRDC code

DAW2112-002RTX

Take home message

- In marginal barley cropping regions where yield targets are below or equal to 3.4 tons per hectare, using foliar fungicides to control net-blotch might not be economically beneficial
- The most effective period for applying foliar fungicide to minimise yield loss is during and immediately after the emergence of the top three leaves (flag leaf, flag leaf -1 and flag leaf -2)
- Two fungicide applications timed between Z35 and Z60 provided the best yield protection
- Efficacy of spray programs to protect yield don't tend to differ between the two net-blotch forms, SFNB (Spot Form Net Blotch) and NFNB (Net Form Net Blotch)
- Consult the 'NetBlotchBM' app when considering a disease management program.

Decision support tools

Effective integrated disease management in agriculture can lead to higher economic gains for growers. However, it demands a thorough understanding of the interactions between host plants and pathogens, and the time to gather data on the crop and make decisions to the economic thresholds for intervention. Decision support tools package the knowledge and economic thresholds for intervention to streamline integrated crop management programs. Decision support tools released by the Department of Primary Industries and Regional Development (DPIRD) in Western Australia are the result of collaborative efforts with disease experts from various Australian grain growing regions. They are founded on extensive field trial data, accumulated over decades. This presentation outlines some of the development process of the recently released Barley Net Blotch Manager (NetBlotchBM) by featuring insights from a meta-analysis of 111 field trials conducted over the past 20 years.

Net-blotch biology and background

Net blotch is a stubble-borne disease which constrains barley yields worldwide, potentially causing up to 44% in yield loss (Jayasena *et al.,* 2007). The causal agent is characterised by two forms: net-form (NFNB) *Pyrenophora teres f. teres*, and spot form (SFNB) *P. teres f. maculata* (Ptm). The two strains differ in their symptoms, distribution, optimum environmental conditions, and likelihood of seed transmission (McLean *et al.,* 2009). Despite some differences between the two ‘forms’, many similarities in the epidemiology remain the same.

Primary net-blotch infections in barley predominantly arise due to ascospore dispersals originating from infected stubble from previous seasons. However, primary infection can also occur from seed transmission (NFNB) and spore dispersals from alternative hosts (McLean *et al.,* 2009; Joergensen 1980).

Ascospore production from stubble is reliant on the presence of moisture with an optimal temperature range between 15 and 20°C. Infection can occur rapidly, especially when leaves remain moist for extended periods. Visible symptoms typically emerge within 48 hours post infection and become more pronounced between 7 to 10 days post infection. This stage precedes the generation of secondary inoculum via conidia, which occurs approximately 14 to 20 days after the initial infection.

Disease progression occurs within a wide temperature range (8–33 °C) with its epidemiology impacted by average temperatures. As the season advances, warmer temperatures tend to increase the levels of airborne conidia, potentially leading to more frequent infection cycles (Van den Berg and Rossnagel, 1991). However, without frequent high humidity or periods of sufficient leaf wetness, epidemics can stall, giving time for the host to grow through infections (Deadman and Cooke 1987).

Wet conditions significantly accelerate the buildup of net-blotch in barley, leading to greater disease-related losses in medium to high rainfall areas (McLean *et al.,* 2022). Consequently, grain yield losses in these zones typically range between 4–25%, on average. In contrast, areas and seasons with lower rainfall tend to experience less impact, reporting average yield losses of 1–5% due to the disease (Khan 1989; McLean *et al.,* 2016).

Net blotch primarily affects grain quality before detectable losses in grain quantity (McLean *et al.,* 2016) complicating the assessment of economic losses. Yield loss predictions from disease severity depend on the timing of assessment relative to the crop's growth stage. Jayasena *et al.* (2002) cites the milky ripe stage (Zadoks Z73) as the optimum single crop growth stage where disease severity corelates with yield loss. The timing of initial infection also plays a role, presenting challenges in timing fungicide applications effectively. Mitigating yield loss to net blotch requires protecting the upper canopy leaves (flag leaf, flag -1 and flag -2) which contribute up to 72% of their photosynthates to grain production (McLean *et al.*, 2009). To-date, application of foliar fungicides are therefore recommended between stem elongation (Z31) and flag leaf emergence (Z39) (McLean and Hollaway 2019; McLean *et al.,* 2022).

Barley seasons with sub-optimal rainfall, or conditions not conducive to achieving maximum yield potential, are less likely to benefit financially from fungicide applications for net-blotch control. Additionally, these sub-optimal conditions often do not favour severe net-blotch infections. Barley yield thresholds, where intervention with a fungicide application is economically justified by loss in potential yield, remain uncertain and require further research.

Spatial factors, such as agro-ecological cropping zones in Australia, which characterise typical barley yield potential and common climate trends may provide additional insight into net-blotch management strategies. In this study we aim to identify yield thresholds where fungicide application results in significant yield protection for different agro-ecological zones corresponding with barley production areas in Australia.

Methods

We undertook a systematic review approach to this meta-analysis when incorporating data provided by collaborating institutions, DPIRD, Agriculture Victoria and Queensland Department of Agriculture and Fisheries. Suitability of the field trial data required it to meet the following criteria: sourced from a barley field trial on net-blotch undertaken in an Australian agro-ecological zone, a stubble inoculated trial, barley yield and variance between treatment replicates, and details of any disease management treatments, such as seed treatments, foliar fungicides, timing of foliar fungicide application and fungicide active ingredients. Trials not meeting the inclusion criteria were dropped before the analysis. Data from 111 trials were obtained and 29 were not included in the analyses for not meeting the inclusion criteria.

From the included trials, disease severity was measured as the percent leaf area diseased, however between trials disease severity was assessed at varying crop growth stages. To standardise the disease severity observations across all trials, we used a critical point approach where severity was estimated at ear emergence (Z50) in the no spray control plot. Area under the disease progress could not be used because the first and last severity ratings were rarely observed at the same growth stages. Because the aim was to determine the effect of the trial disease pressure on yield loss, and not correlating disease severity with individual treatments, the unsprayed control was used in categorising disease pressure for the trial.

The meta-analysis on actual yield evaluated treatment effects of the following fixed effect variables: categories representing foliar fungicide timing and frequency; disease pressure (percent leaf area diseased in the unsprayed controls); seed treatments; and the presence of inoculum on net-blotch infested stubble. Additional ‘random effects’ including barley genotype, net-blotch form, and nested spatio-temporal structured variables agro-ecological zone, trial location and trial id were evaluated for their effect on yield.

Table 1. Simplified discrete foliar fungicide treatments used in the meta-analysis.

Foliar fungicide* treatment timings	Zadok’s stages
Early	<Z30
Node	Z30 – Z32
Stem extension	Z33 – Z35
Flag leaf	Z36 – Z39
Boot	Z40 – Z49
Head emergence	Z50 – Z59
Post-anthesis	>Z60

*Only group 3 – demethylase inhibitors were incorporated in the meta-analysis

Results and discussion

Preface

It is important to note the complexity of the meta-analysis undertaken here. The collated data testing timing of different fungicide treatments were derived from numerous independent trial studies, each subjected to differences in agro-ecological zones, trial location, disease pressure, seasonal rainfall, barley variety, inherent yield potential for the crop in that season, and sampling sizes. The number of trials testing the different timing of fungicide treatments in this meta-analyses and whether data are included from a balanced representation of these variables or primarily from a skewed number of variable categories leading to bias, will be discussed on presentation. However, overall, our meta-analysis does reveal trends allowing us to inform growers on likely best practice in managing net blotch in barley crops, while also highlighting key areas where more data generation would help improve the Barley Net Blotch Manager.

Yield summary

Raw yields varied between 0.09 t/ha to 8.67 t/ha, with just over half the trials yielding greater than 4 t/ha. Raw data indicated yields were likely to vary according to agro-ecological region (Figure 1).

Fungicide timing

Two foliar fungicide applications with one spray at stem extension (Z33–Z35) and one at booting (Z40–Z49) was estimated to protect the most yield (0.692 t/ha; trials = 6). However this result should be viewed with scrutiny due to only six trials featuring this treatment. The next best were two-application regimes at: node development (Z30–Z33) plus booting (Z40-Z49) (0.460 t/ha; trials = 12), and the other occurring at 'early' (<Z29) plus one at head emergence (<Z50) (0.370 t/ha; trials = 9) (Figure 2). A two-spray regime starting with an application at node development and a second at flag-leaf emergence (Z37–Z39) protected an estimated 0.293 t/ha (trials = 31), with no additional benefit on yield compared to when a third spray was applied between boot (Z40–Z49) and post-anthesis (>Z60) (0.222 t/ha; trials = 12).

While there was no significant difference between any of the single spray scenarios, Node (Z30–Z32) on average protected the most yield (0.1737 t/ha; trials = 39). Followed by flag-leaf (0.17 t/ha, trials = 31), boot, (0.16 t/ha, trials = 8 and early (0.12 t/ha, trials = 15). Unexpectantly, treatments with full coverage starting 'early' showed no yield increase compared to unsprayed controls (0.089 t/ha, trials = 16). On closer inspection of the raw data, we found 11 of the 16 trials which included full coverage starting 'early' yielded less than 3 t/ha. Four of the five remaining trials which yielded greater showed no significant yield differences between treatments, while also recording low disease pressure. More higher yielding studies with heavy disease pressure are needed to understand the true effect of this treatment.

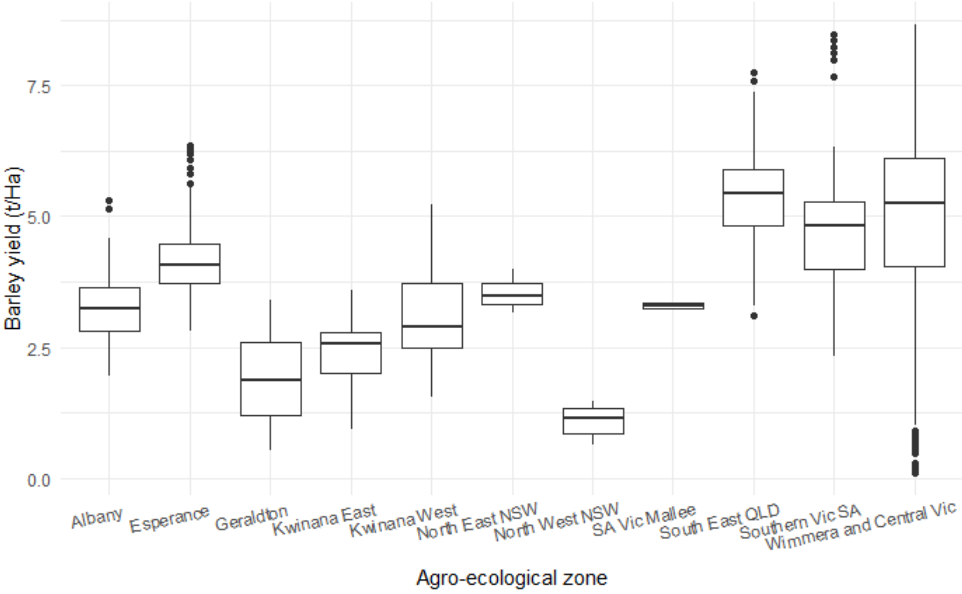

Figure 1. Boxplot of average barley yield in experiments for each agro-ecological zone. Boxes indicate the 25 and 75% quantiles, the central bar indicates the median, vertical lines indicate the 99% range of yields, dots show potential outliers.

While differences between net-blotch form (net-form vs spot-form) were present in individual trials in different agro-ecological zones (Figure 3), the analysis showed no difference on their impact on crop yield (*P*> = 0.7273). Agro-ecological zone accounted for a large and significant amount of the barley yield variation, followed by rainfall and genotype. Locations within agro-ecological zone and variation between or within trials produced lower, albeit important, effects on yield. The efficacy of the foliar fungicide category was dependant on the individual field trial (*P* <0.001) when accounting for agro-ecological zone and location, and therefore likely indicates the differences between growing seasons.

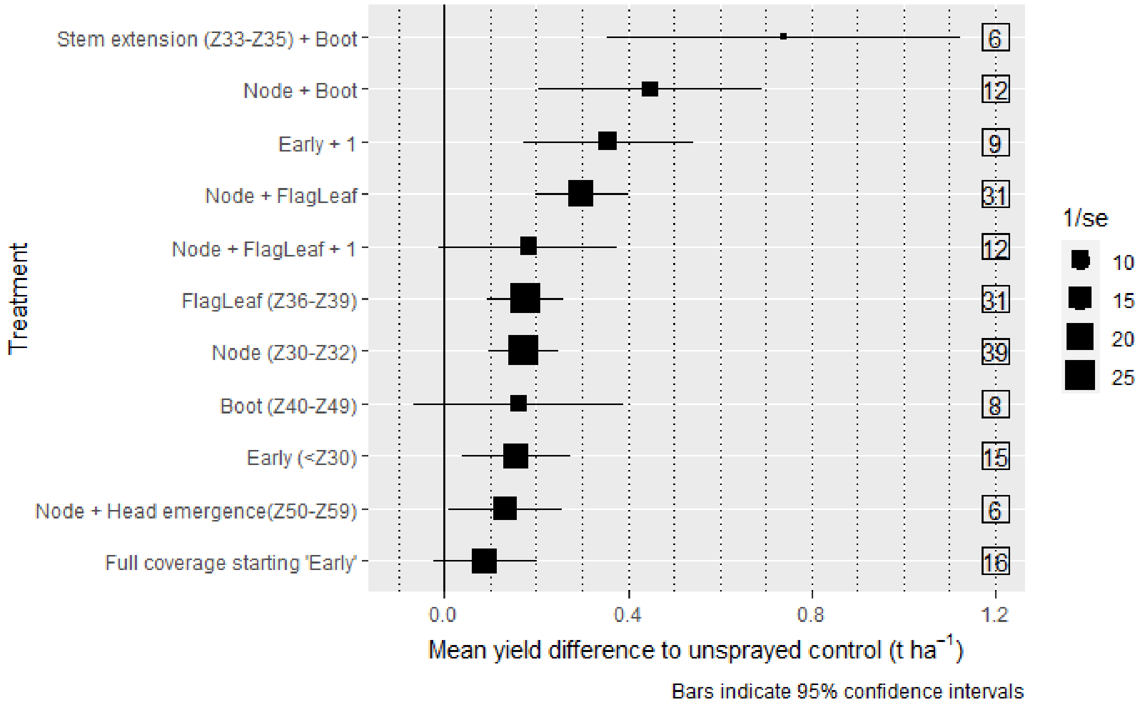

Figure 2. Meta-analysis estimates of mean difference compared to unsprayed (no fungicide) control. Bars indicate 95% confidence intervals. Numbers in the boxes indicate the number of trials of each respective treatment included in the meta-analysis, 1/se is the inverse of the standard error graphed as the size of the point, the smaller the point the larger the uncertainty in the estimation. Treatment labels with '+ 1' indicates an additional fungicide application at a non-specific plant stage;

Seed treatment

Seed dressing Fluxapyroxad was estimated to significantly protect an average of 0.284 t/ha barley yield (*P*<0.001). Growers should also consider fungicide resistance and the risk of other fungal diseases, such as smut, rhizoctonia and pythium, when considering the appropriate seed dressing.

Yield threshold and disease pressure

The yield threshold meta-analysis (results not shown) indicated, that on average across all regions, fungicide intervention did not result in significant yield protection when the crop yielded below 3.43 t/ha. As yields increased the average yield protected would also increase at the rate of 71Kg/ha for each tonne of potential yield. Actual yield thresholds for intervention may vary depending on regional conditions (i.e. disease pressure, local weather and site yield potential). For example, trials within the Albany agro-ecological zone seem to show a lower yield threshold for intervention (approx. 2.5 t/ha) compared with Esperance (approx. 3.5 t/ha) (Figure 3).

While the meta-analysis was unable to accurately define the specific interactive effects of fungicide timing, rainfall and disease pressure, the significant interaction between fungicide timing and individual trial likely includes the of role each of these factors. More specifically, agronomic factors, time of disease onset and the speed in which it can spread through multiple infection cycles will vary between location and season. Therefore, depending on individual circumstances, some fungicide strategies may provide greater yield protection than others.

The meta-analysis which included 'disease pressure' did not return any association between the amount of disease at Z50 in the unsprayed control (trial disease pressure) and losses in crop yield, when compared to treatments with fungicide sprays. This might be masked by the effect of high rainfall driving increased yields in combination with fostering disease pressure.

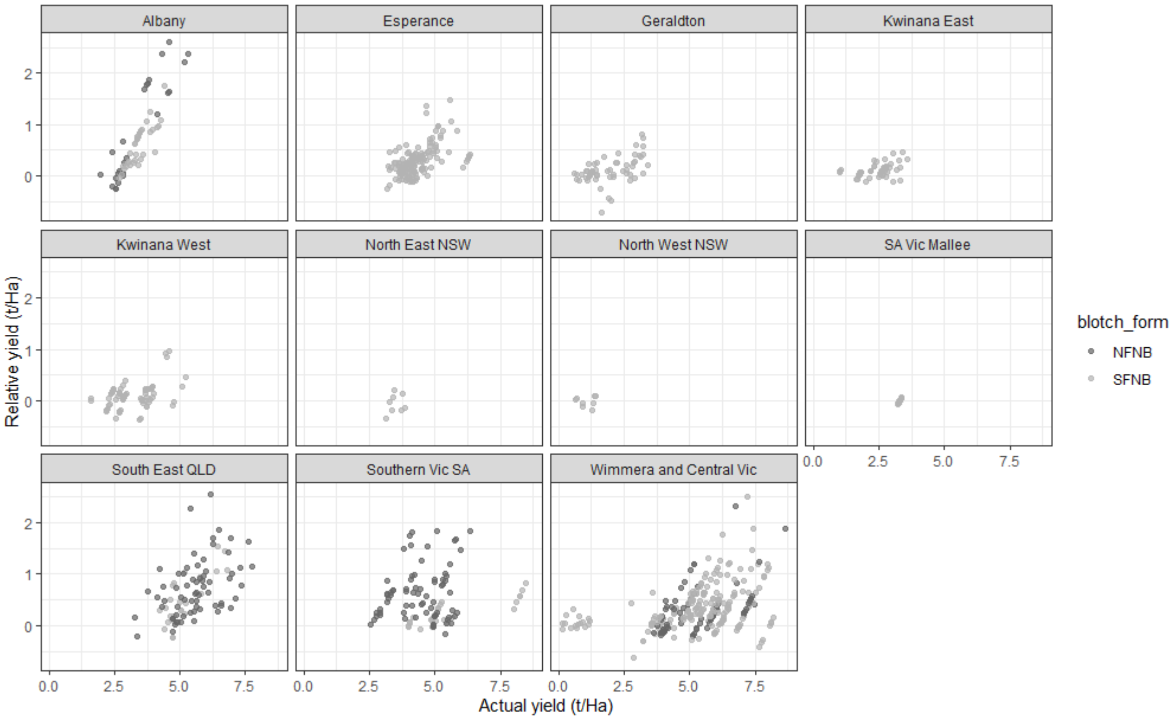

Figure 3. Relative yield (i.e. mean treatment yield - unsprayed control yield, or yield protected relative to the unsprayed control) plotted against the actual mean treatment yields. These plots illustrate potential yield thresholds for fungicide intervention. Different shaded points were used to indicate the targeted net-blotch form for each trial, NFNB and SFNB.

Conclusion

Overall, these meta-analyses support previous research on the yield impacts of net-blotch (McLean and Hollaway 2019; McLean *et al.,* 2022; Jayasena *et al.,* 2007). Treatment regimes incorporating two foliar fungicides were the most effective at protecting barley yield from net-blotch. Applications at around Stem extension (Z35) and early booting (Z40 – Z50) achieved the highest yield protection. The results show that shifting a two-spray program slightly earlier or later in one or both applications, was likely to be less but still effective at protecting barley yields. Fungicide applications made 'early' (<Z30) were the least effective at protecting yield, this might be due to the effect of incorporating a seed treatment reducing the need for early applied foliar fungicides to suppress disease pressure. In most years, delaying the first fungicide application to late stem elongation (Z35–Z39) would result in greater yield benefits than spraying earlier. Applications made following stem elongation would likely protect disease infection on the upper canopy, which is important for grain production. Fungicide applications after head emergence (Z50), on average, were capable of protecting some yield but only if the crop was not already protected with one or two fungicide applications already.

Considering this, these results also reveal greater flexibility in fungicide application timing than individual experiments, and that management actions can benefit from considering local climate and conditions. Fungicide resistance in net-blotch populations will also impact the response to fungicide programs. Net-blotch is recognised as being at high risk of developing fungicide resistance, particularly to group 7 (SDHIs). Avoiding unnecessary sprays, which don't provide an economic benefit, and rotating active ingredients can lower the risk of resistance developing https://afren.com.au/understanding/.

Despite the significance of some of these findings, uncertainty remains in some of the treatments which were not represented by the same number of trials as other treatments. Additionally, some agro-ecological zones contained a greater number of trials than others (Figure 3). While a network meta-analysis does provide flexibility to compare treatments which did not co-occur in the same trial (Madden *et al.,* 2016), the inference certainty is much lower if a treatment is not represented evenly among many of the trials. More field trial data from future research, such as GRDC investment DAQ2304-008RTX (Integrated management strategies for NFNB in low, medium, and high rainfall zones), will help refine and improve the confidence of this meta-analysis and resulting management recommendation.

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Cereal rust update 2024

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Keywords

wheat stripe rust (WYR), wheat leaf rust (WLR), barley leaf rust (BLR), barley grass stripe rust (BGYR), pathotypes and fungicide insensitivity

GRDC code

UOS2207-002RTX (9178966)

Take-home message

Vigilance and preparedness

- Timely detection remains crucial to combat rust threats from escalating.
- Destroying the green bridge is essential to prevent rust survival between cropping cycles.
- Proactive monitoring of vulnerable varieties and adjacent weedy grasses, and promptly respond by sending samples to the University of Sydney for pathotype analysis.

Collaboration for solutions

- Collaboration among researchers, farmers, breeders, and advisors is critical.

Integrated management is key

- Holistic strategies, encompassing resistant varieties and strategic fungicide application especially for fungicide insensitive pathogen isolates, are fundamental for comprehensive rust control and minimizing losses.

Resilience through diversification

- Continuous backing for breeding programs to introduce diverse resistance traits in cereal varieties is paramount.
- Diversifying resistance genes is essential to counter evolving rust pathotypes effectively.

Introduction

The University of Sydney's Plant Breeding Institute conducts a nationwide cereal rust survey and surveillance program, supported by GRDC (UOS2207-002RTX (9178966). This comprehensive initiative focuses on early detection of pathotypes by analysing cereal rust samples received from stakeholders, including farmers, advisors, and breeders. Working with state-based cereal pathologists, agronomists and other stakeholders, the Australian Cereal Rust Control Program monitors the occurrence and identity rust pathotypes in Australian cereal crops as an early warning scheme. The primary goal aims to enable risk management for the industry and guide breeding (Cereal Rust Report vol 20 Issue 3) and chemical decision interventions.

Wheat stripe rust

In 2023, wheat stripe rust (WYR) was detected as early as 7th July 2023, subsequent reports followed from Bethungra NSW (14th July), Tubbul NSW (20th July), Smeaton Victoria (20th July), Naracoorte SA

(24th July), and Cressy/Longford Tasmania (26th July). Out of 309 cereal rust samples received, 215 samples were WYR. Four predominant pathotypes were detected this year, which were all detected in previous seasons: 198 E16 A+ J+ T+ 17+; 238 E191 A- J+ T+ 17+; 238 E191 A+ 17+33+; 239 E237 A- 17+ 33+. The dominance of the '239' pathotype, particularly in southern regions (Victoria, South Australia, and Tasmania), has persisted throughout the year. Below is the summary of each pathotypes detected this year with distribution and frequencies from 2016 to 2023 detailed in Figures 1.

Pt. 198 E16 A- J+ T+ 17+ has decreased in frequency each year since 2020, only being detected in SA and NSW this year. It continues to impact vulnerable varieties such as Borlaug 100⏀, DS Bennett⏀, Illabo⏀, LRPB Trojan⏀ , and Wedgetail⏀ .

Pt. 238 E191 A+ 17+ 33+, first detected in 2021, was again common in 2023, being isolated mostly from New South Wales and Queensland.

Pt. 238 E191 A- J+ T+ 17+, the *Yr25*-virulent derivative pathotype initially identified in 2022, was present at lower levels compared to the other three pathotypes in 2023. Nevertheless, its presence remains noteworthy for gaining insights into the dynamics of pathotype evolution.

In 2023, Pt. 239 E237 A- 17+ 33+ emerged as the dominant pathotype across eastern Australia, notably prevalent in the southern regions of Victoria, South Australia, and Tasmania. The observed dominance is likely associated with regional variations in wheat varieties, indicating that certain varieties are susceptible to specific pathotype groups. This pathotype poses a significant threat to wheat varieties, such as Catapult⏀, Devil⏀, Rockstar⏀, Scepter⏀, and Vixen⏀. The frequent detection of this pathotype underscores the vulnerability of specific wheat varieties, emphasizing the critical importance of ongoing rust resistance breeding to effectively counter the threat posed by these pathotypes.

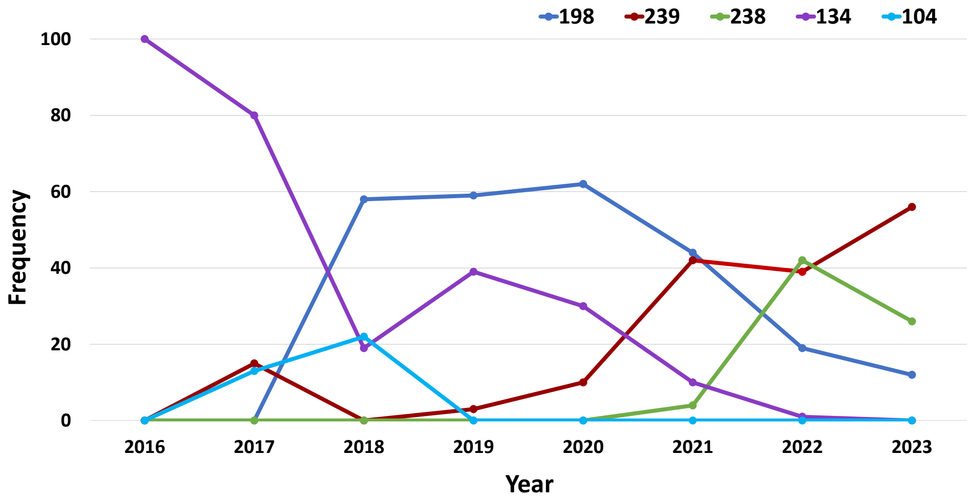


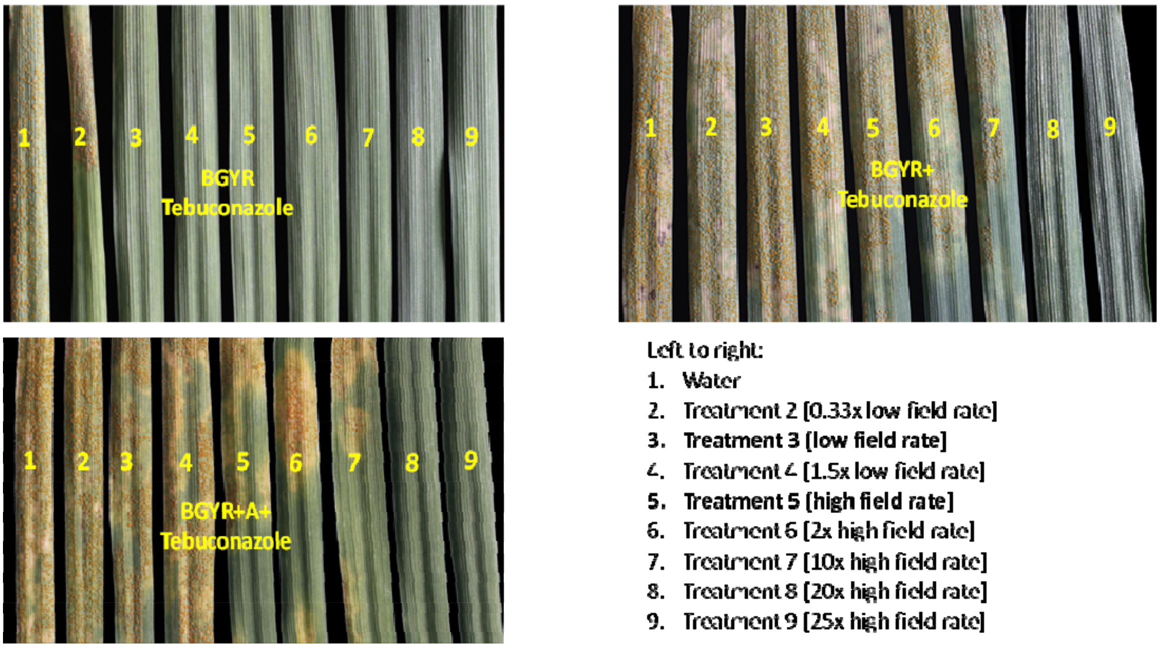
Figure 1. Frequency (%) of the five different pathotype groups of the wheat stripe rust pathogen in eastern Australia, 2016 through 2023

Barley grass stripe rust (BGYR)

Stripe rust, a fungal disease caused by *puccinia striiformis*, exhibits specialised variants for different crops. *Puccinia striiformis* f. sp. *tritici* (WYR) infects wheat and has been prevalent in Australian wheat crops since 1979. Another variant, *puccinia striiformis* f. sp. *hordei* (BYR), which is still not found in Australia, poses a significant threat to barley. A third form of p. *striiformis*, first detected in Australia in 1998, is colloquially known as BGYR (barley grass stripe [yellow] rust) and predominantly affects wild barley grass weed species such as *hordeum glaucum* and *hordeum leporinum*. Through whole genome sequencing, it has been determined that BGYR also exists in North America, infecting triticale and *agropyron cristatum* grass.

The emergence of the BGYR+ variant in 2021, showing increased virulence on barley, is a potential concern for the Australian barley industry. Greenhouse and field testing has raised significant concerns about the vulnerability of several current barley varieties, which should be monitored closely: Capstan⦶, Charger⦶, Empress, Explorer, Fandanga, Fathom⦶, Finniss, Granger⦶, Laperouse ⦶, Maritime⦶, Moby, Neo⦶, RGT Planet⦶, Scope CL Plus⦶, Shepherd⦶ and Spinnaker⦶. BGYR+ has been notably severe on weedy barley grass, leading to substantial natural infections in nurseries at Horsham and Wagga in 2023, prompting worries about the potential spread from weedy barley grass.

In 2022, a significant shift in virulence for the BGYR+ pathotype occurred, with a variant assigned 'BGYR+ A+' gaining virulence for a resistance gene in the Avocet wheat variety. Additionally, recent fungicide insensitivity tests on 2022 surveyed samples found that the BGYR+ detected in 2021 and the mutant pathotype BGYR+ A+ in 2022 from New South Wales displayed insensitivity to fungicides. Despite the absence of registered fungicides specifically for BGYR control, it is concerning that none of the four demethylation inhibitor (DMI) fungicides tested (i.e. tebuconazole, prothioconazole, propiconazole, and triadimenol) were effective at the recommended high field rates of fungicides for other diseases against the two BGYR fungicide insensitive pathotypes (Figure 2.). While BGYR variants in barley crops have not caused yield losses, the consistent detection at low levels in certain barley crops over the past three seasons raises concerns on potential further changes in virulence. PBI is conducting further research to understand their effects and implications.



Left to right:
1. Water
2. Treatment 2 [0.33x low field rate]
3. Treatment 3 (low field rate]
4. Treatment 4 [1.5x low field rate]
5. Treatment 5 (high field rate]
6. Treatment 6 [2x high field rate]
7. Treatment 7 [10x high field rate]
8. Treatment 8 [20x high field rate]
9. Treatment 9 [25x high field rate]

Figure 2. Tebuconazole applications at different rates vs BGYR Isolates (BGYR, BGYR+ and BGYR+A+,), where treatment 3 and Treatment 5 are recommended low and high field rates respectively.

In 2023, significant BGYR+ natural infections occurred in fields that will survive in green bridges, such as barley grass, wheat, and barley regrowth, allowing rust to survive between cropping cycles. This can lead to higher initial rust inoculum, causing rapid disease development. To minimise the risks, barley grass, wheat, and barley regrowth should be destroyed before cropping season begins.

Barley leaf rust (BLR) pathotypes and fungicide insensitivity

The 2023 survey received 33 samples of leaf-rusted barley, revealing three identified pathotypes: 5457 P- (23 isolates), 5457 P+ (9 isolates), and 5656 P+ (4 isolates). All these pathotypes exhibit virulence for the resistance gene *Rph3*, which was initially deployed in Australia in the Yarra cultivar and is currently present in 20 barley cultivars. The detection of virulence for *Rph3* in 2009 has since become widespread in both eastern and western Australia. The 5457 P- and 5457 P+ pathotypes belong to a single clonal lineage of the Australian *puccinia hordei* population, initially detected in WA in 2001 and considered to have an exotic origin. This lineage has been dominant in Australian *P. hordei* populations, comprising 89% of all isolates pathotyped in 2023.

Research on fungicide insensitivity revealed that members of this lineage (5457 P- and 5457 P+) are insensitive to several DMI fungicides, raising concerns about the efficacy of these chemicals in controlling the identified rust pathotypes. The insensitive pathotype exhibited resistance to high field-rate concentrations of all seven DMIs (difenoconazole, epoxiconazole, propiconazole, tebuconazole, triadimenol, prothioconazole and Prosaro® (prothioconazole + tebuconazole)). Compound fungicides like Amistar® Xtra [DMI + QoI (quinone outside inhibitors); azoxystrobin + cyproconazole], Aviator® Xpro® a mixture of DMI + SDHI (succinate dehydrogenase inhibitors; prothioconazole + bixafen) and Radial® (DMI + QoI; azoxystrobin + epoxiconazole) effectively control the insensitive pathotype at high field rates with combined modes of action. Fungicide insensitivity is linked to copy number variation at the PhCYP51 locus, making it necessary to be cautious when using these chemicals due to their dynamic nature and adaptability to mixed modes of action.

Wheat leaf rust (WLR) pathotype and fungicide insensitivity

Out of 15 wheat leaf rust samples, 14 were identified as pt. 104-1,3,4,5,7,9,10,12 +*Lr37* pathotype, while one sample, from South Australia, was classified as pt. 76-1,3,5,7,9,10,12,13 +*Lr37*.

Lr27+31, a complementary ASR leaf rust resistance gene, has been used in Australian wheat breeding since Gatcher was released in 1969. The emergence of virulence for ASR leaf rust resistance genes *Lr13* and *Lr27+31* has led to increased susceptibility to leaf rust in many varieties, including CorackΦ, Emu RockΦ, and WyalkatchemΦ. Pathotype 104-1,3,4,6,7,8,10,12 +*Lr37* combines virulence for these genes, making varieties carrying one or more of these resistances more susceptible in eastern Australia and Western Australia.

The fungicide insensitivity research on the WLR pathotypes revealed that 93-3,4,7.10,12, identified in 2020, exhibited insensitivity to recommended high doses of nine fungicides. However, compound fungicides like Amistar Xtra and Radial both with DMI + QoI modes of action effectively control this insensitive pathotype at high field rates. However, caution is advised when deploying two fungicides extensively, as this can encourage mutations causing fungicide insensitivity for compound chemicals.

A brief overview: understanding fungicide resistance in cereal rust pathogens.

Barley leaf rust (BLR) fungicide-insensitive pathotypes

- The BLR fungicide-insensitive pathotypes trace their origins back to the 5453 P clonal lineage identified in Western Australia in 2001
- Prevalent across all Australian barley-growing regions, exhibiting increased insensitivity.
- Display resistance to all eight DMIs at high field-rate concentrations
- Compound fungicides like Amistar Xtra (DMI + QoI), Aviator Xpro (DMI + SDHI), and Radial (DMI + QoI) effectively control insensitivity at high field rates with combined modes of action.
- Caution advised in extensive use of compound fungicides due to the potential for fungal adaptation to mixed modes of action.

Wheat leaf rust pathotype 93-3,4,7,10,12

- The wheat leaf rust fungicide-insensitive pathotypes 93-3,4,7,10,12 was identified in 2020
- Shows insensitivity to recommended high rates of nine fungicides.
- Amistar Xtra (DMI + QoI) and Radial (DMI + QoI) effectively control this pathotype at high field rates but warrant careful application to avoid further resistance.

Barley grass stripe rust (BGYR) pathotype

- Displays insensitivity to all tested DMI fungicides (tebuconazole, prothioconazole, propiconazole, triadimenol) at recommended high field doses.
- Infects not only barley grasses but also specific wheat and barley lines, making management complex.

Recommendations for industry safeguarding fungicide insensitivity

- Immediate and continuous research on fungicide insensitivity is critical as it's anticipated to pose a significant challenge in the future.
- Collaborative efforts among researchers, farmers, advisors, breeders, and donors are crucial to manage and mitigate the impact of insensitive pathotypes.
- Grain growers are urged to judiciously use fungicides considering the dynamic nature of fungal pathogens and their ability to adapt to various fungicidal modes of action.

Useful resources

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

ACRCP cereal rust map
https://www.google.com/maps/d/edit?mid=1kkPNa0Pk8qn4w3Ac8OpwLpDitG1GM7c&usp=sharing

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**Kindly send freshly collected rust samples solely in paper envelopes to the Australian Cereal Rust Survey, University of Sydney, Reply Paid 88076, Narellan, NSW, 2567.

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Epidemiology and management of sclerotinia stem rot of canola in 2024

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Key words

Sclerotinia stem rot, canola, foliar fungicides

GRDC code

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Take home message

- 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 disease epidemics
- Outbreaks of sclerotinia stem rot were restricted in spring of 2023 due to warm, dry conditions
- The sclerotinia outbreaks in 2022 will continue to have a legacy effect for following broadleaf crops as the sclerotia can survive in soil for many years
- The frequency of canola or lupin in a paddock is very important in determining the risk of a sclerotinia outbreak, as both 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 off the main stem) for main stem protection.

Where did sclerotinia stem rot develop in 2023

In contrast to the extraordinary rainfall conditions across central and southern NSW in spring 2022 that favoured the development of sclerotinia stem rot in canola, dry conditions in late winter and spring 2023 greatly restricted disease severity. Warm, dry growing conditions across central NSW did not favour moisture retention within the crop canopy that is necessary for the disease to develop. In southern NSW more frequent rainfall events and larger crops drove sclerotinia development, but disease progress was halted with hot temperatures in mid-late September. Surveys of commercial canola crops in central and southern NSW found the disease to be present in 42% of crops assessed, indicating the widespread presence of the pathogen across the region in 2023.

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 quickly prevent development of the disease, hence even if flower petals are infected, dry conditions during petal fall will prevent stem infection development. Temperature will determine how quickly infections develop, with infections by Sclerotinia capable of occurring between 5°C and 25°C.

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 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 widespread epidemics of the disease.

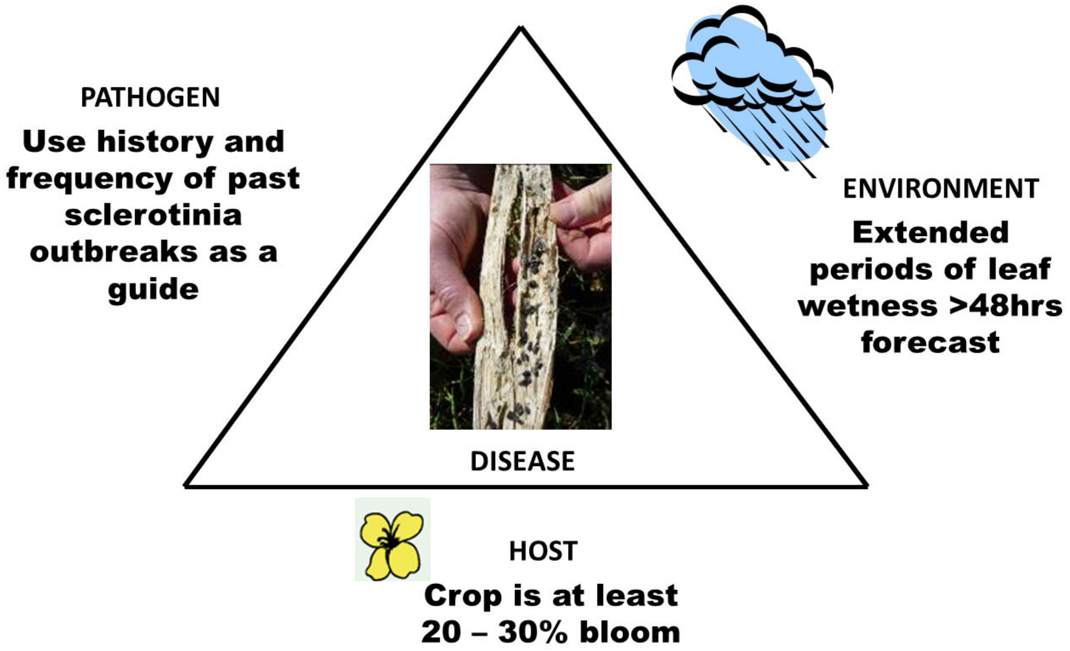

Figure 1. Factors that drive the development of sclerotinia stem rot

Pre-sowing sclerotinia management

Crop rotation

- Rotate canola 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 from 100m to 400m of apothecia (fruiting structures).

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.
- Early maturing varieties sown early can be prone to developing stem infection due to the earlier commencement of flowering when conditions are more likely to be wet for prolonged periods

Crop management

- Always follow the recommended sowing time and seeding rate for your region
- Once flowering starts, the crop becomes susceptible to infection and prolonged exposure to infected 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 stubbles 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 and/or cropping system.

In-crop sclerotinia management – fungicides

- Use foliar fungicides to prevent early stem infection via infected 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 foliar fungicide at 20–30% bloom stage is most effective in reducing main stem infection. Yield loss can be significantly reduced by protecting early petals from infection, and the penetration of fungicide into the crop canopy to protect potential infection sites where petals lodge.

- Multiple foliar fungicide applications may be needed in high disease risk districts to protect 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 will 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
- Be aware of the protection period provided by the foliar fungicide being applied. The current effective protection period offered by registered products ranges from 2 to 5 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 late infections.
- Foliar fungicides will 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 for 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/nsw-winter-crop-variety-sowing-guide-2023

SclerotiniaCM App for iPad and android tablets. Available from https://grdc.com.au/resources-and-publications/apps

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Sclerotinia in canola - How well did the Sclerotinia CM App predict fungicide responses in central western NSW trials in recent wet seasons and were there common reasons for outliers?

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Notes

Early risers: Risks and rewards of running higher N budgets

Notes

Concurrent session - Crown rot

Strategies for managing fusarium crown rot: new data from central NSW in 2023

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Keywords

yield loss, fungicide seed treatment, Victrato®, wheat variety, integrated disease management

GRDC code

DPI2207-004RTX: Integrated management of Fusarium crown rot in Northern and Southern Regions

Take home message

- In the presence of high levels of Fusarium crown rot (FCR) infection wheat variety choice provided a yield benefit of up to 25% to 118% and barley variety choice of up to 102% to 165% in 2023
- Victrato® (registration pending) application provided a 25% to 49% yield benefit in the presence of added FCR at only two of the three sites in 2023 but did not fully reduce yield loss from this disease
- The application of Victrato to more intolerant wheat varieties was equivalent to the yield achieved by sowing a variety more tolerant to FCR without the application of Victrato,
- Victrato should be used in combination with improved varietal tolerance and other integrated disease management strategies to minimise yield loss from FCR.

Introduction

Fusarium crown rot (CR), caused predominantly by the fungus *Fusarium pseudograminearum* (*Fp*), remains a major constraint to winter cereal production in the northern grain region. Cereal varieties differ in their resistance and tolerance to FCR, which can have a significant effect on their relative yield in the presence of this disease. Three fungicide seed treatments have been registered for the suppression of FCR in recent years with a further product Victrato® from Syngenta likely to be available to Australian growers in 2024. Victrato will be registered for the control of FCR with independent data showing this product to have stronger activity against FCR than currently registered products (Simpfendorfer 2022). Growers and advisors are therefore interested in obtaining local data as to where this new product may fit within current integrated disease management (IDM) strategies.

Three replicated field experiments were conducted in 2023 to examine the impact of FCR on yield and quality of cereal varieties along with the role of Victrato in limiting loss in one intolerant bread wheat variety.

Field experiments in 2023

Table 1. Site details

Location	Sowing	Harvest	Crop 2022	Crop 2021	Crop 2020
Coonamble	30 May 2023	8 Nov 2023	Faba bean	Wheat	Wheat
Nyngan	2 Jun 2023	23 Nov 2023	Lupin	Wheat	Canola
Wellington	1 Jun 2023	15 Nov 2023	Pasture	Pasture	Pasture

Table 2. Rainfall data (mm) – farm records Coonamble and Wellington, nearest BOM at Nyngan

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Coonamble	9.0	14.0	18.0	20.0	12.0	18.0	15.0	3.0	7.0	32.0	141.0	0.0
Nyngan	40.8	2.4	52.0	23.4	1.0	45.8	33.6	2.6	0.0	8.0	69.6	0.0
Wellington	26.0	20.0	27.0	36.0	0.0	34.0	35.0	0.0	0.0	28.0	88.0	20.5

Treatments

Cereal varieties evaluated at each site had some variation but mainly consisted of bread wheats. Two durum varieties were also examined at Coonamble (Table 3). Four barley varieties were sown as part of the experiment at both Nyngan and Wellington (Table 4 and 5). The sowing rate of each variety was adjusted to target 100 plants/m^2 based on seed size (1000 grain weight) and percentage germination and treated with Vibrance® (180 mL/100 kg seed) to protect against establishment diseases.

A single bread wheat variety known to be more intolerant to FCR was additionally treated with Victrato at two different rates, either 200 mL/100 kg seed or 400 mL/100 kg seed at each site. The variety was LRPB Reliantᶲ at Coonamble and LRPB Flankerᶲ at Nyngan and Wellington.

Each variety then had added or no added FCR at sowing using sterilised wheat grain colonised by at least five different isolates of *Fp* at a rate of 2.0 g/m of row. This process provides uniform and high (>70%) FCR infection in inoculated plots to allow comparison with lower background FCR infection levels in the no added FCR treatment.

All field experiments had a complete randomised block design with three replicates of each treatment combination. Establishment, yield, grain quality and Fusarium crown rot incidence and severity at harvest were measured.

What did we find?

Coonamble 2023

In the no added FCR treatment, yield ranged from 2.80 t/ha in the durum variety DBA Auroraᶲ up to 3.31 t/ha in the bread wheat variety LRPB Mustangᶲ (Table 3).

Dry conditions during the flowering and grain-fill period (August to October) with a total of only 42.0 mm of rainfall (Table 2) were conducive to expression and yield loss from FCR infection. All varieties suffered significant yield loss under high levels of FCR infection (added FCR), ranging from 12% in bread wheat variety LRPB Lancerᶲ (0.35 t/ha) up to 46% in durum variety Caparoiᶲ (1.35 t/ha; Table 3). In the presence of added FCR there was a 25% (0.53 t/ha) yield difference between the best (LRPB Lancerᶲ) and worst (LRPB Reliantᶲ) bread wheat variety.

Table 3. Yield of durum and bread wheat varieties with no added and added fusarium crown rot (FCR) – Coonamble 2023

Crop	Variety	Yield (t/ha)				Yield loss (%)
		No added FCR		Added FCR		
Durum	DBA Auroraⓓ	2.80	d	1.91	i	32
	Caparoiⓓ	2.91	cd	1.56	j	46
Bread wheat	LRPB Lancerⓓ	2.95	cd	2.60	e	12
	LRPB Reliant ⓓ + Victrato® 400 mL	2.94	cd	2.60	e	12
	Sunmasterⓓ	3.23	ab	2.54	ef	21
	LRPB Reliantⓓ + Victrato® 200 mL	2.99	cd	2.49	ef	17
	LRPB Mustangⓓ	3.31	a	2.46	ef	26
	LRPB Stealthⓓ	3.07	bc	2.35	fg	24
	LRPB Raiderⓓ	2.89	cd	2.24	gh	22
	LRPB Hellfireⓓ	2.91	d	2.20	gh	24
	Suntopⓓ	2.85	d	2.14	i	25
	LRPB Reliantⓓ	2.83	d	2.08	j	27
	Site mean	**2.97**		**2.26**		
	CV (%)	**4.5**				
	***P* value**	**<0.001**				

In the no added FCR treatment, the application of Victrato to LRPB Reliantⓓ seed did not significantly increase yield over the control (Table 3). This indicates minimal background FCR infection at this site with a faba bean break crop being grown in the previous season (Table 1).

In the added FCR treatment, Victrato reduced the extent of yield loss from 27% down to 17% at the 200 mL application rate and 12% at the higher 400 mL rate (Table 3). Victrato provided a significant yield benefit of 0.41 t/ha (+20%) at the 200 mL rate and 0.52 t/ha (25%) at the 400 mL rate compared with the control LRPB Reliantⓓ treatment but the difference between the two Victrato rates was not statistically significant (Table 3). However, the yield benefit of applying Victrato under high disease pressure (added FCR) in the more intolerant variety LRPB Reliantⓓ was equivalent to the yield achieved by sowing other more tolerant varieties in the absence of Victrato at this site (Table 3).

Nyngan 2023

In the no added FCR treatment, yield ranged from 0.79 t/ha in LRPB Raiderⓓ up to 1.42 t/ha in the barley variety Spartacus CLⓓ at this low yielding site in 2023 (Table 4).

Dry conditions during the flowering and grain-fill period (August to October) with a total of only 10.6 mm of rainfall (Table 2) were conducive to expression and yield loss from FCR infection. Except for LRPB Hellfireⓓ, all varieties suffered significant yield loss under high levels of FCR infection (added FCR), ranging from 18% in Scepterⓓ (0.21 t/ha) up to 53% in the barley variety RGT Planetⓓ (0.43 t/ha; Table 4). In the presence of added FCR there was a 53% (0.31 t/ha) yield difference between the best (Scepterⓓ) and worst (LRPB Lancerⓓ) bread wheat and 165% (0.64 t/ha) between the best (Spartacus CLⓓ) and worst (RGT Planetⓓ) barley variety.

Table 4. Yield of barley and bread wheat varieties with no added and added fusarium crown rot (FCR) – Nyngan 2023

		Yield (t/ha)		Yield loss
Crop	**Variety**	**No added FCR**	**Added FCR**	**(%)**
Barley	Spartacus CLⅆ	1.42 a	1.02 efg	28
	Maximus CLⅆ	1.22 b	0.99 efgh	19
	Compassⅆ	1.22 b	0.96 fghij	21
	RGT Planetⅆ	0.81 klmn	0.38 q	53
Bread wheat	Scepterⅆ	1.13 bcde	0.92 ghijkl	18
	LRPB Flankerⅆ + Victrato® 400 mL	0.94 fghijk	0.87 hijklm	8
	LRPB Mustangⅆ	1.20 bc	0.87 hijklm	28
	Sunmasterⅆ	1.07 cdef	0.86 hijklmn	20
	LRPB Hellfireⅆ	0.97 fghi	0.85 ijklmn	13
	LRPB Flankerⅆ + Victrato® 200 mL	0.92 ghijkl	0.82 jklmn	11
	Sunchaserⅆ	1.04 defg	0.76 mno	27
	LRPB Flankerⅆ	0.95 fghijk	0.73 mnop	23
	LRPB Reliantⅆ	1.16 bcd	0.73 nop	38
	LRPB Raiderⅆ	0.79 lmn	0.63 op	20
	LRPB Stealthⅆ	0.86 hijklmn	0.61 p	29
	LRPB Lancerⅆ	0.83 ijklmn	0.61 p	27
	Site mean	**1.03**	**0.79**	
	CV (%)	**9.4**		
	***P* value**	**0.007**		

In the no added FCR treatment, the application of Victrato to LRPB Reliantⅆ seed did not significantly increase yield over the control (Table 4). This indicates minimal background FCR infection at this site with a lupin break crop being grown in the previous season (Table 1).

In the added FCR treatment, Victrato provided only a slight yield increase in LRPB Flankerⅆ which was not significant at this site (Table 4).

Wellington 2023

In the no added FCR treatment, yield ranged from 1.49 t/ha in the barley variety RGT Planetⅆ up to 2.51 t/ha in the barley variety Maximus CLⅆ at this site in 2023 (Table 5).

Dry conditions during the flowering and grain-fill period (August to October) with a total of only 28.0 mm of rainfall (Table 2) were conducive to expression and yield loss from FCR infection. All varieties suffered significant yield loss under high levels of FCR infection (added FCR), ranging from 13% in the barley variety Spartacus CLⅆ (0.32 t/ha) up to 55% in LRPB Flankerⅆ (1.10 t/ha; Table 5). In the presence of added FCR there was a 118% (1.08 t/ha) yield difference between the best (Scepterⅆ) and worst (LRPB Flankerⅆ) bread wheat and 102% (1.09 t/ha) between the best (Spartacus CLⅆ) and worst (RGT Planetⅆ) barley variety (Table 5).

Table 5. Yield of barley and bread wheat varieties with no added and added fusarium crown rot (FCR) – Wellington 2023

Crop	Variety	Yield (t/ha)				Yield loss (%)
		No added FCR		Added FCR		
Barley	Spartacus CLⓓ	2.47	a	2.15	bcd	13
	Maximus CLⓓ	2.51	a	2.13	cde	15
	Compassⓓ	2.47	a	1.92	efg	22
	RGT Planetⓓ	1.49	jkl	1.06	mn	28
Bread wheat	Scepterⓓ	2.36	ab	2.00	def	16
	Beckom	2.32	abc	1.63	hij	30
	LRPB Stealthⓓ	1.93	efg	1.57	ijk	19
	LRPB Hellfireⓓ	2.04	de	1.55	ijk	24
	Sunmasterⓓ	2.06	de	1.42	jkl	31
	LRPB Lancer	1.80	fgh	1.40	kl	22
	LRPB Flankerⓓ + Victrato® 400 mL	2.13	cde	1.37	kl	36
	LRPB Mustangⓓ	2.17	bcd	1.27	lm	41
	LRPB Raiderⓓ	2.05	de	1.06	mn	48
	LRPB Flankerⓓ + Victrato® 200 mL	1.97	def	1.04	n	47
	Sunchaserⓓ	1.73	ghi	1.02	n	41
	LRPB Flankerⓓ	2.02	de	0.92	n	55
	Site mean	**2.10**		**1.47**		
	CV (%)	**7.5**				
	***P* value**	**<0.001**				

In the no added FCR treatment, the application of Victrato to LRPB Flankerⓓ seed did not significantly increase yield over the control (Table 5). This indicates minimal background FCR infection at this site with a legume pasture being grown in the previous three seasons (Table 1).

In the added FCR treatment, Victrato reduced the extent of yield loss from 55% down to 36% only at the higher 400 mL rate (Table 5). Victrato provided a significant yield benefit of 0.45 t/ha (+49%) only at the 400 mL rate compared with the control LRPB Flankerⓓ treatment (Table 5). However, the yield benefit of applying Victrato under high disease pressure (added FCR) in the more intolerant variety LRPB Flankerⓓ was equivalent to the yield achieved by sowing other more tolerant varieties in the absence of Victrato. The yield benefit provided by Victrato at the 400 mL rate on LRPB Flankerⓓ was still lower than the yield achieved by sowing either Scepterⓓ or Beckomⓓ without Victrato at this site in 2023 (Table 5).

Grain quality and pathology

This data was not available at the time or writing this report.

Conclusions 2023

Individual wheat varieties differed in their performance in the presence of FCR infection with variety choice providing a yield benefit of up to 25% at Coonamble, 53% at Nyngan and 118% at Wellington in 2023. This difference was also evident in the two sites with barley entries with 102% yield benefit at Wellington and 165% at Nyngan between the best and worst barley variety in the presence of high FCR infection levels. Victrato application to more FCR intolerant wheat varieties provided mixed results across the three trials in a relatively dry season. Victrato provided a 20% to 25% yield benefit in the presence of added FCR at Coonamble with both application rates, a 49% yield benefit at Wellington only at the 400 mL rate and no significant benefit at either application rate at Nyngan. This is consistent with our previous studies that have highlighted the reduced efficacy of fungicide seed treatments in seasons with limited in-crop rainfall (Simpfendorfer 2022). The application of Victrato to more intolerant wheat varieties was equivalent to the yield achieved by sowing a variety more tolerant to FCR without the application of Victrato at all sites. Hence, Victrato should be used in combination with improved varietal tolerance and other IDM strategies to minimise yield loss from FCR within central NSW cropping systems.

Integrated management of FCR

To manage the risk of yield losses in cereals, firstly identify the risk of Fusarium crown rot in each paddock. High-risk paddocks generally include durum, bread wheat or barley crops being sown into a paddock with a history of stubble retention and tight cereal rotations (including oats). Other considerations include:

- Use effective weed management to reduce grass weed hosts in-crop and fallow situations which serve as alternate hosts for the FCR fungus.
- Remember the larger the grass weed when controlled the longer that residue serves as a potential inoculum source
- Given the recent Fusarium head blight epidemic in 2022, ensure that you are sowing seed free of Fusarium infection as infected seed introduces FCR infection into paddocks.

All other management options are implemented prior to sowing so knowing the risk level within paddocks is important. This can be quantified through PreDicta® B testing (SARDI) or stubble testing (NSW DPI).

If medium to high FCR risk, then:

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

If still considering sowing a winter cereal:

- Consider stubble management options in terms of both impacts on FCR inoculum but also fallow soil moisture storage.
    a. ***Cultivation*** accelerates stubble decomposition which can decrease FCR risk (as the causal pathogen is stubble-borne) BUT it takes moisture and time. Cultivation also increases the spread of Fusarium crown rot inoculum across a paddock in the short term and increases exposure of below ground infection points (coleoptile, crown and sub-crown internode) in cereal plants to contact with stubble fragments infected with the FCR fungus. Cultivation close to sowing therefore increases the incidence of plants which get infected with FCR. Cultivation can also significantly reduce soil moisture storage during fallow periods.
    b. ***Stubble baling*** removes a proportion of the above ground inoculum from a paddock potentially reducing FCR risk. The pathogen will then be concentrated in the shorter stubble butts and below ground in the previous rows. Hence, baling in combination with inter-row sowing is more likely to reduce FCR risk. Reduced ground cover after bailing and removal of cereal straw can reduce fallow efficiency.

c. ***Stubble burning*** destroys above ground inoculum but depends on the completeness of the burn. Burning has no effect on the survival of the FCR fungus below ground in crown tissue even with a hotter summer burn. Hence the pathogen will be concentrated below ground in the previous rows with survival between seasons dependent on the extent of summer rainfall. Burning of cereal stubble can considerably reduce fallow soil moisture storage so a 'late-Autumn' burn is preferable to an 'early-Summer' burn. Stubble burning in combination with inter-row sowing is more likely to reduce FCR risk.

d. ***Reducing cereal stubble height*** limits the length of stubble which the FCR fungus can vertically grow up during wet fallow periods restricting the overall inoculum load within a paddock. When relative humidity is >92.5% the FCR fungus can colonise vertically up retained standing cereal stubble in a process termed 'saprotrophic growth'. At 100% relative humidity this saprotrophic growth can occur at a maximum rate of 1 cm per day (Petronaitis *et al.* 2020). The FCR fungus can therefore saprotrophically grow to the cut height of the cereal stubble under prolonged or accumulated periods of rainfall. Consequently, harvesting and leaving retained cereal stubble longer (e.g. stripper fronts) leaves a greater length of stubble for subsequent potential saprotrophic growth of the FCR fungus. This is not a major issue in terms of FCR risk if the retained infected cereal stubble is left standing and kept intact. However, if the infected stubble is disturbed and redistributed across a paddock through grazing, mulching, cultivation or the subsequent sowing process then this can increase the incidence of FCR infection. Recent research in NSW has also demonstrated that increased cereal harvest height allowed saprotrophic growth of the FCR fungus above the harvest height of a following chickpea crop. This resulted in FCR infected cereal stubble being spread out the back of the header during the chickpea harvest process increasing FCR risk for the next cereal crop (Petronaitis *et al.* 2022). Consider matching cereal stubble height at or after harvest in paddocks planned for a following shorter status break crop such as chickpea or lentils to prevent redistribution of retained FCR infected cereal stubble during the break crop harvest process.

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

- Ensure nutrition is appropriate for the season. Excessive nitrogen will produce bulky crops that hastens moisture stress and makes the expression of FCR more severe. Whitehead expression can also be made more severe by zinc deficiency.
- Consider a seed fungicide treatment to suppress FCR. Fungicide seed treatments, including Victrato®, are not a stand-alone treatment and must be used as part of an integrated management approach.

References and further resources

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

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Implications of sowing Fusarium infected wheat seed in 2023

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Keywords

Fusarium head blight, Fusarium crown rot, yield, fungicide seed treatment

GRDC code

DPI2207-004RTX: Integrated management of Fusarium crown rot in Northern and Southern Regions

Take home messages

- Sowing wheat or durum seed with ≤5% Fusarium grain infection had limited impact on yield even when no fungicide seed treatment was applied
- Sowing seed with 7.5% to 10% Fusarium grain infection had an average yield penalty of 13% (range 4% to 23%) with no seed treatment but was largely eliminated by the application of the seed treatment
- Sowing seed with >10% Fusarium grain infection had an average yield penalty of 27% (range 17% to 40%) with no seed treatment which was nearly halved to an average yield loss of 15% (range 9% to 27%) with the application of the seed treatment
- Implications on the incidence and severity of Fusarium crown rot introduced through Fusarium infected grain should also be considered.

Introduction

The prevalence of fusarium head blight (FHB) across large areas of eastern Australia in 2022 was unprecedented with implications for seed retained from infected crops (Simpfendorfer and Baxter 2023). Fusarium grain infection reduces germination and vigour of seed retained for sowing along with causing seedling blight (death) in plants arising from infected grain. The fungus replaces the contents of infected seed with its own mycelium, so while seed treatments can help reduce the level of seedling blight, they cannot restore the quality of heavily infected seed sources. Sowing Fusarium infected seed also introduces fusarium crown rot (FCR) into paddocks. Sourcing quality seed for sowing created issues in some regions in 2023.

Based on north American experience the general advice if retaining seed for sowing is:

- <1% Fusarium grain infection = no issues
- 1% to 5% Fusarium grain infection = consider using seed treatment (e.g. full rate Vibrance® or EverGol® Energy) to limit seedling blight, and slightly increase sowing rate
- >5% Fusarium grain infection = source cleaner seed if possible.

The opportunity was taken to test the effect of varying levels of Fusarium grain infection on yield and FCR incidence under Australian conditions using grower retained seed lots from 2022 across the northern grain region.

Fusarium grain infection levels in 2022

A 'free' seed testing service was offered to growers to support them in determining Fusarium grain infection levels. In total 1,934 seed lots from the 2022 harvest were tested consisting of 1,595 bread wheat, 191 durum and 148 barley samples (Table 1). The biggest issue with Fusarium grain infection levels was in durum wheat, which is very susceptible to FCR and FHB, with 82% of 2022 seed lots having greater than the recommended 5% level of Fusarium infection. Fusarium grain infection levels were still a widespread issue in bread wheat and barley seed retained from 2022 with 33% of bread wheat and 26% of barley seed lots having greater than the recommended 5% level of infection (Table 1).

Table 1. *Fusarium* spp. grain infection levels in bread wheat, durum wheat and barley seed lots harvested across eastern Australia in 2022.

Region	Bread wheat			Durum wheat			Barley		
	<5%	>5%	Max	<5%	>5%	Max	<5%	>5%	Max
SE NSW	163	27	16%				3	1	6%
SW NSW	149	57	43%	12	47	71%	12	4	9%
CE NSW	147	76	37%	0	2	30%	18	4	49%
CW NSW	257	169	43%	0	2	45%	20	12	19%
NE NSW	88	99	42%	16	87	69%	28	12	34%
NW NSW	62	39	28%	1	16	68%	13	4	13%
Sth Qld	118	25	26%	0	1	23%	10	1	7%
Victoria	71	37	33%	1	1	35%	6	0	5%
South Aus	9	0	2%	5	0	2%			
Tasmania	2	0	1%						

Values are the number of grower seed lots with less than or greater than 5% Fusarium grain infection.
Max = maximum level of Fusarium grain infection (%) measured in each cereal crop type and region.

Levels of FHB infection and resulting Fusarium grain infection were prevalent across eastern Australia in 2022 but varied between regions. For example, in bread wheat the incidence of grain infection levels greater than 5% was most common in north-east NSW (53% of samples) followed by central-west NSW (40% of samples), north-west NSW (39% of samples), central-east NSW and Victoria (both 34% of samples) and south-west NSW (28% of samples). Fusarium grain infection levels in bread wheat greater than 5% were less prevalent in Qld (17% of samples) and south-east NSW (14% of samples) with the lowest level in South Australia and Tasmania (0% of samples; maximum 2% or 1% infection, respectively) from limited testing (9 and 2 samples, respectively) conducted from those states (Table 1).

What we did

Seven replicated small plot field experiments were conducted across the northern grain region in 2023 using locally sourced grower retained seed lots of a single variety. Seed lots (SL) were selected based on varying levels of Fusarium grain infection with SL1 lowest (0% to 1.7%), SL2 minor (3.3% to 5.0%), SL3 intermediate (7.5% to 10.0%) and SL4 highest (11.8% to 57.5%; Table 2). All sowing rates were adjusted to target 100 plants/m^2 based on seed size (1000 grain weight) and percentage germination. With each seed lot there were separate replicated plots sown comparing no seed treatment versus treatment with Vibrance (180 mL/100 kg seed) + Victrato® (400 mL/100 kg seed) (not currently registered for use within Australia). Field trials had a complete randomised block design with three replicates of each seed lot by seed treatment combination. Establishment, yield, grain quality and Fusarium crown rot incidence and severity were measured on all plots.

Table 2. Fusarium grain infection levels (%) in four local grower seed lots (SL) of different wheat or durum varieties tested at 7 locations in 2023. Note only three seed lots tested at Westmar.

		Seed lot			
Location	**Variety**	**SL1**	**SL2**	**SL3**	**SL4**
Westmar	LRPB Hellfireⓓ	0.3%	5.0%	-	18.8%
Walgett	LRPB Hellfireⓓ	1.7%	5.0%	9.5%	19.5%
Coonamble	LRPB Hellfireⓓ	1.0%	4.0%	7.5%	14.5%
Nyngan	LRPB Lancerⓓ	0.0%	4.0%	8.3%	29.0%
Wellington	Scepterⓓ	0.5%	3.0%	7.5%	11.8%
Lake Cargelligo	Scepterⓓ	0.5%	3.3%	9.5%	18.0%
Deniliquin	DBA Vittaroiⓓ	1.0%	4.0%	10.0%	57.5%

What did we find?

Plant establishment

Average plant establishment did not achieve the target plant population of 100 plants/m^2 except for Scepterⓓ SL4 at Wellington (103 plants/m^2). Average plant populations established across the local seed lots at each site were highest at Westmar and Wellington (88 plants/m^2), then Deniliquin (85 plants/m^2), Nyngan (84 plants/m^2), Coonamble (71 plants/m^2), Lake Cargelligo (70 plants/m^2) down to Walgett (66 plants/m^2). The interaction between seed lot and seed treatment was only significant with Vittaroiⓓ durum at Deniliquin. Seed lot 4 at this site had the highest Fusarium grain infection level (57.5%) of all tested which significantly reduced establishment in the absence of seed treatment (Table 3). However, in the presence of seed treatment this same seed lot had significantly higher establishment than the other three seed lots with lower Fusarium grain infection levels. This is potentially through the seed treatment reducing the level of seedling blight in this heavily infected seed lot. Except for this site, differences in plant establishment between treatments did not appear to have a major influence on yield outcomes which highlights the importance of adjusting sowing rates for germination and seed weight of individual seed lots.

Table 3. Effect of Vittaroiⓓ seed lot (SL) and seed treatment on plant establishment (plants/m^2) at Deniliquin in 2023.

	Minus seed treatment				Plus seed treatment			
Location	**SL1**	**SL2**	**SL3**	**SL4**	**SL1**	**SL2**	**SL3**	**SL4**
Deniliquin	81 b	93 b	78 b	55 c	83 b	91 b	85 b	114 a

Values followed by the same letter not significantly different at the 95% confidence level.

Yield

In the absence of seed treatment, the minor increase in Fusarium infection levels between SL1 (0% to 1.7%) and SL2 (3.3% to 5%) only reduced yield at Nyngan (11% yield loss; Table 4). A further increase in Fusarium infection level with SL3 (7.5 to 10.0%) reduced yield by between 4% (Wellington) to 23% (Nyngan) at 5 of 7 locations (except Coonamble where not significant and Westmar where no SL3 treatment) compared with the lowest levels in the SL1 treatment. The highest Fusarium infection levels in SL4 (11.8% to 57.5%) had an associated yield loss of between

17% (Westmar and Wellington) to 40% (Deniliquin) compared with the lowest Fusarium infection levels in SL1 in the absence of seed treatment (average 27% yield loss; Table 4).

Table 4. Yield (t/ha) of local grower seed lots of different wheat or durum varieties with varying levels of Fusarium grain infection at 7 locations in 2023 without and with fungicide seed treatment.

	Minus seed treatment				**Plus seed treatment**				
Location	**SL1**	**SL2**	**SL3**	**SL4**	**SL1**	**SL2**	**SL3**	**SL4**	**Con**
Westmar	2.94 a	3.03 a	-	2.45 c	2.97 a	3.05 a	-	2.65 b	96%
Walgett	1.75 a	1.73 a	1.48 b	1.26 c	1.76 a	1.72 a	1.74 a	1.50 b	90%
Coonamble	3.10 a	2.93 a	2.90 ab	2.23 c	3.04 a	3.09 a	2.96 a	2.72 b	99%
Nyngan	0.96 a	0.85 b	0.74 c	0.62 d	0.99 a	0.95 a	0.87 b	0.78 c	86%
Wellington	2.23 b	2.27 ab	2.13 c	1.85 d	2.34 a	2.28 ab	2.28 ab	2.07 c	82%
Lake Cargelligo	2.52 ab	2.56 ab	2.14 d	1.97 d	2.55 ab	2.61 a	2.40 bc	2.33 c	89%
Deniliquin	4.57 b	4.66 ab	4.16 c	2.73 e	4.70 ab	4.89 a	4.80 ab	3.45 d	97%

Values followed by the same letter not significantly different at the confidence (con) level at each location. Lettering only applies within individual locations.

When the seed treatment was applied, there was generally no yield difference between SL1, SL2 and SL3 treatments at each location (Table 4). Exceptions were at Nyngan where SL3 was 12% lower yielding than SL1 and 8% lower yielding than SL2, along with Lake Cargelligo where SL3 was 8% lower yielding than SL2 but equivalent to SL1. Application of the seed treatment reduced but did not eliminate the extent of yield loss between the lowest (SL1) and highest (SL4) Fusarium grain infection levels which ranged from 9% (Lake Cargelligo) to 27% (Deniliquin) with an average across locations of 15% (Table 4).

Grain quality and pathology

Unfortunately, this data was not available at the time of writing this report. However, visual inspection of some sites during grain filling had a noticeable increase in the incidence of whiteheads in SL4 plots especially in the absence of seed treatment. Pathology assessments to determine the incidence and severity of FCR in each plot are currently being conducted.

Summary

Sowing wheat or durum seed with low (<5%) Fusarium grain infection had limited impact on yield when no seed treatment was used and no impact when the seed treatment was applied. Sowing seed with moderate (7.5% to 10%) Fusarium grain infection had an average yield penalty of 13% at 5 of 6 locations (not present in Westmar trial) when no seed treatment was used and no impact at 5 of 6 locations when the seed treatment was applied. Sowing seed with high (11.8% to 57.5%) Fusarium grain infection had an average yield penalty of 27% in the absence of seed treatment which was roughly half at 15% when the seed treatment was applied.

Based on only yield, this data broadly supports current north American recommendations around sowing cereal seed with varying levels of Fusarium grain infection. This data indicates that growers may still be able to consider sowing cereal seed with 5 to 10% Fusarium grain infection if the seed treatment is used without negatively impacting on yield. However, this does not consider the potential introduction of FCR into paddocks and subsequent inoculum issues for following cereal crops.

This was not a fungicide seed treatment study and only examined one option known to have stronger Fusarium activity that was used for experimental purposes with Victrato® not currently registered for use within Australia. This does not indicate what activity may be achieved with other registered fungicide seed treatments or a lower rate of this unregistered product which is anticipated for commercial release in 2024.

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Increased wheat plant population: the interaction with variety, Fusarium crown rot and nitrogen

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Key words

Fusarium crown rot, *Fusarium pseudograminearum*, wheat, plant population, nitrogen, yield stability, variety, screenings

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Take home message

- Fusarium crown rot (FCR) pressure had a greater impact on wheat yield and quality than plant population or nitrogen (N) status under low to moderate yield conditions.
- The interaction of FCR pressure, N status and plant population varied depending upon variety.
- Beckomᶲ and LRPB Flankerᶲ outyielded LRPB Raiderᶲ and LRPB Lancerᶲ, but suffered greater yield loss from FCR. Despite this, under higher FCR pressure both Beckomᶲ and LRPB Flankerᶲ out yielded LRPB Lancerᶲ and LRPB Raiderᶲ.
- Higher plant populations either increased yield or had no impact at the three sites.
- Under higher FCR pressure in moderate yield environments of 3–4.5 t/ha, increasing plant populations appeared to reduce the impact of FCR.

Background

Growers are urged to use other weed control tactics besides herbicides to continue to farm sustainably in the future. One option is to increase crop competition against weeds. This reduces the ability of the weed to compete for limited resources like moisture and nutrients in the short term, but also benefits in the medium to longer term through reduced weed seed set.

Increasing crop competition can be achieved through crop choice, row spacing or plant populations. The first 2 options are restricted by several factors, such as crop suitability, growing environments and profitability, as well as the need to invest in new machinery and/or modification to change plant row spacings. However, changing plant populations is a relatively easy option achieved by simply adjusting sowing rates.

Many growers and advisors are concerned that increasing plant populations could lead to an increased risk of yield and grain quality instability, ultimately reducing crop profitability. This view is more common in the lower rainfall growing areas where relatively low plant populations are the norm. If growers were confident that increasing plant population did not carry the risk of reduced yield or poor grain quality, it would be an easy and relatively low-cost option in the battle against weeds and herbicide resistance.

In response, Grain Orana Alliance (GOA), with the support of the Grains Research and Development Corporation (GRDC), has for the past 4 years conducted a series of trials investigating the impact of wheat population on yield and quality in the low rainfall environments of the GOA region (central west NSW). It is clear from this data set of 10 trials (over 5 years; 2018, 2020-2023, and 15 varieties) that increasing plant population resulted in higher yield (**Figure**) with fewer screenings in the majority of cases. There were cases where yield was reduced and/or screenings increased, however the impact was less frequent and severe compared to the yield benefits of higher plant populations.

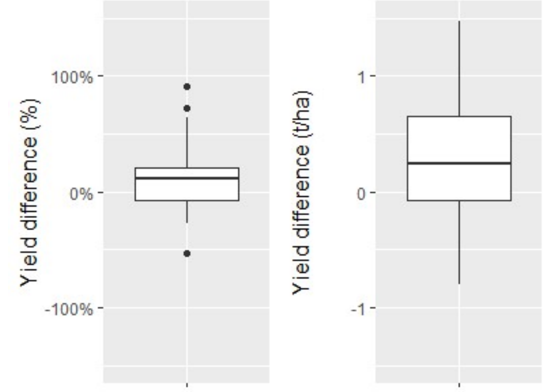


Figure 1. Yield difference % (left) and t/ha (right) moving from the lowest to the highest wheat population averaged across 5 trial years, 10 sites and 15 varieties.

It has been hypothesised that fusarium crown rot (FCR), may be contributing to a common commercial perception of higher plant populations having reduced yield and increased screenings. Previous trials were largely conducted in low FCR risk situations, such as following canola or pulse break crops, which may explain the differing outcomes. But for growers it is not always possible to sow into low disease risk paddocks.

FCR impacts the crown and lower stem bases of infected wheat plants reducing its ability to transport water which is most influential on yield and quality in hot and/or dry springs during seed set and grain filling. Growers and advisors in the region question whether increased plant population could further exacerbate stress during this period and hence further exacerbate the impact of FCR. In addition, will increasing nitrogen (N) rates exacerbate the yield impact of FCR through excessive moisture use before grain fill, leading to increased stress during grain filling.

In 2023 three collaborative trials, between NSW DPI, Brill Ag and GOA with the support of GRDC, were established across central west and southern NSW to investigate if there is an interaction between plant variety, populations, FCR and N nutrition.

The trials

Three small-plot trials were established. At the Coonamble and Nyngan sites, trials were randomised, complete block factorial designs and at Ganmain trials were a split-plot (with nitrogen as main block) factorial design, all examining the 4 variables outlined in Table 1.

Table 1. Treatments implemented in 2023 trials at Ganmain, Coonamble and Nyngan, NSW.

Wheat variety	Target plant population (pl/m^2)	N strategy	FCR inoculum
Beckomᶲ	Moderate (targeting 70 plants/m^2)	-N (40 kg/ha added at Ganmain, 25 kg/ha at Nyngan and Coonamble)	-FCR (background level)
LRPB Flankerᶲ			
LRPB Lancerᶲ	High (targeting 150 plants/m^2)	+ N (130 kg/ha added at Ganmain, 100 kg/ha at Nyngan and Coonamble)	+FCR (plots inoculated)
LRPB Raiderᶲ			

Plant population

Seed was accessed from the GRDC experimental seed supply program to ensure trueness to type and was not treated with any seed dressings. Seeding rates were calculated based on individual variety germination rates, seed size (1000 seed weight) and assumed establishment percentages. Individual sowing rates are shown in Table 2.

Table 2. Seeding rates used for varieties tested at two contrasting plant populations in 2023 at Ganmain, Coonamble and Nyngan, NSW.

Variety	Seeding rate (kg/ha)	
	Moderate	High
Beckomᶲ	29	61
LRPB Flankerᶲ	37	79
LRPB Lancerᶲ	35	76
LRPB Raiderᶲ	37	80

FCR

The +FCR plots were inoculated at sowing with non-viable wheat seed colonised by *F. pseudograminearum* (mixture of 5 isolates) at the rate of 1.4 g/m row (100 grams/plot) to establish a medium to high disease pressure (Forknall *et al.,* 2019). The -FCR plots received no artificial inoculation. PreDicta® B tests were conducted confirming Coonamble, Nyngan and Ganmain sites had FCR inoculum levels below detection (BDL) and all had canola as the previous crop. The Coonamble site was burnt to enable sowing, Nyngan was Kelly disced, and Ganmain was treated with a stubble cruncher.

Nitrogen

All N was applied as urea and incorporated by sowing, except Ganmain which had 40 kg N/ha broadcast over all treatments on 4 August.

Table 3. Site details for the 3 trials in 2023. FCR status, BDL = below detection limit, GSR = growing season rainfall

Trial location	FCR status	Sowing date	Starting N (0–60 cm)	GSR (May–Sept)
Coonamble	BDL	19 May 2023	80 kg/ha	53 mm
Nyngan	BDL	18 May 2023	98 kg/ha	54 mm
Ganmain	BDL	24 May 2023	55 kg/ha	140 mm

Results summary

The results presented were analysed using ASReml and any references to differences are statistically significant to 95% confidence. Results presented with the same letter are not significantly different (*P*=0.05). A factorial analysis of the trials resulted in the following findings.

Nyngan

- High plant population had no impact on yield, but increased screenings from 3.3% to 4.0% compared to moderate plant population.
- The +N treatment reduced yield by ~0.16 t/ha (12%) and increased screenings from 3.5% to 3.8% compared to the -N treatment.

- The +FCR reduced yield by ~0.38 t/ha (26%) and increased screenings from 2.1% to 5.2% compared to the -FCR treatment.

Coonamble

- High plant population increased yield by ~0.35 t/ha (~9%), and reduced screenings from 2.3% to 2.0% compared to moderate plant population.
- The +N treatment increased yield by ~0.29 t/ha (8%) and had no impact on screenings compared to the -N treatment.
- The +FCR reduced yield by ~0.61 t/ha (-16%) and increased screening from 1.9% to 2.4% compared to the -FCR treatment.

Ganmain

- High plant population increased yield by ~0.39 t/ha (12%) and increased screenings from 1.8% to 1.9% compared to moderate plant population.
- The +N treatment increased yield by 0.29 t/ha (9%) increased screenings from 1.6% to 2.1% compared to the -N treatment.
- The +FCR reduced yields by ~0.39 t/ha (-10%) and increased screenings from 1.1% to 2.6% compared to the -FCR treatment.

Beckomᶲ yielded the highest or equal highest across all sites. LRPB Flankerᶲ was the lowest yielding at Ganmain and Coonamble, LRPB Lancerᶲ and LRPB Raiderᶲ were equally the lowest at Nyngan. Differences between the lowest to the highest yielding varieties at Nyngan was 0.46 t/ha (+30%), Coonamble was 0.49 t/ha (+14%), and at Ganmain 0.97 t/ha (24%).

In summary across all sites, increasing plant population improved yield by 0–12%. Whereas +FCR had the largest negative effects of between 10–-27% yield reduction. Whilst there is a clear message in this alone, investigation of the influence of population on various combinations of variety, N and FCR pressure, revealed some interesting interactions.

Detailed results

The following results are based on an ANOVA and compare “paired” treatments, the pairs being +FCR and -FCR, or moderate versus high plant population whilst other parameters such as variety and N nutrition remains the same.

In the Tables 4 to 9 shading denotes a significant difference between the treatments within the comparison. The lettering is across all treatments but only within either yield or screenings.

Nyngan

The effect of +FCR was significant (Table 4), negatively impacting three of the varieties (except LRPB Lancerᶲ) in at least three N and population scenarios. LRPB Flankerᶲ was the most affected by +FCR, with up to 0.94 t/ha yield loss in similar plant population and N nutrition scenarios. Beckomᶲ and LRPB Raiderᶲ were less affected with up to 0.56 t/ha yield loss. LRPB Lancerᶲ was least affected by +FCR, with yield reduced by a maximum of 0.21 t/ha, in the +N, high population treatment (Table 4).

Adding FCR increased screenings in all variety, population and N combinations, with screenings ranging from 1.4% up to 6.1%, with LRPB Flankerᶲ and Beckomᶲ being the most affected.

Table 4. Impact of FCR pressure on yield and screenings of various combinations of wheat variety (Var), N nutrition and plant population (Pop), Nyngan 2023.

Var	N	Pop	Yield (t/ha)				Δ Yield (t/ha)	Screenings (%)				Δ SCN (%)
			-FCR		+FCR			-FCR		+FCR		
Beckom⏀	+N	High	1.36	efgh	1.53	def	NS	2.3	jklmno	6.0	cd	3.8
		Moderate	1.77	abcd	1.25	ghij	-0.52	2.1	klmno	5.9	cde	3.7
	-N	High	1.81	ab	1.27	ghij	-0.54	2.5	ijklmn	7.2	ab	4.7
		Moderate	2.00	a	1.44	efg	-0.56	1.6	no	4.7	fg	3.1
LRPB Flanker⏀	+N	High	1.55	def	0.90	mno	-0.65	3.0	ijk	6.6	bc	3.6
		Moderate	1.31	fghi	0.89	mno	-0.42	2.0	klmno	8.1	a	6.1
	-N	High	1.76	bcd	0.82	o	-0.94	2.6	ijklm	6.7	bc	4.0
		Moderate	1.79	abc	0.93	lmno	-0.86	2.0	lmno	5.0	ef	3.0
LRPB Lancer⏀	+N	High	1.08	ijklmn	0.87	no	NS	2.2	klmno	3.9	gh	1.7
		Moderate	1.04	jklmno	1.02	klmno	NS	1.6	no	3.2	hij	1.6
	-N	High	1.29	ghi	1.11	ijklm	NS	1.8	mno	3.4	hi	1.6
		Moderate	1.24	ghijk	1.05	jklmno	NS	1.4	o	2.8	ijkl	1.4
LRPB Raider⏀	+N	High	1.20	ghijk	0.95	lmno	-0.25	2.3	jklmno	5.3	def	3.0
		Moderate	1.21	ghijk	0.89	mno	-0.32	1.9	lmno	4.5	fg	2.6
	-N	High	1.56	cde	1.06	jklmn	-0.5	2.5	ijklmn	5.0	ef	2.5
		Moderate	1.26	ghij	1.14	hijkl	NS	1.8	mno	4.8	fg	3.1

When comparing the effects of plant population (Table 5), there were 3 paired comparisons where yield increased with population by 0.24–0.30 t/ha or 18–24% – Beckom⏀ with +N and +FCR, LRPB Flanker⏀ with +N and -FCR and LRPB Raider⏀ with -N and -FCR.

Only in Beckom⏀ with +N and -FCR was there a yield decrease (0.41 t/ha or 23%) with the high plant population. All other comparisons of high and low population resulted in no yield impact (Table 5).

Table 5. Impact of plant population on yield and screenings of various combinations of wheat variety (Var), N nutrition N and FCR, Nyngan 2023.

VAR	N	FCR	Yield (t/ha)				Δ Yield (t/ha)	Screenings (%)				Δ SCN (%)
			Moderate population		High population			Moderate population		High population		
Beckomɸ	+N	+FCR	1.25	ghij	1.53	def	0.28	5.9	cde	6.0	cd	NS
		-FCR	1.77	abcd	1.36	efgh	-0.41	2.1	klmno	2.3	jklmno	NS
	-N	+FCR	1.44	efg	1.27	ghij	NS	4.7	fg	7.2	ab	2.5
		-FCR	2.00	a	1.81	ab	NS	1.6	no	2.5	ijklmn	NS
LRPB Flankerɸ	+N	+FCR	0.89	mno	0.90	mno	NS	8.1	a	6.6	bc	-1.5
		-FCR	1.31	fghi	1.55	def	0.24	2.0	klmno	3.0	ijk	NS
	-N	+FCR	0.93	lmno	0.82	o	NS	5.0	ef	6.7	bc	1.7
		-FCR	1.79	abc	1.76	bcd	NS	2.0	lmno	2.6	ijklm	NS
LRPB Lancerɸ	+N	+FCR	1.02	klmno	0.87	no	NS	3.2	hij	3.9	gh	NS
		-FCR	1.04	jklmno	1.08	ijklmn	NS	1.6	no	2.2	klmno	NS
	-N	+FCR	1.05	jklmno	1.11	ijklm	NS	2.8	ijkl	3.4	hi	NS
		-FCR	1.24	ghijk	1.29	ghi	NS	1.4	o	1.8	mno	NS
LRPB Raiderɸ	+N	+FCR	0.89	mno	0.95	lmno	NS	4.5	fg	5.3	def	0.8
		-FCR	1.21	ghijk	1.20	ghijk	NS	1.9	lmno	2.3	jklmno	NS
	-N	+FCR	1.14	hijkl	1.06	jklmn	NS	4.8	fg	5.0	ef	NS
		-FCR	1.26	ghij	1.56	cde	0.3	1.8	mno	2.5	ijklmn	NS

There were 3 paired treatments where screenings increased (between 0.8% and 2.5%) at higher plant population, each +FCR (see Table 5, shaded cells): Beckomɸ -N, LRPB Flankerɸ -N, and LRPB Raiderɸ +N. LRPB Flankerɸ +N resulted in lower screenings at the high plant population compared with the moderate plant population. All other comparisons of plant population resulted in no effects on screenings.

Coonamble

The addition of +FCR reduced yield by up to 1.20 t/ha (32%) in all paired combinations of variety, population, and N rate, except for one (Table 6). Beckomɸ and LRPB Flankerɸ were affected more than LRPB Lancerɸ and LRPB Raiderɸ by +FCR. Screenings in LRPB Flankerɸ increased with +FCR, regardless of N or population. Several other comparisons showed increases in screenings, but none resulted in screenings greater than 5%, the limit for milling wheat (Table 6).

Table 6. Impact of FCR pressure on yield and screenings of various combinations of wheat variety (Var), N nutrition and plant population (Pop), Coonamble 2023

Var	N	Pop	Yield (t/ha)				Δ Yield (t/ha)	Screenings (%)				Δ SCN (%)
			-FCR		+FCR			-FCR		+FCR		
Beckom	+N	High	4.43	a	3.96	cde	-0.47	1.5	j	1.9	fghij	NS
		Moderate	4.41	a	3.45	hijk	-0.96	2.1	efgh	2.2	defg	NS
	-N	High	4.34	ab	3.60	ghi	-0.74	1.4	j	1.6	hij	NS
		Moderate	3.68	efgh	3.12	mn	-0.56	1.4	j	2.0	fghi	0.6
LRPB Flanker	+N	High	4.12	bc	3.35	ijklmn	-0.77	1.8	ghij	2.4	cdef	0.6
		Moderate	3.83	defg	2.61	o	-1.22	2.2	defg	2.8	abc	0.6
	-N	High	3.94	cde	3.06	n	-0.88	1.9	fghij	2.6	bcde	0.7
		Moderate	3.41	hijkl	2.69	o	-0.72	2.2	defg	3.3	a	1.2
LRPB Lancer	+N	High	3.98	cd	3.53	hij	-0.45	1.5	ij	1.9	fghij	NS
		Moderate	3.55	ghi	3.24	jklmn	-0.31	1.9	fghij	2.2	defg	NS
	-N	High	3.62	fghi	3.12	lmn	-0.5	1.5	ij	2.1	defghi	NS
		Moderate	3.19	klmn	3.07	n	NS	2.1	defgh	2.6	bcd	NS
LRPB Raider	+N	High	4.14	abc	3.52	hij	-0.62	2.2	defg	2.4	cdef	NS
		Moderate	4.07	bcd	3.37	ijklm	-0.7	2.1	efgh	2.4	cdef	NS
	-N	High	3.90	cdef	3.46	hijk	-0.44	2.1	defgh	3.1	ab	0.9
		Moderate	3.50	hij	3.18	klmn	-0.32	2.0	fghi	2.6	bcde	0.5

Increasing population from a moderate to high had no impact in six comparisons (Table 7). Yield increased by 8% to 28% or up to 0.74 t/ha in the remaining ten comparisons of plant population.

In no comparisons did increasing plant population from moderate to high increase screenings. Three of the 16 comparisons at Coonamble resulted in lower screenings (0.4–0.7%) when plant population was increased (Table 7). In no cases were screenings >5%, the threshold for milling wheat. There was no impact of plant population on screenings in LRPB Raider.

Table 7. Impact of population on yield and screenings of various combinations of wheat variety (Var.), N nutrition and FCR, Coonamble 2023.

VAR.	N	FCR.	Yield (t/ha)		Δ Yield (t/ha)	Screenings (%)		Δ SCN (%)
			Moderate population	High population		Moderate population	High population	
Beckomᶲ	+N	+FCR	3.45 hijk	3.96 cde	0.51	2.2 defg	1.9 fghij	NS
		-FCR	4.41 a	4.43 a	NS	2.1 efgh	1.5 j	-0.6
	-N	+FCR	3.12 mn	3.60 ghi	0.48	2.0 fghi	1.6 hij	NS
		-FCR	3.68 efgh	4.34 ab	0.66	1.4 j	1.4 j	NS
LRPB Flankerᶲ	+N	+FCR	2.61 o	3.35 ijklmn	0.74	2.8 abc	2.4 cdef	NS
		-FCR	3.83 defg	4.12 bc	0.29	2.2 defg	1.8 ghij	NS
	-N	+FCR	2.69 o	3.06 n	0.37	3.3 a	2.6 bcde	-0.7
		-FCR	3.41 hijkl	3.94 cde	0.53	2.2 defg	1.9 fghij	NS
LRPB Lancerᶲ	+N	+FCR	3.24 jklmn	3.53 hij	NS	2.2 defg	1.9 fghij	NS
		-FCR	3.55 ghi	3.98 cd	0.43	1.9 fghij	1.5 ij	NS
	-N	+FCR	3.07 n	3.12 lmn	NS	2.6 bcd	2.1 defghi	NS
		-FCR	3.19 klmn	3.62 fghi	0.43	2.1 defgh	1.5 ij	-0.6
LRPB Raiderᶲ	+N	+FCR	3.37 ijklm	3.52 hij	NS	2.4 cdef	2.4 cdef	NS
		-FCR	4.07 bcd	4.14 abc	NS	2.1 efgh	2.2 defg	NS
	-N	+FCR	3.18 klmn	3.46 hijk	NS	2.6 bcde	3.1 ab	NS
		-FCR	3.50 hij	3.90 cdef	0.4	2.0 fghi	2.1 defgh	NS

Ganmain

Most paired comparisons of +/-FCR had no impact on yield (Table 8). There was no effect of FCR in LRPB Lancerᶲ, however LRPB Raiderᶲ and LRPB Flankerᶲ yield was lower at moderate populations when FCR pressure was increased, but there was no impact at higher populations regardless of N. Beckomᶲ yield was reduced under +N and high population. Screenings increased with +FCR for all but 2 comparisons: LRPB Lancerᶲ -N at both moderate and high plant population.

Table 8. Impact of FCR pressure on yield and screenings of various combinations of wheat variety (Var), N nutrition and plant population (Pop), Ganmain 2023.

Var.	N	Pop.	Yield (t/ha)				Δ yield (t/ha)	Screenings (%)				Δ SCN (%)
			-FCR		+FCR			-FCR		+FCR		
Beckomᶲ	+N	High	4.77	a	4.31	bc	-0.46	1.2	klmn	2.4	fgh	1.2
		Moderate	4.08	bcde	3.69	efghi	NS	1.0	mn	3.0	de	2.0
	-N	High	4.08	bcde	3.69	efghi	NS	0.9	n	1.7	ijk	0.8
		Moderate	3.95	bcdef	3.56	fghijk	NS	0.9	n	1.4	klm	0.5
LRPB Flankerᶲ	+N	High	3.64	efghij	3.20	jklmn	NS	1.1	mn	2.9	de	1.8
		Moderate	3.17	klmn	2.49	op	-0.68	1.0	mn	3.3	cd	2.3
	-N	High	3.47	ghijkl	3.04	lmn	NS	0.9	n	2.8	def	1.9
		Moderate	2.91	mno	2.41	p	-0.5	1.1	lmn	2.7	efg	1.5
LRPB Lancerᶲ	+N	High	3.67	efghi	3.34	ijklm	NS	0.9	n	2.0	hi	1.1
		Moderate	3.45	ghijkl	3.21	jklm	NS	0.9	n	1.4	klm	0.5
	-N	High	3.40	hijkl	3.41	hijkl	NS	1.0	n	1.1	lmn	NS
		Moderate	2.92	mno	2.73	nop	NS	1.0	mn	1.1	lmn	NS
LRPB Raiderᶲ	+N	High	4.29	bcd	4.02	bcdef	NS	2.0	hij	5.2	a	3.2
		Moderate	4.43	ab	3.65	efghij	-0.78	1.5	jkl	4.2	b	2.7
	-N	High	4.01	bcdef	3.83	defgh	NS	1.3	klmn	3.5	c	2.2
		Moderate	3.90	cdefg	3.40	hijkl	-0.5	1.4	klm	2.2	gh	0.8

Increasing the plant population at Ganmain did not reduce yield (Table 9). There were 8 cases with no impact, and for the remaining eight, yield increased 0.47–0.71 t/ha (19–29%) with increased plant population. LRPB Flankerᶲ responded in all 4 population comparisons, +/- N and +/- FCR. Beckomᶲ responded in two comparisons, both +N and +/- FCR, as did LRPB Lancerᶲ for the -N treatment. LRPB Raiderᶲ did not respond to plant population.

Three comparisons resulted in higher screenings with increased population but only one was >5% (Table 9). Screenings were slightly lower in Beckomᶲ with +N and +FCR.

Table 9. Impact of plant population (Pop) on yield and screenings of various combinations of wheat variety (Var), N nutrition and FCR, Ganmain 2023.

VAR	N	FCR	Yield: (t/ha) Moderate population		Yield: (t/ha) High population		Δ Yield (t/ha)	Screenings (%) Moderate population		Screenings (%) High population		Δ SCN (%)
Beckom$^{Ⓓ}$	+N	+FCR	3.69	efghi	4.31	bc	0.62	3.0	de	2.4	fgh	-0.6
		-FCR	4.08	bcde	4.77	a	0.69	1.0	mn	1.2	klmn	NS
	-N	+FCR	3.56	fghijk	3.69	efghi	NS	1.4	klm	1.7	ijk	NS
		-FCR	3.95	bcdef	4.08	bcde	NS	0.9	n	0.9	n	NS
LRPB Flanker$^{Ⓓ}$	+N	+FCR	2.49	op	3.20	jklmn	0.71	3.3	cd	2.9	de	NS
		-FCR	3.17	klmn	3.64	efghij	0.47	1.0	mn	1.1	mn	NS
	-N	+FCR	2.41	p	3.04	lmn	0.63	2.7	efg	2.8	def	NS
		-FCR	2.91	mno	3.47	ghijkl	0.56	1.1	lmn	0.9	n	NS
LRPB Lancer$^{Ⓓ}$	+N	+FCR	3.21	jklm	3.34	ijklm	NS	1.4	klm	2.0	hi	0.6
		-FCR	3.45	ghijkl	3.67	efghi	NS	0.9	n	0.9	n	NS
	-N	+FCR	2.73	nop	3.41	hijkl	0.68	1.1	lmn	1.1	lmn	NS
		-FCR	2.92	mno	3.40	hijkl	0.48	1.0	mn	1.0	n	NS
LRPB Raider$^{Ⓓ}$	+N	+FCR	3.65	efghij	4.02	bcdef	NS	4.2	b	5.2	a	1.0
		-FCR	4.43	ab	4.29	bcd	NS	1.5	jkl	2.0	hij	NS
	-N	+FCR	3.40	hijkl	3.83	defgh	NS	2.2	gh	3.5	c	1.3
		-FCR	3.90	cdefg	4.01	bcdef	NS	1.4	klm	1.3	klmn	NS

Discussion

The 3 trial sites in 2023 could be broadly categorised into 2 yield environments: low at Nyngan ~1 t/ha and moderate at both Ganmain and Coonamble, yielding up to ~4.7 t/ha. Despite this, all sites showed significant impacts from the addition of FCR. Nyngan had the largest percentage yield loss across all varieties and N levels from +FCR (26% or ~0.38 t/ha). Ganmain had only ~12% average yield loss across all varieties and N levels from +FCR. Interestingly, the actual tonnage of yield loss from FCR at Ganmain was 0.39 t/ha which was equivalent to the 0.38 t/ha loss associated with FCR infection at Nyngan even though these two sites had vastly different yield potentials in 2023. Individual varieties suffered much bigger losses. At Nyngan, individual varieties had yield reductions of up to 53%, Coonamble up to 32% and Ganmain up 21%, due increased FCR.

The effects of +FCR on screenings at Nyngan was substantial and impacted all treatment combinations. In many situations, +FCR resulted in screenings above 5%, which generally pushed the samples out of higher priced milling grades. Similarly, +FCR at Ganmain increased screenings in all but two comparisons. Only in one comparison were screenings >5% in response to +FCR.

The N impact varied between sites. There were slight yield reductions and increased screenings at Nyngan, possibly displaying typical haying off, a common concern of growers in these environments. However, the impacts were quite minimal in comparison to the effects of +FCR at this site. At Ganmain +N had no impact on yield and only a small increase in screenings. Again, the effects of this are dwarfed by that of +FCR. At Coonamble there was a large increase in yield and no impact on screenings from the +N application.

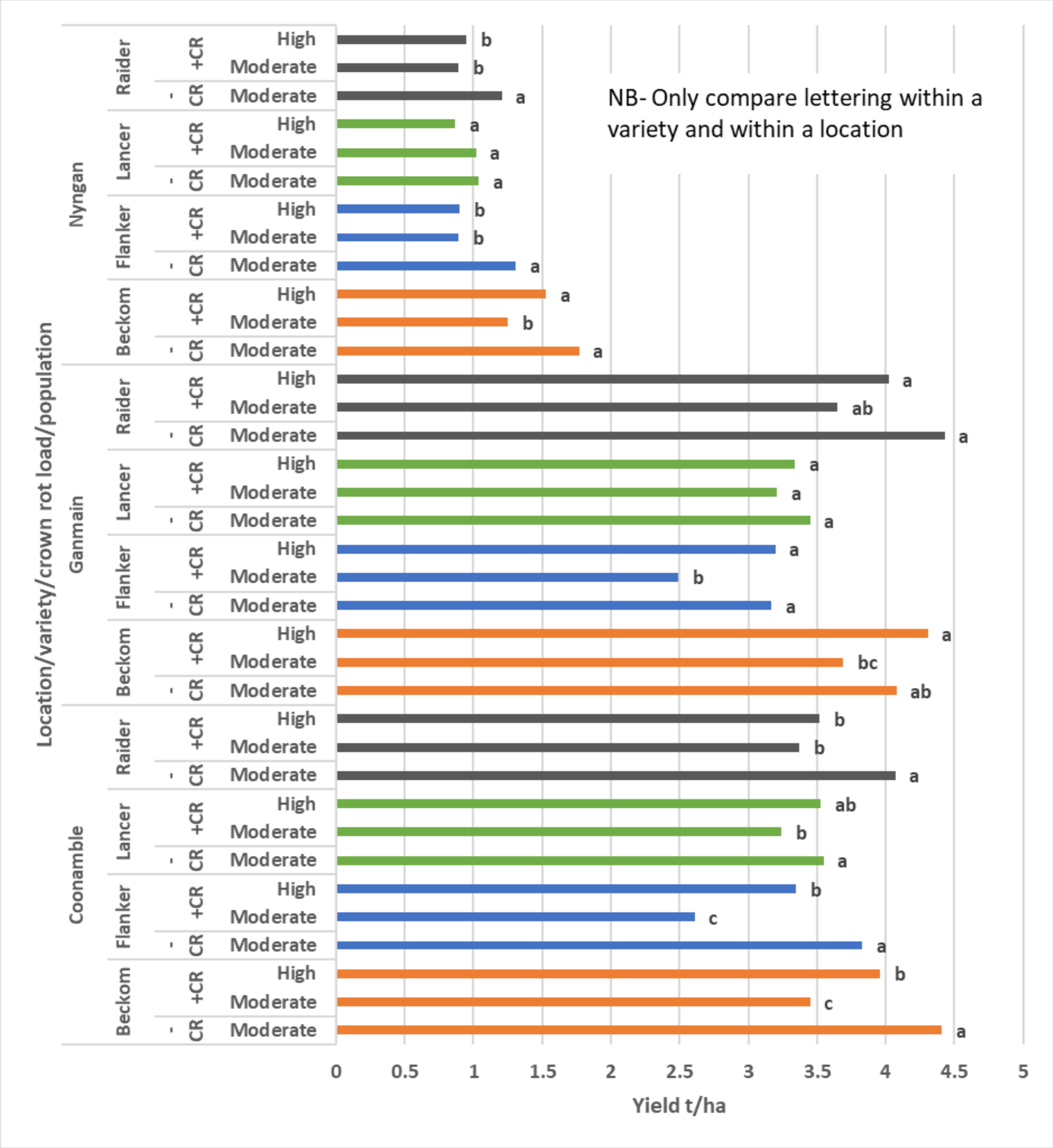
All the above results are intertwined with variety. At all sites Beckom⦶ was a top performer compared to the other varieties and both it and LRPB Flanker⦶ were affected the most by +FCR. Interestingly, even with the impacts of FCR on these two varieties, they often outperformed the other 'more tolerant' LRPB Lancer⦶ and LRPB Raider⦶, even in the absence of FCR (-FCR).

The effects of increasing plant population were often positive for yield and screenings. This benefit was greatest at the higher yielding sites at Coonamble and Ganmain. For both locations there was no negative impacts on yield but increases of up to 29% or 0.75 t/ha with the higher plant population.

At Coonamble, there was either no effect or a decrease on screenings with higher plant populations. For most treatments at Ganmain there was no impact of population on screenings, except in a few cases where a slight increase (<1.3%) was recorded.

Nyngan was less responsive to increasing plant populations, most treatments having no response. The few cases that did respond were mostly positive with yield gains of up to 0.30 t/h or 24% with the higher plant population treatment. Only one comparison out of 16 pairs resulted in a yield decrease of 0.41 t/ha with the high plant population. In only 3 out of 16 comparisons, screenings increased with higher plant population and were >5%.

An interesting interaction of FCR and plant population is illustrated in Figure 2. As already discussed, at moderate plant population the introduction of FCR can reduced yield. If we consider many of the factors investigated in these trials, for the +FCR treatments, increasing plant population often increased yield but not to the same extent as where FCR was lower. This was most evident in the higher yielding sites of Coonamble and Ganmain and in the less tolerant varieties Beckom and LRPB Flanker. This could prove a useful tool for growers to combat the impacts of FCR in moderate risk situations. In the lower yielding Nyngan site, the benefits were less. The reasons for this positive response cannot be explained, however it was observed but not measured that crop maturity was earlier at high population. The high population crops escaped heat and moisture stress that the moderate populations experienced, resulting in improved yields. This may warrant further investigation.



NB- Only compare lettering within a variety and within a location

Figure 2. Impact of increased plant population at high and low FCR pressure, and high nitrogen on yield of various varieties at Nyngan, Coonamble and Ganmain, 2023.

Conclusions

Growers are being encouraged to increase crop competition through increasing plant populations to aid in weed control. These trials have shown concerns by advisors and growers of decreased yield and increased screenings, particularly in low yielding environments, may not be well founded.

The first year of these trials reiterates the significant effect that FCR can have on wheat in both low and moderate yielding situations. The negative impacts resulted in both yield reduction and reduced grain quality (increased screenings).

Manipulation of plant population is emerging as a possible tool to reduce the effects of FCR. There was little negative impact of increasing plant population and more positive effects which resulted in increased yield, and in some cases reduced screenings.

Variety choice had a large effect on yield in the presence of FCR. Beckom⌽ and LRPB Flanker⌽ had the greatest yield reductions from FCR compared to LRPB Lancer⌽ and LRPB Raider⌽, however in many cases Beckom⌽ and LRPB Flanker⌽, under higher FCR pressure, still outyielded these more tolerant varieties. The performance of these more intolerant varieties could also be improved under higher FCR pressure by increasing plant population.

This initial research has demonstrated that increasing plant population did not negatively impact crop performance and consistently resulted in improved yield and grain quality. This did not account for the benefits that increased plant populations could offer in terms of weed control. These trials have potentially identified that growers could increase plant populations to limit potential negative impacts of FCR, which was the largest driver of yield reduction in these trials.

Reference

Forknall CR, Simpfendorfer S, Kelly AM (2019) Using yield response curves to measure variation in the tolerance and resistance of wheat cultivars to Fusarium crown rot. *Phytopathology* **109**: 932-941.

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A foe in the fallow: what happens with Fusarium crown rot between seasons?

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Key words

cereal stubble, stubble management, integrated disease management, post-harvest, wheat, barley, durum wheat, oat, Fusarium

GRDC codes

BLG211: Grains Agronomy & Pathology Partnership (GAPP) PhD, a GRDC & NSW DPI co-investment
DAQ00208: Statistics for the Australian Grains Industry (North)
DPI2207-004RTX: Integrated management of Fusarium crown rot in Northern and Southern Regions
DAQ2007-002RTX: Northern Farming Systems

Take home message

- Cereal varieties with better partial resistance can still experience significant (up to ~6-fold) increases in *Fusarium pseudograminearum* (*Fp*) colonisation after senescence (crop maturity)
- Colonisation of cereal stubble by *Fp* after harvest can be maintained at high levels for at least 1 year under natural field conditions
- Post-harvest colonisation of cereal stubble by *Fp* could contribute inoculum for future seasons, particularly if infected stubble is disturbed and redistributed e.g., via harvest of a shorter-stature break crop (e.g., chickpea)
- Lowering the harvest height of cereal crops infected with *Fp* can prevent colonisation of retained stubble after harvest and may be a useful management strategy in high-risk scenarios.

Introduction

Fusarium crown rot (FCR) is a chronic disease of cereals in Australia and causes significant damage to infected crops through yield loss and reduced grain quality. In the northern region (northern NSW and Qld), the disease is primarily caused by the fungus *Fusarium pseudograminearum* (*Fp*), but *F. culmorum* and *F. graminearum* can also cause FCR. These fungi can survive three or more years in cereal stubble (Summerell and Burgess 1988), which has become increasingly problematic due to cereal stubble retention.

Recent research has confirmed that *Fp* can also continue to colonise cereal stubble after harvest, known as saprotrophic colonisation. Over a 6-month summer fallow, saprotrophic colonisation by *Fp* resulted in a 60 to 70% increase in the height that *Fp* was detected in standing stubble at two sites in northern NSW (Petronaitis *et al.,* 2022). Post-harvest colonisation of stubble by *Fp* may therefore contribute to the build-up of FCR inoculum in stubble-retention systems.

Saprotrophic colonisation of cereal stubble by *Fp* has not been well-characterised. During plant development, *Fp* will colonise stems more aggressively in hosts which are more susceptible to FCR (e.g., durum wheat) (Knight and Sutherland 2017). This can lead to more inoculum accumulation during the growing season. It is unknown whether aggressive colonisation continues after harvest in more susceptible hosts, and whether using cereals with improved levels of genetic resistance provides any subsequent inoculum benefit (e.g., by slowing or preventing *Fp* colonisation of stubble). This is important to investigate, as crop and variety selection are among the most popular strategies that growers and advisors use to manage FCR (Figure 1).

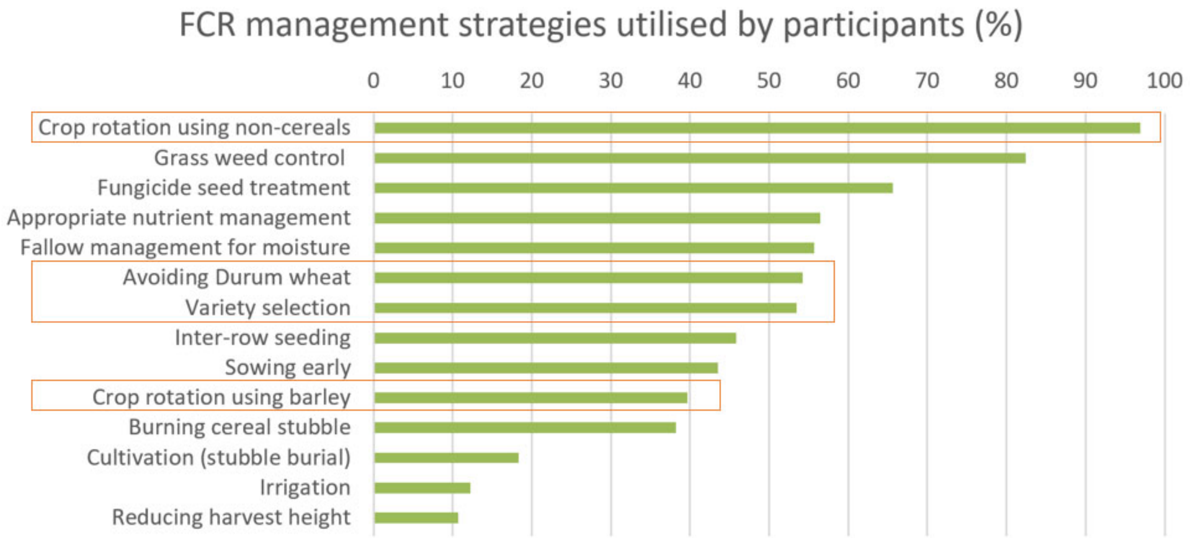

Figure 1. Strategies used in the last 2 years to manage FCR by 130 participants who completed the Fusarium crown rot survey: a grower and agronomist questionnaire conducted in August 2023 under the GRDC and DPI co-investment (DPI2207-004RTX). Strategies that involve crop and variety selection are circled. Participants include growers and agronomists from Qld, NSW, SA, and Vic.

Glasshouse experiment method

Ten cereal cultivars with a range of FCR ratings (Table 1) were selected and the movement of *Fp* tracked within the stems, from seedlings through to post-harvest stubble.

Table 1. Ten cultivars were selected for the study based on their relevance to the northern region and covering a range of crop types and FCR resistance ratings.

Cultivar name	Crop species	FCR resistance rating
LRC2012-122	Bread wheat	MR–MS to MR[1]
LRPB Hellfireᶲ	Bread wheat (APH)	MS–S
LRPB Lancerᶲ	Bread wheat (APH)	MS–S
LRPB Stealthᶲ	Bread wheat (APH)	S
LRPB Kittyhawkᶲ	Dual purpose wheat (APH)[2]	S–VS
DBA Lillaroiᶲ	Durum wheat	S–VS
Oxfordᶲ	Barley	MS–S
Commanderᶲ	Barley	S
Spartacusᶲ	Barley	S
Eurabbie	Oat	NA

[1] Germplasm and FCR rating kindly supplied by Cassy Percy, University of Southern Queensland, 2021.
[2] For simplification, Kittyhawkᶲ was considered as a bread wheat in the analyses.
Abbreviations: Australian Prime Hard (APH), Durum Breeding Australia (DBA), Fusarium crown rot (FCR), Leslie Research Centre (LRC), Longreach Plant Breeders (LRPB), moderately resistant (MR), moderately susceptible (MS), not applicable (NA), susceptible (S), very susceptible (VS).

The experiment was conducted in a glasshouse at Tamworth Agricultural Institute (Tamworth, NSW). Two seeds of an individual cultivar were placed in grow bags containing potting mix and covered with a 2 cm layer of *Fp* grain inoculum-potting mix combination (1% grain inoculum by weight). Plants were thinned to one plant per bag after 10 days. Plants were assessed at four sampling times (in days after planting, or DAP) at various targeted growth stages (GS): stem elongation (80 DAP, GS32), anthesis (113 DAP, GS61), maturity (147 DAP, GS90), and post-harvest (166 DAP, GS90 + 2 weeks), the latter following regular moisture treatment. Plants were washed and rated visually for severity of FCR (stem browning). The main tiller was retained for culturing, and any remaining tillers were dried at 30 °C for 24 hours and submitted to the South Australian Research and Development Institute (Adelaide, South Australia) for qPCR analysis of *Fp* DNA.

Main tillers were surface sterilised using 5% sodium hypochlorite solution (5 mL sodium hypochlorite solution, 45 mL distilled water, 50 mL >98% ethanol) for 1 minute then washed three times with sterile reverse osmosis water and dried for 2 hours in a laminar flow. The tillers were aseptically trimmed into 1 cm segments and numbered sequentially starting from the crown. Segments were cultured on 1/4 potato dextrose agar (PDA) + novobiocin and incubated under alternating white and near ultraviolet lights for a 12 h photoperiod of 66.6% alternating fluorescent (FL36W/865, Sylvania, East Sussex, United Kingdom) and 33.3% blacklight blue (F36T8 BLB, Crompton lighting, Bradford, United Kingdom) for 5 days at 25 °C. The incidence of stem colonisation was determined by scoring each tiller section for the growth of *Fp* based on colony morphology. Maximum colonisation was defined as the highest tiller section at which *Fp* was detected within the tiller and reported as a height (in cm).

The factorial combination of treatments, being all combinations of cultivar and sampling time, were assigned to tubs according to a split-plot design. In this case, sampling times were randomly assigned to main plots, where a main plot was defined as a group of 10 grow bags arranged in a 2 x 5 configuration. Using this configuration of grow bags, and due to the size of the tubs, two main plots occurred within each plastic tub. Cultivars were randomly assigned to individual grow bags within main plots. All treatment combinations were replicated six times.

The response variable, maximum height of colonisation, was analysed using a linear mixed model framework, whereby cultivar, sampling time and their interaction, were fit as fixed effects, while terms describing the experimental design structure were fit as random. The model was fit using the ASReml-R package in the R statistical computing environment.

Glasshouse experiment results – what did we find?

Analysis of maximum colonisation revealed a significant interaction between cultivar and sampling time. During the growing season (stem elongation and anthesis), *Fp* did not colonise as high up main tillers in oat var. Eurabbie compared with most of the other cultivars (Figure 2). This was the only case in which host resistance to FCR significantly suppressed *Fp* colonisation in the living plant. By maturity, improved genetic resistance did not appear to suppress colonisation by *Fp* in any of the cultivars tested (including oat). Some of the cultivars with better FCR resistance ratings experienced the highest increase in *Fp* colonisation, for example LRPB LancerⓅ (~4-fold increase) and LRC2012-122 (~6-fold increase) (Figures 2 and 3). As such, *Fp* colonisation of stems around the time of harvest did not relate comparatively with the reported host resistance ratings of the different cultivars tested.

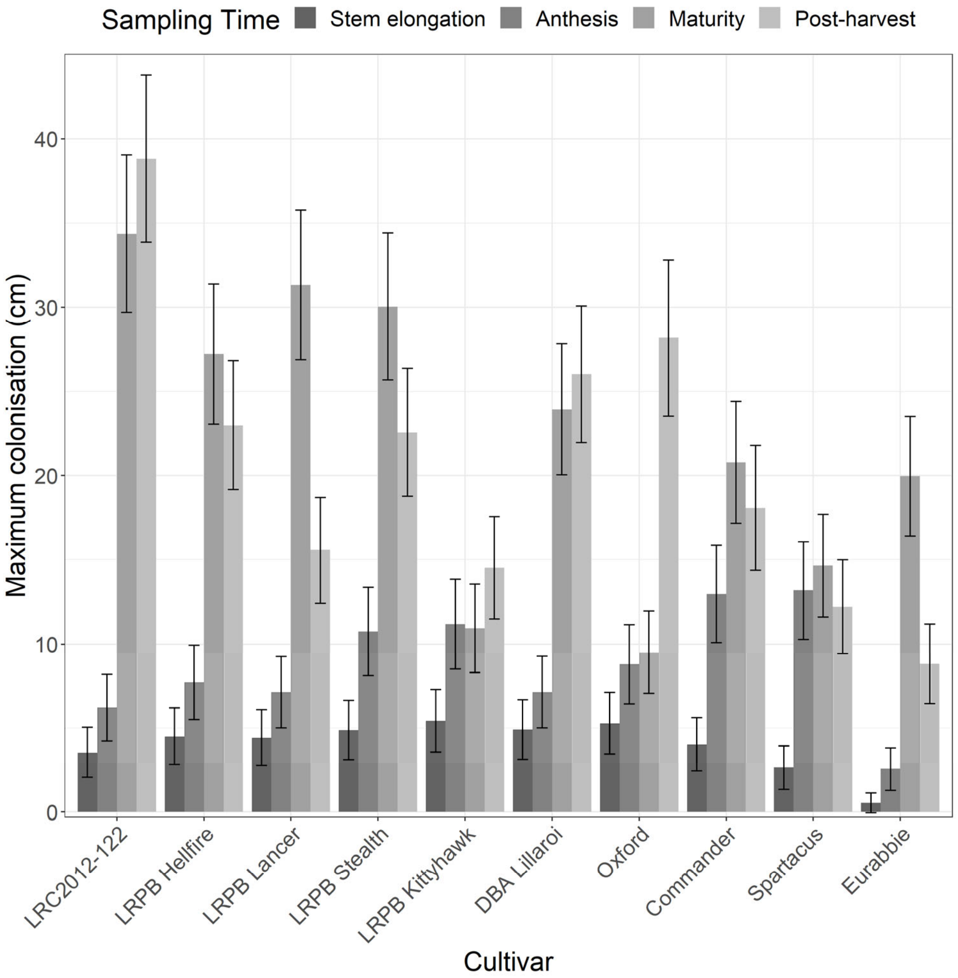

Figure 2. Maximum vertical colonisation (cm) of the main stem of different cereal cultivars by *Fp* at four different time points: stem elongation, anthesis, maturity, and post-harvest. Error bars represent the approximate back-transformed standard error of the mean.

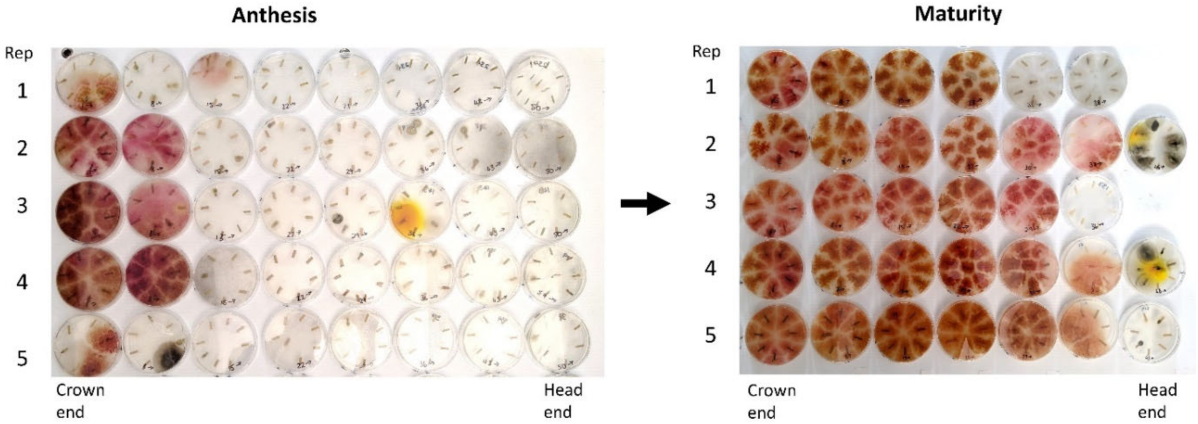

Figure 3. Example of the large increase in *Fp* colonisation observed between anthesis and maturity in the partially FCR-resistant wheat germplasm LRC2012-122. The *Fp* colonies appear as dark patches surrounding the stubble pieces (colonies are red when printed in colour). This shows extensive colonisation of the plant by *Fp* following plant senescence. Samples are representative of all six replicates in the experiment.

The *Fp* DNA levels and crown rot index (CRI) results aligned well with the FCR ratings (data not shown), confirming that we achieved the desired range of different infection and disease severity levels. Interestingly, the MR–MS to MR line LRC2012-122 had relatively low *Fp* DNA and CRI, but the highest height of *Fp* colonisation at maturity and post-harvest. Conversely, the two cultivars with the highest *Fp* DNA levels and CRI (S-rated barley cv. Commander and S–VS wheat cv. LRPB Kittyhawk) were among the cultivars with the lowest height of *Fp* colonisation from maturity onwards (Figure 2). These results showed that lower levels of stem colonisation (determined via culturing) did not translate to lower DNA levels or disease symptoms in the plant, and vice-versa. This could be explained by more susceptible cultivars accumulating higher levels of DNA in-season due to aggressive colonisation by *Fp* (Knight and Sutherland 2017), which is not experienced during saprotrophic colonisation.

Additional watering of the stubble between maturity and post-harvest did not consistently increase saprotrophic colonisation by *Fp*. This is contrary to prior work, which showed the FCR pathogen can colonise sterile cereal stubble at a rate of up to 1 cm/day under consistently high humidity (Petronaitis *et al*., 2020). In the field, *Fp* can increase by up to 21 cm (or to the final cut height of stubble) over a 6-month summer fallow (Petronaitis *et al.,* 2022). We suspect further saprotrophic colonisation might have been detectable via culturing in the present study if the post-harvest period had been extended beyond 2 weeks. The good news is that there may not be significant change in *Fp* colonisation during shorter periods, e.g., a harvest window. This may allow for additional time to test *Fp* levels in stubble and/or manage, if needed, to prevent further post-harvest colonisation.

Crop/variety selection is still a useful tool for managing FCR

The glasshouse experiment supports the use of cereal cultivars with partial resistance as part of an integrated management strategy for FCR. The more (partially) resistant cultivars were generally associated with a reduction in *Fp* DNA and disease severity, which can protect against yield and quality losses to FCR. The preliminary results from the FCR questionnaire show that growers and agronomists already employ this strategy frequently. Further education of industry is still required about which crops and varieties are most suitable, as almost 40% of participants indicated they have implemented a barley in their rotation in the last 2 years to reduce FCR risk. However, barley is susceptible to FCR, and exhibited the largest *Fp* DNA accumulation of all crop types in the glasshouse experiment. The general earlier maturity of barley compared with wheat can reduce exposure to heat and/or moisture stress during grain filling. This can be protective against FCR expression and associated yield loss from FCR in barley but is not guaranteed to reduce *Fp* inoculum levels.

Infection of more FCR-resistant cultivars by *Fp* can be difficult to detect visually, as basal browning symptoms are milder. Growers may therefore be unaware of *Fp* infection and/or the extent of colonisation in crops with minimal FCR symptoms. In our study, oat var. Eurabbie had lower (but still detectable) basal browning symptoms compared with barley and wheat cultivars. Oat may therefore be affected by FCR more frequently than previously thought, with visible detection via basal browning possible. The oat also contained similar levels of *Fp* DNA compared to several of the bread wheat cultivars in our experiment. Oat is therefore not recommended as a break crop for the purpose of reducing FCR risk within a cropping sequence. Still, oat crops may present a more diverse option for managing FCR as the stubble can decompose more rapidly than wheat and barley (to potentially displace *Fp*). It may also have the advantage of being grazed by stock which can also reduce stem colonisation by FCR pathogens (Nelson and Burgess 1995).

What are the dangers of post-harvest colonisation of stubble?

Saprotrophic colonisation of cereal stubble by *Fp* could contribute additional inoculum for future seasons. This is particularly important given that less-susceptible cereal crop types/cultivars can still experience extensive colonisation by *Fp* after harvest. In the glasshouse study, it appeared that plants which were less affected by FCR (e.g., oat and LCR2012-122) experienced higher levels of saprotrophic colonisation – possibly because the plants were able to grow taller and healthier due to improved partial resistance to FCR. This additional *Fp* inoculum, which is often not accounted for in integrated disease management, may be contributing to the persistence of FCR within cropping systems.

Previous work has shown that *Fp* can persist for at least 12 months in upper parts of cereal stubble that have been saprotrophically colonised after harvest (Petronaitis *et al.,* 2022). Inoculum maintained long-term in this section of the stubble may become problematic if standing stubble is disturbed, perhaps by being knocked over or distributed prior to sowing a new cereal crop. Examples of this include light tillage (e.g., Kelly chaining) or when harvesting a shorter stature break crop (e.g., chickpea or lentil) which have been sown into cereal stubble infected by *Fp*. This is because the infected stubble is likely to be spread at harvest when collecting pods low to the ground. Reducing the height of infected cereals at the time of cereal harvest can prevent saprotrophic colonisation (Petronaitis *et al.,* 2022). This strategy may be useful in high FCR risk scenarios where shorter-stature break crops (e.g., chickpea and lentil) are planned in the rotation, to prevent the spread of *Fp* inoculum during break crop harvest.

Further field evidence of saprotrophic colonisation by *Fp*

Preliminary data from Northern Farming Systems (DAQ2007-002RTX) trials at four sites in northern NSW have provided further evidence of saprotrophic colonisation of post-harvest stubble by *Fp*. Stubble naturally infected with *Fp* was collected from four experimental sites from plots containing cereals (barley and/or wheat) in late 2022 and re-sampled 12 months later. Locations include 2 experimental sites at Trangie (one characterised as ‘grey soil’ and one ‘red soil’), one at Spring Ridge, and one at Narrabri. Main tillers from 25 stubble butts per plot were sterilised and cultured as described above, except that stem pieces were assessed in 5 cm increments. Note the average *Fp* incidence for each sampling time have been reported here without statistical analysis (Figure 4).

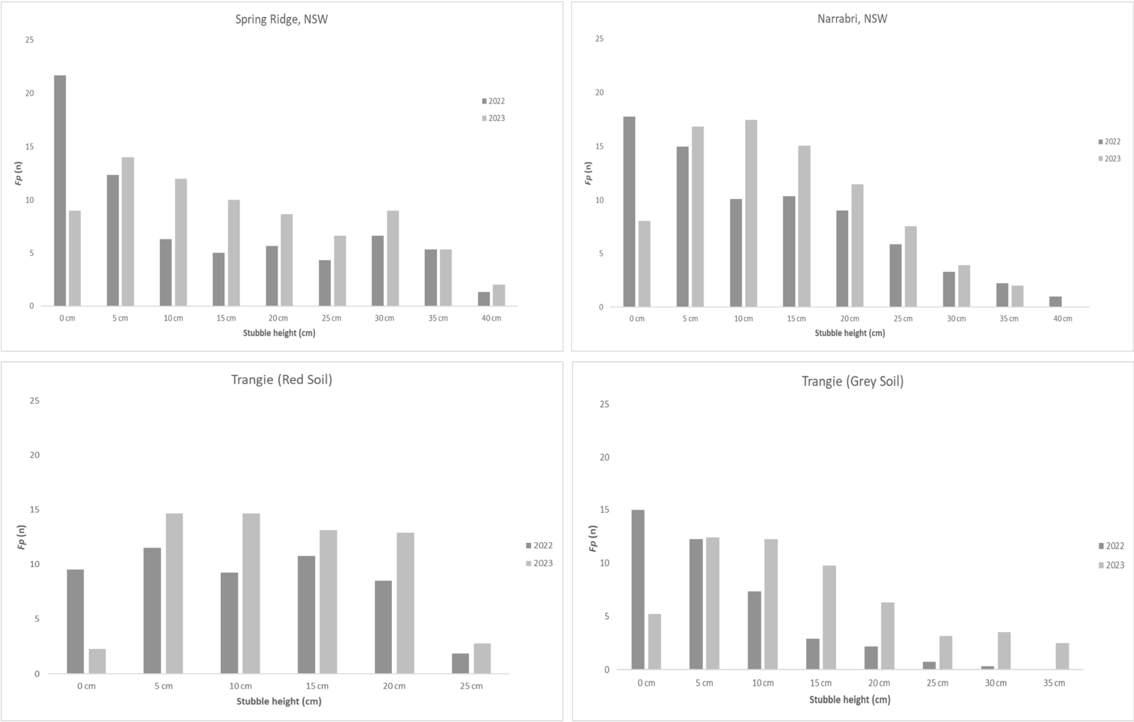

Figure 4. Preliminary data of the incidence of *Fp* recovery (*Fp* (n) being number of tillers producing *Fp* colonies) at 5 cm increments along the stubble length (stubble height, cm) at four different Northern Farming Systems experimental sites in northern NSW.

These preliminary data appear to have a similar pattern occurring at all four sites over the 12 months: there has been a general reduction in pathogen recovery in the crown (0 cm), maintenance of *Fp* incidence in the lower stem (5 cm) and then an increase in *Fp* incidence from approximately 10 cm and above (Figure 4). This reflects the rapid displacement of *Fp* from the crown by other soil microbes in the first year, but also reinforces how persistent *Fp* can be in the upper parts of retained cereal stubble. These results are in line with findings from randomised and replicated field experiments conducted on inoculated durum wheat stubble from 2019 to 2020 (Petronaitis *et al.,* 2022), suggesting that the pattern of saprotrophic colonisation is repeatable across different cereal crops, seasons and environments. Extensive stubble survey work conducted under a FCR co-investment (GRDC and NSW DPI, project code DPI2207-004RTX) will be used to further explore the frequency and extent of saprotrophic colonisation of stubble by *Fusarium* species in grower paddocks. This will help to better understand what factors may promote saprotrophic colonisation of retained cereal stubble by *Fp* in the farming system.

Conclusions

Preventing infection of cereal plants by *Fp* offers the greatest protection from FCR. For now, partial resistance to FCR offers benefits like slowing infection and reducing yield loss. Even the more resistant winter cereals such as oat can still get infected by *Fp* but can be asymptomatic (i.e., do not always express FCR) so *Fp* may go undetected in these crops. Inoculum may then accumulate after harvest once plant defence mechanisms are no longer active. Preliminary field results are showing that *Fp* incidence increases within the stems of stubble across a range of environments and crop types in the first year after harvest. More work is needed to understand what drives saprotrophic colonisation and the implications for FCR risk in future seasons.

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Concurrent session - Soils and technology

Soil constraints project - an update on the economic response of long term soil amelioration strategies

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Take home message

- Deep ripping compacted soils appears to have short term benefits but soil collapses shortly afterwards sometimes to a worse state than the original condition
- While tillage and nutrition treatments have stood out in historic wet seasons, the recent dry season indicates gypsum with ripping has improved water capture and yields
- Return on investment from treatments has occurred in shorter timeframes than expected
- Results from on-farm research trials indicate positive responses are soil dependent and the importance of finding the right solution for your soil.

Background

Vast amounts of soil in the northern grains region (NGR) are thought to be sodic, producing yield gaps between water-limited potential yield and currently achieved production (Hochman and Horan 2018, Orton 2018). This yield gap is a function of physical, chemical, and biological factors that reduce the capacity of soil to capture, store and release water and for plants to access water that has been stored. Many soils can be dispersive at many depths and can prevent root access through structural decline. Sodicity (a high exchangeable sodium percentage, ESP) is a major cause of aggregate dispersion and may compromise soil structure. Dispersive behaviour decreases both soil water availability and nutrient acquisition, increases risk of runoff and erosion, and impairs biological (soil microbial and plant root) activity. Acidity, salinity (both its presence through osmotic effects and its absence encouraging dispersion) and compaction further constrain yield potentials. The current project focuses on sodicity as the major constraint with often related constraints considered as compounding and/or interacting factors.

Amelioration of subsoil constraints is a challenging and expensive process. The benefits are likely to be seen through higher crop yields, arising from improved water storage and increased root access to stored water and nutrient availability. In wetter seasons, benefits may be observed by improved access to deep nutrition, however in poorer seasons where subsoil moisture is required to finish a crop, subsoil amelioration may have a larger impact on yield.

A series of linked investments is assessing the economics of ameliorating constrained surface and sub-surface soils in the NGR. The research into soil amelioration and management has two components; first is a set of six medium term (established in 2019) small-plot core experiments exploring mechanisms behind amelioration strategies (i.e., can sodicity be fixed). There are three sites in northern and central New South Wales (NSW) managed by the University of New England (UNE) located at Forbes, Armatree and Spring Ridge, and three sites in southern Qld managed by the Department of Agriculture and Fisheries (DAF) at Talwood, Millmerran and Dulacca. The second component of the investment is collaborating with growers (~20 sites) across the NGR with commercially relevant rates of ameliorant at commercially relevant scales to determine the feasibility of fixing soils on-farm.

This paper briefly reports on the field trial grain yield results from both the core site trials and on-farm research sites to-date and early responses to farm-scale implementation.

Core site experiments

The soils at the core sites have been comprehensively described in previous Update papers but are summarised below (Table 1). This research focussed on eliminating sodium as a constraint for the upper 50 cm of a soil profile. It was 'proof-of-concept' research, intended to explore effects on soil water storage and grain yield under various amelioration strategies.

Table 1. Brief site soil type description for core experimental sites

Site	Description
Armatree	Red Sodosol, not dispersive (0-10cm) to dispersive (10-20) surface, to strongly alkaline and dispersive at depth, compact surface layers
Forbes	Brown Vertosol, not dispersive (0-10cm) to dispersive (10-20) surface, to strongly alkaline and dispersive at depth
Spring Ridge	Black Vertosol, moderate ESP and salinity in surface, increasing to high ESP and salinity at depth, but both are non-dispersive due to the salinity
Talwood	Red/Brown Vertosol with surface soils not spontaneously dispersive, subsurface highly dispersive at 60-70cm
Millmerran	Grey/Brown Vertosol, surface and subsurface soils not spontaneously dispersive, very compact soil through the profile.
Dulacca	Grey/Brown Vertosol, surface soils not spontaneously dispersive but subsurface highly dispersive.

Similar treatment structures are used in both NSW and Qld, with both physical and chemical ameliorants, a range of options exploring impacts and/or interactions between tillage (shallow and deep), deep placement of nutrients (as inorganic or organic forms), surface and subsurface applications of gypsum to reduce ESP to < 3%, incorporating organic amendments (lucerne pellets in NSW and composted feedlot manure in Qld), and applying elemental sulfur (ES) to decrease soil pH (Table 2). For subsoil amelioration, gypsum rates were compared with organic amendment compost (Qld)/lucerne pellet (NSW) application, and elemental sulfur to dissolve natural calcium carbonate to produce gypsum in-situ. Organic matter also acts to limit aggregate dispersion (as well as providing nutrients at depth) and, whilst not reducing ESP, may act to improve water holding capacity and pore stability. A detailed description of treatments is presented in a previous GRDC Grains Research Update paper (see further reading). Gypsum rates ranged from 2 to 30 t/ha depending on the magnitude of the sodicity at each site.

Table 2. Treatment structure for core soil constraints sites. Blue text (**bold**) indicates treatments applied across NSW sites only. Treatments were Shallow-rip (S-Rip), Deep-rip (D-Rip), Banded nutrients (BN), Surface and/or Deep gypsum (Surf Gyp/Deep Gyp), Surface and/or Deep organic ameliorant (feedlot manure Qld/ lucerne pellets NSW) (Surf OM/Deep OM) and Deep elemental sulfur (Deep ES). All treatment indicates all amendments were applied together except fertiliser.

Description	**Rip**	**Fertiliser**	**Gypsum**	**Organic matter**	**Elemental sulfur**
Control					
S-Rip	Shallow				
S-Rip + BN	Shallow	Band			
S-Rip + BN + Surf Gyp	Shallow	Band	Surface		
D-Rip + BN	Deep	Band			
D-Rip + BN & Deep Gyp	**Deep**	Band	Deep		
D-Rip + BN + Surf Gyp	**Deep**	Band	Surface		
D-Rip + BN + (Deep + Surf) Gyp	Deep	Band	Surface + Deep		
D-Rip + BN + Deep ES + Surf Gyp	**Deep**	Band	Surface		Deep
D-Rip + BN + Deep BN	Deep	Surface + Band			
D-Rip + (Deep + Surf) OM	Deep			**Surface** + Deep	
D-Rip + Surf OM + Deep ES	Deep			**Surface** + Deep	Deep
D-Rip + All	Deep		Surface + Deep	Surface + Deep	Deep
D-Rip Control	**Deep**				

Results and discussion

While treatment responses are highly dependent on the location, season, crop, and the longevity of each treatment, the average yield advantage (relative to the control) indicates global trends for the 2020-2023 seasons. Various crop rotations were chosen by the growers on whose sites the long-term trials are situated, and these are included in Figure 2 and 3 captions.

Armatree: Responded strongly to physical disturbance, particularly deep ripping. This site also responds well when ameliorated to depth, helping to retain the benefits from disturbance. Especially in the recent drier 2023 season, gypsum amendments have increased water use efficiency along with treatments including organic matter and elemental sulfur (which forms gypsum in situ as well as relieving alkaline pH constraints). The large and continuing contributions of the organic matter treatments (in the form of lucerne pellets) continue to provide a source of nutrition and while this is not a commercially economic treatment, the positive yield response suggests there are beneficial contributions of large organic N inputs to sustainable nutrient cycling.

Forbes: The main constraint is compaction and therefore this site is highly responsive to deep ripping and amendments. The benefit of the deep rip control treatment is declining over time but where ripping was combined with amendments to stabilise the physical effect, longer lasting benefits have been observed. Gypsum, elemental S and organic matter treatments are all improving yields.

Spring Ridge: Shrink-swell soil with some deep structural and salinity constraints. Generally, not a responsive site. Some response to treatments containing high nutrition (in wet seasons) and deep ripping, with some minor responses to deep gypsum. Responses in the winter crop-double crop (following sorghum) appear to be related to root access of unused water from the preceding sorghum crop, more than treatment effects acting to increase the amount of available water or increase water capture.

Talwood: Early responses to nutrition, particularly where deep P was applied. The composted manure does not appear to be benefiting crop growth in the same way as inorganic fertilisers, unlike the other Qld sites. Note that one of the only two crops planted was heavily affected by midge and mice and as the OM amendments resulted in earlier flowering, their yield was less impacted by damage from midge and mice, when compared to treatments which flowered later.

Millmerran: Strong responses to additional nutrition (including OM). In drier seasons, trends towards stronger performance from gypsum and OM treatments. Overall the addition of band nutrients and surface spread gypsum appear to be having the most consistent yield benefits.

Dulacca: Responses to deep ripping and nutrition with surface applied gypsum trending towards some benefit in drier seasons. Responses in the winter crop-double cropped (following sorghum) appear to be related to access of unused water from the preceding sorghum crop more than treatment effects on bucket size or recharge.

Table 3. Relative yield advantage (%) above the control by site averaged across the 2020-2023 growing seasons. Control values are made to represent 100% and all treatments above 100% are greater than the control across all seasons, while those lower than 100% on average yield lower than the control. Treatments were Shallow-rip (S-Rip), Deep-rip (D-Rip), Banded nutrients (BN), Surface and/or Deep gypsum (Surf Gyp/Deep Gyp), Surface and/or Deep organic ameliorant (feedlot manure Qld/ lucerne pellets NSW) (Surf OM/Deep OM) and Deep elemental sulfur (Deep ES). All treatment indicates all amendments were applied together except fertiliser.

	Relative yield advantage (%) above control yield for 2020-2023					
Treatment	Armatree	Forbes	Spring Ridge	Talwood	Dulacca	Millmerran
Control	100	100	100	100	100	100
S-Rip	103	90	102	103	103	105
S-Rip + BN	102	109	102	124	101	119
S-Rip + BN + Surf Gyp	114	107	106	123	108	127
D-Rip + BN	113	130	97	124	108	120
D-Rip + BN & Deep Gyp	123	118	110	123	112	120
D-Rip + BN + Surf Gyp	123	123	99	122	108	126
D-Rip + BN + (Deep + Surf) Gyp	121	134	111	126	118	125
D-Rip + BN + Deep ES + Surf Gyp	117	124	99	121	111	121
D-Rip + BN + Deep BN	126	116	111	130	116	128
D-Rip + (Deep + Surf) OM	129	126	96	100	107	130
D-Rip + Surf OM + Deep ES	138	124	95	84	124	131
D-Rip + All	131	125	100	82	131	127
D-Rip Control	110	115	109			

Reflecting on the course of the first 4 years of the trial our observations are as follows. The details can be confirmed through careful study of the economic responses outlined below but space constraints preclude presenting all the yield data for 21 crop years individually.

There were up-front responses to ripping and nutrition at nearly all locations, but the effect of ripping is disappearing over time as expected. The advantages of ripping are significant though (see Table 3) and it may seem sensible to just regularly rip without amendment; a practice we would caution against. OM treatments have been maintaining advantage probably as a source of nutrition, particularly N and P, in most sites. The gypsum and deep ES treatments at the NSW sites do seem to stabilise soil structure effectively after ripping as indicated in the RTK elevation data we have collected over time. The surface of those plots remains higher, indicating lower bulk density (and hence better structure and porosity). Comparison of two years with different rainfall patterns at Armatree suggests that gypsum is more effective in drier seasons (and that perhaps there is a delay in the production of in situ gypsum by elemental sulfur application as we would expect) (Figure 1). Overall, there is evidence of re-engineering soil structure through calcium (Ca), pH and carbon additions.

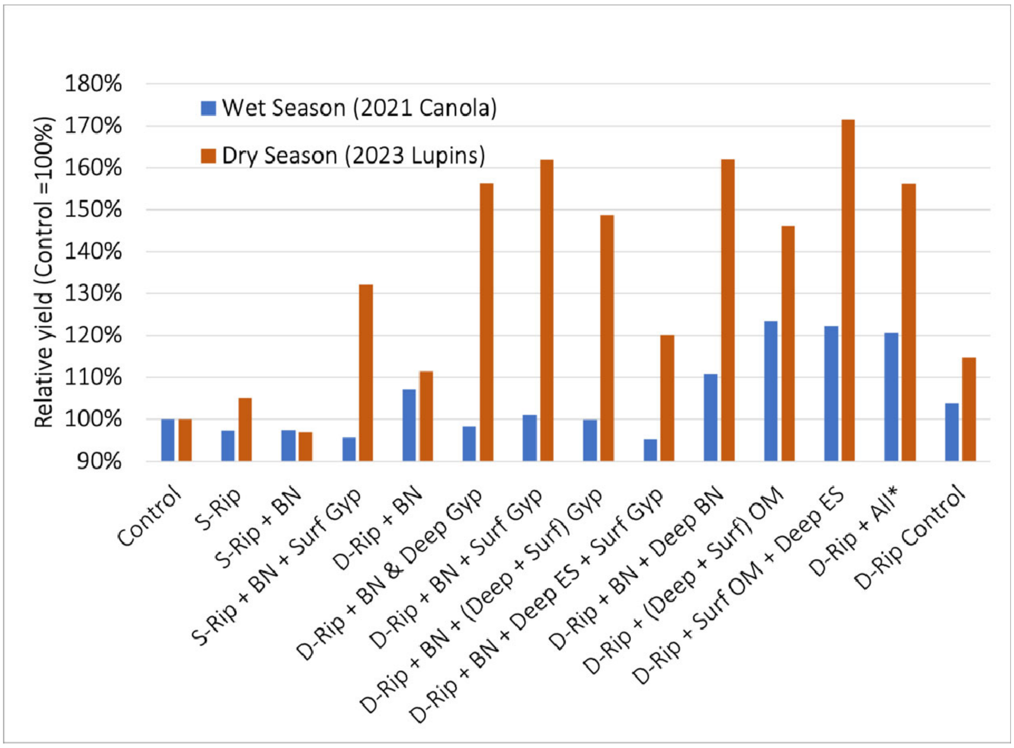

Figure 1. Relative yield (compared with control treatment) for a reference wet season (2021) growing canola at the Armatree core experimental site and a reference dry season (2023) growing lupins at the same site. Treatments were Shallow-rip (S-Rip), Deep-rip (D-Rip), Banded nutrients (BN), Surface and/or Deep gypsum (Surf Gyp/Deep Gyp), Surface and/or Deep organic ameliorant (feedlot manure Qld/ lucerne pellets NSW) (Surf OM/Deep OM) and Deep elemental sulfur (Deep ES).

We now have a long enough elapsed time period to begin to examine the economics of subsoil intervention. We have made a series of what we consider sensible assumptions, in pulling together these graphs.

The economic modelling was largely in line with that reported by Geoff Cockfield et al. (Final Technical Report project in USQ1803-003RTX) and have been carried forward. Treatment costs were estimated from a combination of previous studies, grower estimates, expert opinion and average market prices of inputs. The application costs include amendment material costs at farm gate (product prices + transport and handling) and costs associated with applying amendments including labour (paid or imputed) and all machinery costs (operation and depreciation), derived from grower estimates and/or contract machinery operation prices.

Variation from this data for this report is minor but includes a reduction of input costs of lucerne pellets for NSW core sites from a pelletised product cost to a bulk lucerne cost. We have updated crop variable running costs based on a generalised agricultural management plan (using practicing agronomists) per crop for a model area in the centre of the northern region (Moree) and applied this globally throughout all sites.

We have calculated the cumulative net return for each intervention at all six core sites (Figures 2 and 3). Note that where a site had negative return recorded in one or more crops, the correct way to read the total return for each intervention, requires the reader to remove the loss from the top of each bar. We have also estimated the payback period for each intervention for each site (Table 4).

Armatree: Following three wet and one dry season, return against deep ripping treatments with amendments ranges between $1000-2000 increase in income per ha above the control (Figure 2A). Based on the 4-year average, payback periods for ripping with gypsum ranges between 2 and 6 years, with benefits appearing particularly in dry seasons (Table 4).

Forbes: Across three crops at Forbes, net returns of ripping treatments against the control ranged between $2200-$3300 per ha higher than the control. Deep ripping with banded nutrients or with gypsum had the greatest returns after 3 crops. For these treatments payback periods were less than 1 year for nutrition, increasing to almost 2 years for higher input rates.

Spring Ridge: Generally lower benefits were realised from the Spring Ridge site across 4 crops, with a range of cumulative income benefits from deep ripping between a net cost of $400/ha to a net benefit of $300/ha better than the control, with most treatments doing better than the control.

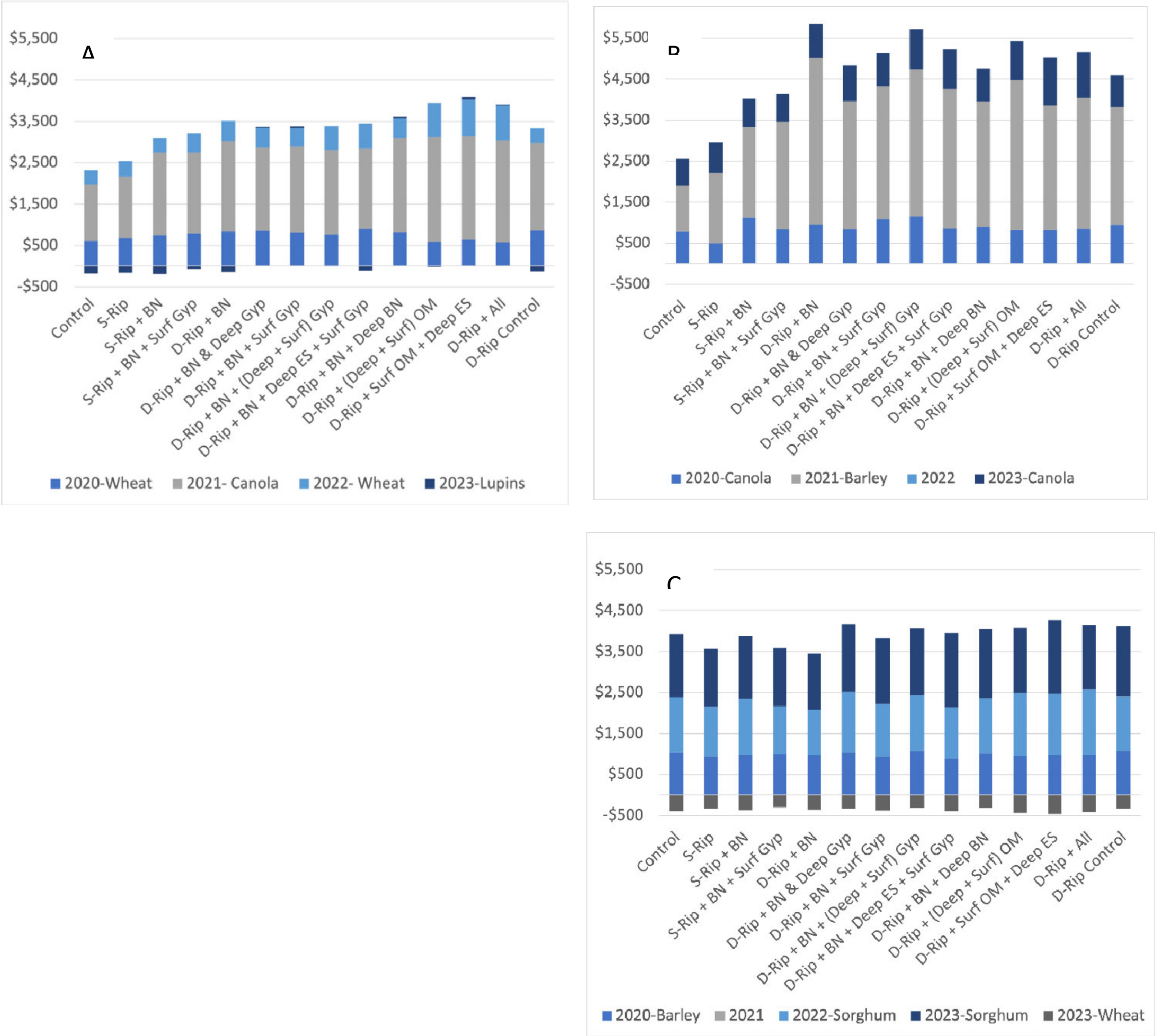

Figure 2. Cumulative net return from crops grown between 2020 and 2023 for subsoil amelioration treatments. Values presented are the mean for each treatment from the A) Armatree, B) Forbes and C) Spring Ridge experimental core sites. Legend captions indicate the year and crop planted each season. Years followed by no crop indicate a fallow. Treatments were Shallow-rip (S-Rip), Deep-rip (D-Rip), Banded nutrients (BN), Surface and/or Deep gypsum (Surf Gyp/Deep Gyp), Surface and/or Deep organic ameliorant (feedlot manure Qld/ lucerne pellets NSW) (Surf OM/Deep OM) and Deep elemental sulfur (Deep ES).

Talwood: intervention for the two crops over 4 years ranges from a net cost of $300/ha for some of the high-rate treatments (where treatments have depressed yields), to a net income benefit over the control of $667/ha net income for the deep rip with high rates of fertiliser. The deep and surface applied gypsum and deep P treatments also performed quite well, with higher yields compared to the control treatments. Combinations of ripping and additional nutrition (deep) in the form of fertiliser appear to be having benefits at this site.

Dulacca: 4-year return (5 crops) resulted in some treatments with cumulative income of up to $762 return per ha higher than the control treatments. Across all crops, the best returns were from treatments that included deep gypsum.

Millmerran: 4-year return (4 crops) resulted in some treatments with cumulative income from $450 to $1000/ha higher than the controls. This site responds strongly to deep applications of banded nutrients, treatments which include banded nutrients are providing better returns against controls. This is mostly a replacement of depleted subsoil P which requires ripping interventions to incorporate. Some responses to OM amendments and surface gypsum applications although the relatively cheaper cost of composted manure at this location makes the payback period much shorter for the OM treatment. There is a response to banded nutrition at this site, but the structural constraint appears to be a greater limit to productivity.

Figure 3. Cumulative net return from crops grown between 2020 and 2023 for subsoil amelioration treatments. Values presented are the mean for each treatment from A) the Talwood, B) Dulacca and C) Millmerran experimental core sites. Legend captions indicate the year and crop planted each season. Years followed by no crop indicate a fallow. Treatments were Shallow-rip (S-Rip), Deep-rip (D-Rip), Banded nutrients (BN), Surface and/or Deep gypsum (Surf Gyp/Deep Gyp), Surface and/or Deep organic ameliorant (feedlot manure Qld/ lucerne pellets NSW) (Surf OM/Deep OM) and Deep elemental sulfur (Deep ES).

Payback period is obviously strongly linked to the productive potential of an environment and in areas with lower yield potential, the relative benefits are somewhat lower and payback periods correspondingly longer. Of note are the longer payback times for soils with higher buffer capacity, which reflects the higher inputs required to significantly change the soil properties.

Based on the last 4 years rotation, in general, QLD sites suggest best economically viable management strategies involve low capital expenses on inputs with some returns suggesting tillage and nutrient treatments are paying the bills.

NSW sites with higher levels of response (Armatree and Forbes) suggest that payback periods for more expensive treatments are shorter than expected and that more comprehensive treatments are potentially justified. While some of the treatments have indicated quick return on investment, and hence payback periods are short, the longevity of these treatments is also shorter and the incrementally improving treatments are likely to show much greater cumulative returns in time (e.g. ES and OM treatments).

The Spring Ridge site indicates long payback periods as the yield advantages from treatments have been limited (the site appears to be acting as unconstrained much of the time perhaps because the higher salinity counteracts some of the dispersion we would expect due to the high ESP).

Table 4. Payback period of initial amelioration investment based on the average net return following the first 4 years following application. Variable expenses are generalised and based on commonly recommended inputs. Returns are relative to the yield and quality of harvested grain.

Payback period of initial investment (years)						
Treatment	Armatree	Spring Ridge	Forbes	Talwood	Dulacca	Millmerran
Control	-	-	-	-	-	-
S-Rip	1		1	3	2	
S-Rip + BN	1		0	2	43	1
S-Rip + BN + Surf Gyp	2		2	8	19	4
D-Rip + BN	1		0	2	6	2
D-Rip + BN & Deep Gyp	3	12	2	12	25	10
D-Rip + BN + Surf Gyp	2		1	8	22	5
D-Rip + BN + (Deep + Surf) Gyp	4	24	2	18	19	10
D-Rip + BN + Deep ES + Surf Gyp	6	313	3	19	52	13
D-Rip + BN + Deep BN	1	6	1	4	9	3
D-Rip + (Deep + Surf) OM	14	251	9	60	17	6
D-Rip + Surf OM + Deep ES	9	66	7		13	12
D-Rip + All	19	176	13		23	33
D-Rip Control	0	2	0			

On farm research (OFR) sites

83% of OFR sites (sampled using plot header) resulted in yield advantages to amendments ranging from 20-83% increase in yield (average 41% increased yield for the best performing treatment at each site). It should be noted that these results are drawn from the drier 2023 season where there were some poor yields. Hence treatment advantages might not be large tonnages even if their percentage increase is significant. Various treatments worked better at different locations, so outcomes were very site dependent. Key constraints for each soil are outlined in Table 5.

Table 5. Brief site soil type description for responsive On Farm Research sites 2023

Site	**Description**
Parkes	Red Sodosol with moderately sodic (non-dispersive) topsoil neutral pH and high bulk density over a sodic, dispersive and alkaline subsoil with high bulk density. P availability (Colwell) is 32 mg/kg in the surface (0-10cm) and 6 mg/kg at depth (10-20cm)
Armatree	Red Sodosol with moderately sodic and dispersive topsoil, acid pH and high bulk density over a sodic, dispersive and alkaline subsoil with high bulk density. P availability (Colwell) is 40 mg/kg in the surface (0-10cm) and 8 mg/kg at depth (10-20cm). Moderate salinity throughout the profile.
Millmerran	Grey/Brown Vertosol with sodic and non-dispersive topsoil, neutral pH. Sodic at depth with dispersion increasing with alkaline pH. P availability (Colwell) is 28 mg/kg in the surface (0-10cm) and 6 mg/kg at depth (10-20cm)
North Star	Red Chromosol with non-dispersive soil throughout the profile. The profile is generally not sodic with an increase in patches at depth. pH is generally neutral but alkaline at depth. P availability (Colwell) is 28 mg/kg in the surface (0-10cm) and 8 mg/kg at depth (10-20cm)
Croppa Creek	Red/grey soil (variable site) with a non-sodic surface increasing to sodic at depth but generally not-dispersive. Neutral pH in the surface increasing to highly alkaline at depth with some salinity (EC).

At Millmerran the addition of surface lime and gypsum with ripping increased yields by 33% against deep ripping alone, while at Armatree, lime increased yields by 28% while gypsum was less effective. Both sites were highly compact and the addition of calcium (as lime to low pH surface soils) seems to have improved the maintenance of soil structure following disturbance. At North Star, deep P with ripping resulted in an 83% yield benefit. This is consistent with the generally low levels of available P at depth and the reliance on stored moisture this season. At Parkes, the best treatments had a 40% increase in yield compared with controls (in a season with cooler and moister grain filling conditions), with the largest responses to high rates of OM (manure, biosolids etc) when combined with lime or gypsum (all without ripping). These treatments are likely to have had significant influence on the structure and nutrition in this lighter but compact red soil. Deep ripping (no amendment) also provided substantial benefits at some sites (including Parkes, Millmerran and Armatree), however core site data indicates that these treatments may be short lived and recommending this has potential implications for long term soil structural and soil carbon declines, so care should be taken.

For the five sites measured with hand harvests in strips (less statistical power), two produced statistically significant results. Croppa Creek -manure, gypsum and deep fertiliser in combination provided the greatest benefits for growth with an 114% increase (double) in canola yield. Gypsum by itself and manure by itself had little benefit but the combination was important. This suggests that where deep constraints occur, improving structure can help with plant access of water but nutrition has to support increased yield potential. The North Star site was variable but had a trend to increased yield with added P and gypsum.

Several of the OFRs that demonstrated yield responses required a combination of amendments - e.g. extra nutrition and gypsum together, with little response to individual amendments. If looking at amending a strip or paddock, consider including combinations of amendments depending on your site. It is important to note that improving available water (through structural improvements) isn't worth much if you don't have the nutrition to support additional growth. Core site experiments have not provided this insight as all structural treatments had additional nutrition supplied.

Further reading

Ameliorating sodicity; what did we learn about ameliorating sodicity constraints with a range of treatments? Yield responses to ripping, gypsum and OM placement in constrained soils. GRDC Grains Research Update paper 2022. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/03/ameliorating-sodicity-what-did-we-learn-about-ameliorating-sodicity-constraints-with-a-range-of-treatments-yield-responses-to-ripping,-gypsum-and-om-placement-in-constrained-soils

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Mapping soil constraints in 3D for more informed decisions on crop inputs and soil amelioration - a new decision support tool

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Notes

Taking the first steps to automated agronomy – don't be alarmed!

Tim Neale, DataFarming

Key words

automation, agronomy, sensors, satellites

GRDC codes

DFL2312-001RTX, DFL2304-001RTX, DFL2304-002RTX

Take home message

GRDC has embarked on several new ambitious projects to explore, research, test, and navigate the pathway to autonomy in grain production systems. A key part of this is crop agronomy. Our three projects are examining how we can detect weeds, diseases, pests, nutrition disorders, and other anomalies using sensors, artificial intelligence, and satellite imagery – and feed this information back to machinery (robots) to treat affected areas.

The projects are in the very early stages; however, they aim to focus on:

1. Green on brown weed detection (fallow) from satellite, and section control herbicide application
2. Green on green weed detection (e.g. ryegrass in cereals) from satellite, and section control application
3. Early-stage disease detection (foliar diseases in cereals, rhizoctonia, charcoal rot) from satellite and targeted control with fungicides/cultural practices
4. Early detection of anomalies in crop growth using satellite imagery and providing alerts to farmers and agronomists
5. Use of 'drone in a box' technology for targeted crop scouting
6. Fusion of a number of datasets to help make decisions (yield, as-applied, imagery, EM, topography, BioScout, protein)
7. Use of natural language models/AI to produce pesticide/nutritional recommendations
8. Looking at the barriers to adoption of autonomous agronomy, and how an agronomist role might change over time.

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Predicting and mapping grain protein content to better understand variability – utilising John Deere's new Harvestlab™ 3000 grain sensing system

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Key words

precision agriculture, grain protein content, machine learning, grain protein sensor, yield

GRDC code

UOS2002-001RTX, UOS2206-009RTX

Take home message

- Maps of grain protein content are useful for understanding how and why grain protein varies and for informing management decisions
- While maps of grain protein content are not available for every field, farm, and season, a combination of on-farm and/or publicly available data can be used to build a model to predict and map grain protein content to fill information gaps across fields and farms
- Predictions of grain protein content within a field can be improved if at least one header is equipped with a grain protein sensor within a field at harvest
- The relationship between yield and grain protein content is not always negative. Further research is needed to understand what is driving variations in grain protein content within and between fields, farms, and seasons.

Background

Grain protein content is one of the key determinants of the price that grain growers receive for grain. Like grain yield, within and between field variation of grain protein content can be large (Figure 1). Grain protein content is determined by a range of factors, including crop type, crop variety, nitrogen available in the soil and applied as fertiliser, and moisture availability during the growing season. Accurately measuring grain protein content within a field, across a farm, and over multiple seasons, can be useful to manage the quality of marketed grain, better understand and improve nitrogen nutrition decisions, and assess the outcomes of agronomic programs or consider alternate management strategies (Whelan, 2019).

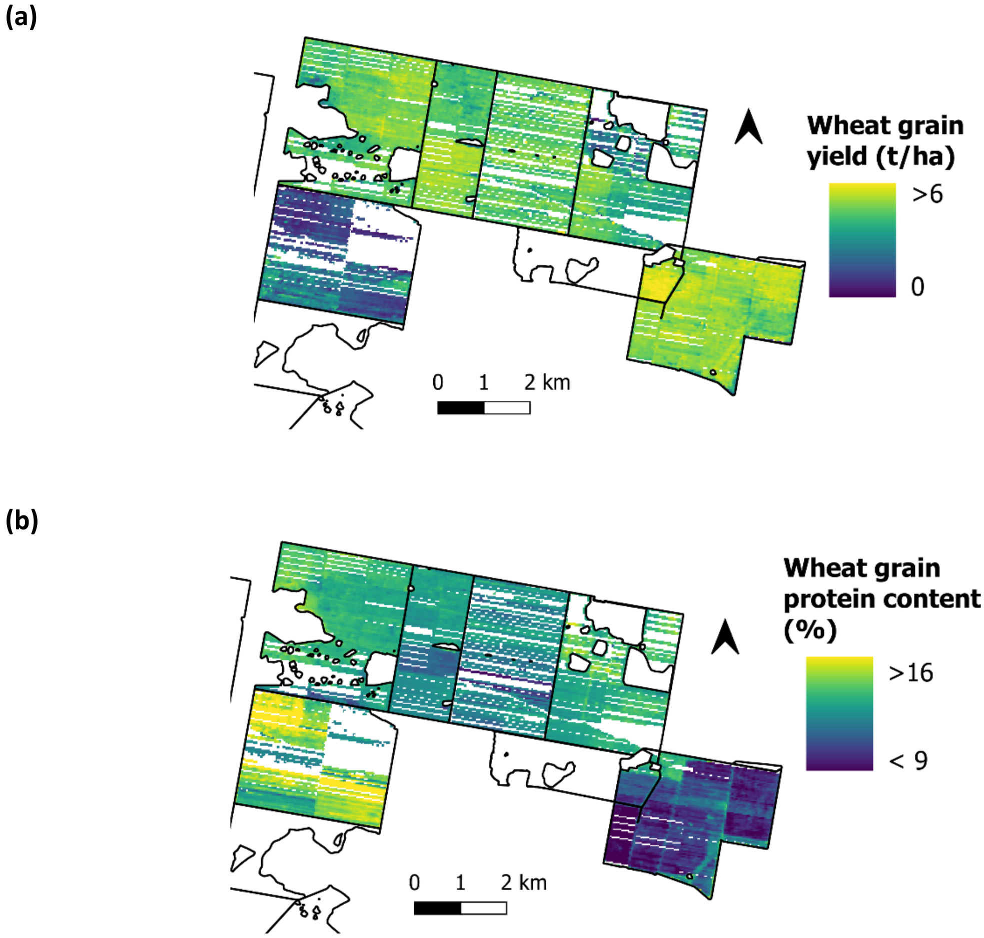


Figure 1. Spatial variation of (a) wheat grain yield, and (b) wheat grain protein content across a northern New South Wales farm.

In 2023, John Deere commercially released the HarvestLab 3000^{TM} grain sensing system in Australia for real-time, on-the-go measurement of protein, starch, and oil values for wheat, barley, and canola. The sensor is mounted onboard the harvester and uses near infrared (NIR) spectroscopy to take measurements of continuous grain flow. The sensor emits NIR radiation which passes through a glass window onto the grain sample. A portion of this radiation is absorbed by the grain, while some is reflected back to the sensor. This NIR reflectance is then measured and the wavelengths are analysed and used to determine properties such as grain protein, oil, or moisture content.

While more growers are adopting the use of grain protein sensors, maps of grain protein content are not available across every field, farm, or for every season. This is resulting in considerable knowledge gaps. There is the potential to utilise this grain protein sensor data to understand how and why grain protein content varies and to improve management. Together with grain yield maps, grain protein content maps can provide an opportunity to make future nitrogen management decisions and optimise both yield and quality, for more profitable and environmentally sustainable production systems.

Today, we have vast amounts of public data that is free to access, including remote sensing imagery. These data layers can represent variability and the factors driving grain protein, including soil moisture stress or potential limitations like a nitrogen deficiency, both within a season and over longer time scales. These publicly available data layers can be used on their own, or in conjunction with on-farm data such as yield maps or cropping history information, to model and map grain protein content.

We present a data-driven, machine learning approach which utilises a combination of on-farm and/or publicly available data layers and sources to model and predict grain protein content within fields and fill knowledge gaps across farms. The aims of this project were to:

1. Create a model to predict grain protein content in areas of a farm without a grain protein sensor, using readily available data;
2. Assess the benefits of using on-farm and/or publicly available data for improving predictions; and
3. Map grain protein content within fields at different spatial resolutions.

In addition, the relationship between grain protein content and yield was also examined spatially within fields.

By building a predictive model to predict grain protein content in areas of a farm without a grain protein sensor, growers and advisors can be equipped with the necessary information and tools to make better management decisions for more profitable and environmentally sustainable production systems. As growers are faced with increasing production costs, maps of grain protein content can be used in conjunction with yield maps, input costs, and the final grain price to map gross margins and better understand the costs of variable grain protein content. Likewise, grain protein maps can be useful to understand nitrogen dynamics and agronomy, including variation in nitrogen availability and the implications of fertiliser decisions prior to or during the growing season. Improving this understanding can have positive outcomes for on-farm economics, production efficiencies, and environmental sustainability. This project aims to demonstrate the value in collecting grain protein data, and the use of this information alongside the growing amount of on-farm and publicly available information to better understand grain protein content.

Method

We present the use of grain protein sensor data from the John Deere HarvestLab 3000^{TM} grain sensing system for mapping and modelling grain protein content in ~80 fields of winter wheat from 2020 to 2022 across two large aggregations in Western Australia (WA) and northern New South Wales (NNSW). Different combinations of on-farm and/or publicly available data layers that can represent variability in grain protein content and the factors that drive this variation were used with machine learning (Random Forest) models to predict and map grain protein content. All data used within the models are described in Table 1. All on-farm data, including agronomic details such as sowing/ harvest dates and variety, and cropping history, was accessed via Precision Cropping Technology (PCT) AgCloud. All publicly available data layers, including remote sensing imagery and terrain attributes, were accessed via the R package *'dataharvester'* (Haan *et al.,* 2023; Harianto *et al.,* 2023), and are available for every field and farm across Australia. Two different data combinations were compared to assess the value of collecting field-specific information compared to using only publicly available data layers:

1. On-farm + publicly available data: all on-farm and publicly available data was used to build predictive models for grain protein content;
2. Publicly available data only: no on-farm information was used to build predictive models for grain protein content, and only publicly available data layers were used.

Table 1. On-farm and publicly available data layers for modelling grain protein content using machine learning (Random Forest) models.

Data	Source	Data category		Data layers
On-farm	PCT AgCloud	Agronomic data		Sowing date
				Harvest date
				Variety
		Cropping history		1 season prior
				2 seasons prior
Publicly available	*'dataharvester'*	Remote sensing (Sentinel-2A, 10 m spatial resolution)	Current season maximum	Normalised Difference Red Edge (NDRE)
				Normalised Difference Vegetation Index (NDVI)
				Enhanced Vegetation Index (EVI)
			Long-term averages	EVI: 1, 5, and 10 year averages
				NDVI and Red Band: 5th, 50, and 95th percentiles
			Bare Earth Imagery	
		Terrain attributes	Digital Elevation Model	
			Radiometrics	Dose rate, Thorium, Uranium, Potassium

Grain protein sensors may not be available across all fields or farms. In some cases, entire fields may not have maps of grain protein content, or only one header may be equipped with a grain protein sensor. This leaves information gaps across parts of or for an entire field. These two scenarios were tested using two validation methods:

1. A leave one field-year-out cross validation (LOFYOCV) method was used to simulate cases where grain protein sensor data was not available for an entire field; or
2. A two-fold cross validation (2FCV) method was used to simulate cases where only one header is equipped with a grain protein sensor and grain protein data is only available for part of a field.

Grain protein maps were then produced for the different data combinations (on-farm and/or publicly available data) and validation methods (LOFYOCV or 2FCV). Predictions were made at a fine (30 m) resolution and were also aggregated to management zones within each field to reduce noise and provide maps of grain protein content that are more informative for management decisions such as for nitrogen removal and prescription application maps. Each field was divided into six management zones based on yield data for the current season by splitting the data into six even categories. For model validation, all predictions were compared to the observed grain protein values recorded by the John Deere HarvestLab 3000™ grain sensing system at the same location.

While this study did not aim to identify the drivers of grain protein content variability within each model, the relationship between grain yield and protein content was explored. Local correlations between grain yield and protein content were mapped across each field to better understand how this relationship varies spatially and between seasons.

Results and discussion

The model quality was assessed by calculating the root-mean-square error (RMSE) and the Lin's Concordance Correlation Coefficient (LCCC). The RMSE represents the accuracy of the predictions (how close the predictions are to the true values) and provides a measurement of prediction accuracy in the variable's units (in the case of grain protein content, %). The LCCC is a measure of both the precision (how close the predictions are to each other) and the accuracy of predictions. The LCCC value explains the fit of the observed and predicted values to a 1:1 line, where values of 0 are a poor fit (poor agreement between observed and predicted values) and 1 for a perfect fit (perfect agreement between observed and predicted values). The LCCC is unitless and is useful for comparing the precision and accuracy of predictions between variables of different magnitudes (Lin, 1989).

Two different data combinations were tested: on-farm + publicly available data, and publicly available data only. Predictions were made at a fine-resolution (Fine-Res) and were aggregated to management zones (M. Zones) within each field, and models were validated using leave one field-year-out cross validation (LOFYOCV) and two-fold cross validation (2FCV). The results are presented in Figure 2.

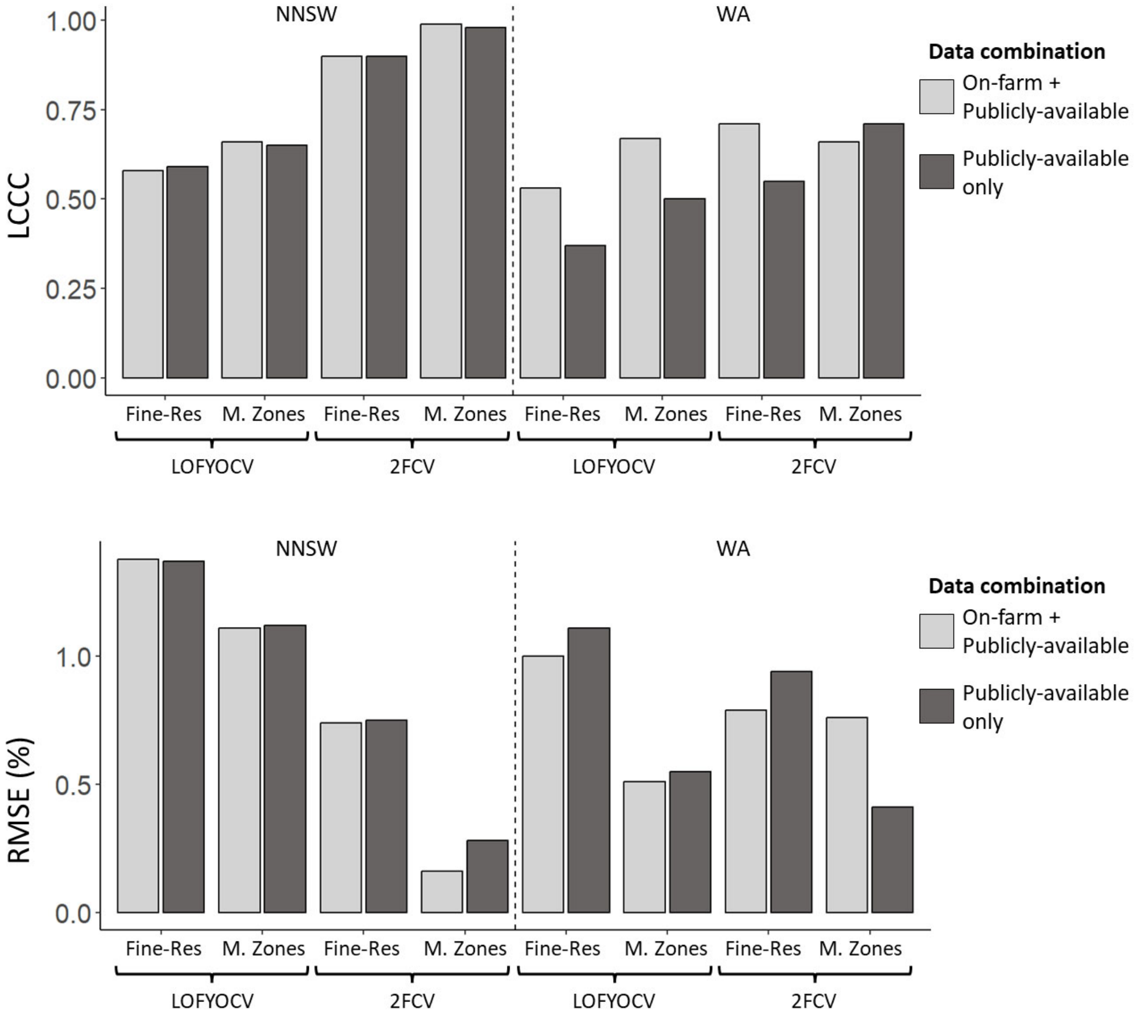
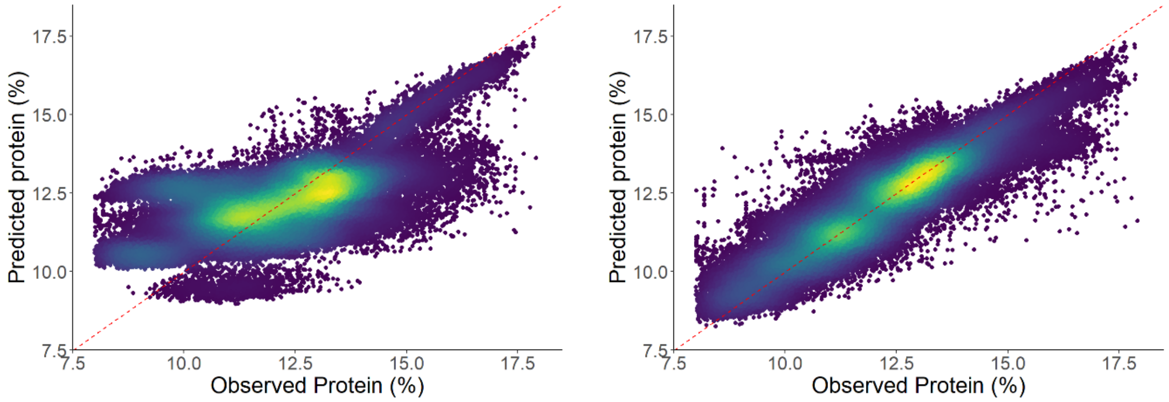


Figure 2. Lins Concordance Correlation Coefficient (LCCC) and Root Mean Square Error (RMSE) values for northern NSW (NNSW) and Western Australia (WA) aggregations for models built using two different data combinations: on-farm + publicly available data layers, and publicly available data only. Fine-Res: Fine-resolution, M. Zones: Management zones. RMSE values are presented in the units of grain protein content, %.

For the NNSW aggregation, there was little difference in both the LCCC and RMSE between the two different data combinations. This suggests collecting on-farm data (e.g. yield data, sowing and harvest dates, cropping history) is not necessary and publicly available data alone is sufficient to build a predictive model for grain protein content in NNSW. For the WA aggregation, the combination of both on-farm and publicly available data layers produced better model quality results.

The agreement between observed and predicted grain protein content values when validated at a fine (30 m) resolution and when aggregated to management zones using the LOFYCV and 2FCV methods are presented in Figure 3 for the NNSW aggregation. Model quality statistics from the data combination that had the best performance (i.e. highest LCCC and lowest RMSE) for both the NNSW and WA aggregations are presented in Table 2.



A) LOFYOCV – fine-resolution **B) 2FCV – Fine-resolution**

C) LOFYOCV – Management zones **D) 2FCV – Management Zones**

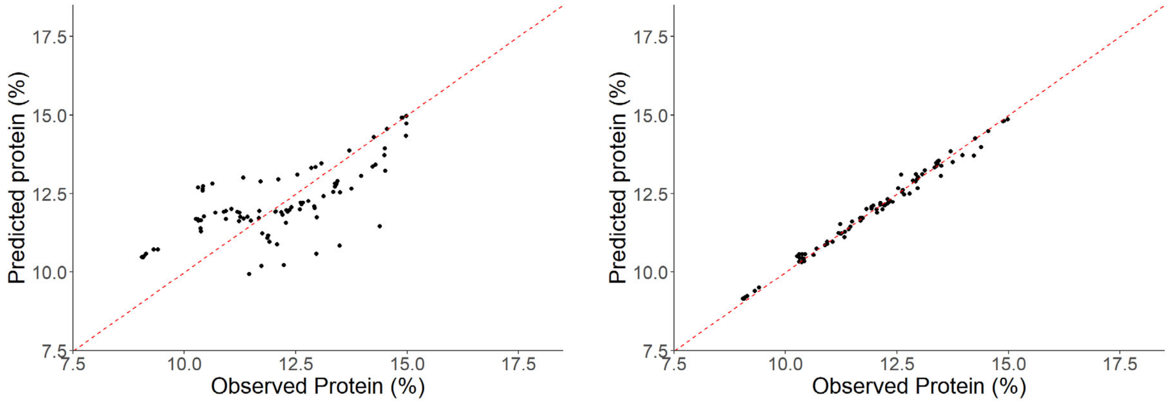


Figure 3. Observed and predicted values of grain protein content from Random Forest models for the northern New South Wales (NNSW) aggregation. Models were validated using leave one field-year out cross validation (LOFYOCV; A and C) and two-fold cross validation (2FCV; B and D) with validations performed at a fine (30 m) resolution (A and B) and aggregated to management zones (C and D).

Table 2. Model quality statistics for grain protein content (Random Forest) models for the northern NSW (NNSW) and Western Australia (WA) aggregations. Predictions were made at a fine-resolution and were aggregated to management zones using the leave one field-year-out cross validation (LOFYOCV) and two-fold cross-validation (2FCV) methods. Model quality statistics (Lins Concordance Correlation Coefficient, LCCC; Root Mean Square Error, RMSE) are presented for the best data combination for each aggregation (NNSW = Publicly available data only, WA = On-Farm + Publicly available data).

Aggregation	Validation Method	Statistic	Fine resolution	Management Zones
NNSW	LOFYOCV	LCCC	0.59	0.65
		RMSE	1.37	1.12
	2FCV	LCCC	0.90	0.98
		RMSE	0.75	0.28
WA	LOFYOCV	LCCC	0.52	0.67
		RMSE	1.01	0.50
	2FCV	LCCC	0.70	0.92
		RMSE	0.80	0.23

Overall, model quality improved when predictions were aggregated to management zones, compared to when they were validated at a fine (30 m) spatial resolution (Figures 2 and 3, Table 2). While fine-resolution grain protein maps provide a high-degree of detail describing the spatial variability of grain protein content, these may be difficult to use to make operational decisions. When implementing precision agriculture (PA) practices it is common practice to divide a field into management zones. Aggregating grain protein content predictions to management zones can smooth small-scale noise and may be useful for informing management decisions such as nitrogen prescription maps.

Model quality was better when the 2FCV method was used compared to the LOFYOCV method (Figures 2 and 3, Table 2). This is logical because only half of a field is removed when using the 2FCV method, compared to the entire field being removed during LOFYOCV. By retaining half of the field in 2FCV, valuable field-specific information that may describe and explain variability in grain protein content is used in the model building process. The 2FCV method simulated cases where only one header within a field is equipped with a grain protein sensor, resulting in grain protein content data being collected for only half the field. On the other hand, the LOFYOCV method simulated cases where grain protein data is not available for an entire field. Model quality can be improved if some harvest data within a field is collected for the current season. Available data for part of a field may help capture any seasonal interactions between grain protein and environmental (e.g. rainfall or temperature) or soil conditions (e.g. constraints or moisture), or management implications (e.g. variety choice, fertiliser application).

While the uptake of grain protein sensors is increasing, it is unlikely that we will see a map of grain protein content for every field, farm, or season in the near future. Here, we highlight the potential to use existing on-farm agronomic information and publicly available data layers to model and map grain protein content to fill-in previously unmapped areas of a farm. Publicly available data layers were chosen to represent the factors that drive variability in grain protein content, meaning that bespoke soil samples or Electromagnetic (EM) surveys, for example, are not required for individual fields and growers should not be burdened with additional data collection. Further, this approach did not aim to produce a bespoke model for every field, and instead one model was built for each aggregation. The addition of more fields and seasons worth of data within an aggregation should improve model performance by capturing a greater range of growing conditions. If several seasons of yield and protein data can be collected which represent a range of environment conditions and management scenarios, it is likely that we will be able to map previous seasons of grain protein content data to better understand long-term trends or make forecasts for the current or future seasons.

Figure 4 shows a comparison of observed (Figure 4a) and predicted (Figure 4b) grain protein content values at a fine resolution for a field in the NNSW aggregation using the 2FCV method.

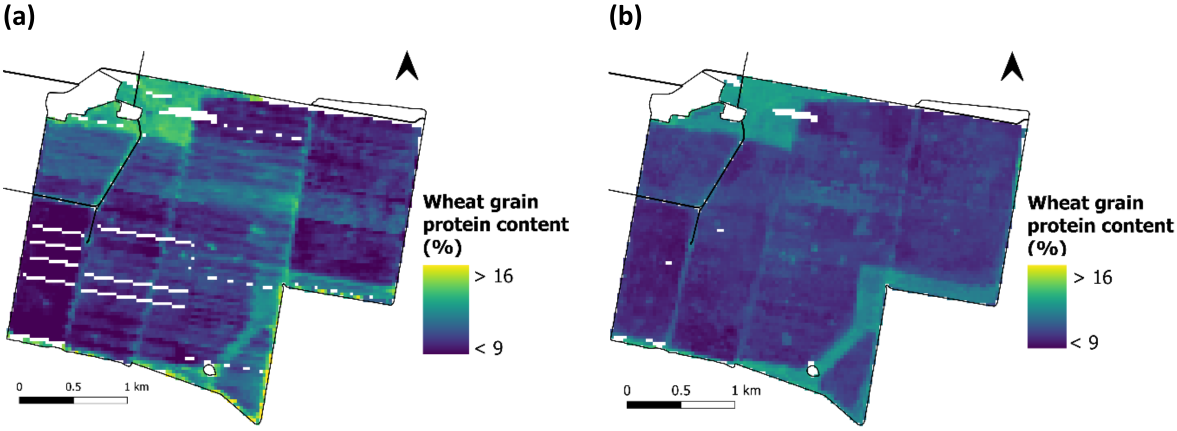


Figure 4. Observed grain protein values (a) were compared with Random Forest model predictions at a fine-resolution using the two-fold cross validation (2FCV) method (b).

Overall, model quality for the entire NNSW and WA aggregations was moderate-to-good (Figures 2 and 3, Table 2), but it is still unclear what is driving variability. The factors driving grain protein content predictions within models will be examined in future research, but seasonal fluctuations in environmental conditions and management decisions may influence predictions between fields and seasons. High-yielding, high-protein grain may be desirable for some markets, but grain yield and protein content are often negatively correlated. This inverse relationship is considered to be the result of grain protein dilution by total carbohydrates, which is predominately driven by soil moisture and nitrogen availability. In non-limiting soil moisture situations, increasing the soil nitrogen supply will typically increase grain yield, whereas increasing the nitrogen supply where soil moisture is severely limited will typically increase grain protein (Whelan *et al.,* 2009). Generally, high yield/low protein at harvest may be the result of sub-optimal nitrogen management, whereas low yield/high protein may be the result of a lack of soil moisture supply and a dry finish (Scott, 2022). Other factors such as variety, environmental conditions, and soil constraints also influence the grain yield/protein relationship.

To explore this yield/protein relationship, local correlations between grain yield and protein content were mapped within fields and an example is shown in Figure 5. These grain yield and protein content maps showed considerable variation in both the strength and direction of the relationship between yield and protein.

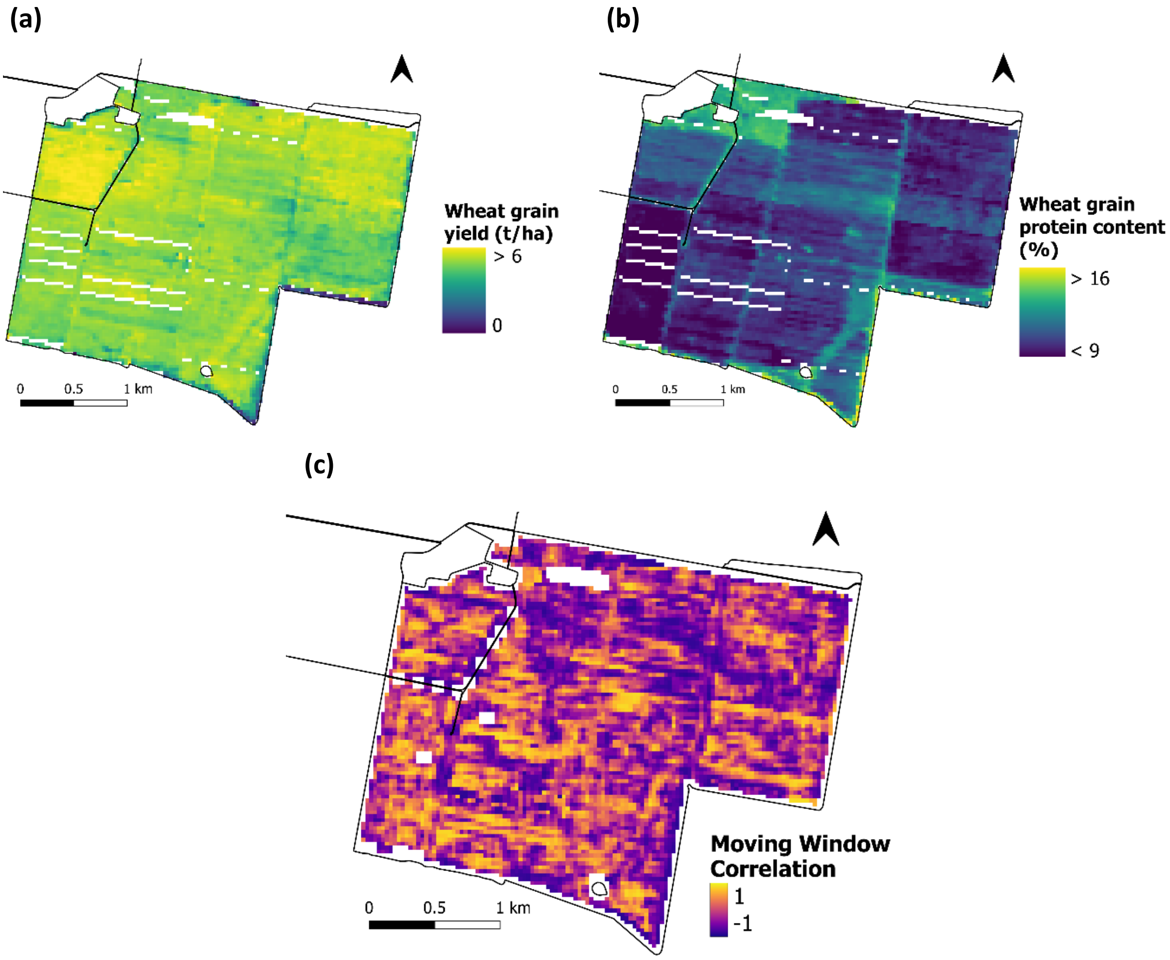


Figure 5. Observed wheat grain yield (t/ha; a) and protein content (%; b) for a field in northern NSW, and their correlations across the field (c). Values closer to -1 indicate a negative relationship between yield and protein, whereas values closer to 1 indicate a positive relationship between yield and protein.

Future research aims to investigate these relationships further through the use of interpretive machine learning models and additional data layers. Typically, machine learning models like Random Forest models are considered a "black box", where it can be difficult to understand what factors are driving predictions within the model. Interpretive machine learning can be used to overcome this limitation. Interpretive machine learning refers to a collection of techniques developed to identify the importance of individual predictors in a model and determine what was used to make a prediction (Jones *et al.,* 2022). Interpretive machine learning has been used to identify the causes of crop yield variability in cotton (Jones *et al.,* 2022), where digital soil maps and terrain information was used to map cotton lint yield and interpretive machine learning was then used to identify the contribution of each predictor variable to the modelled yield prediction. Interpretive machine learning can be used to understand what may be driving variations in grain protein content and what may explain these changing relationships between yield and protein within and between fields, farms, and seasons. By identifying the contribution of each variable to modelled grain protein predictions, we can then map the major drivers of grain protein content within a field and across farms. Applying this over multiple seasons may also help to identify any seasonal fluctuations or changes in the drivers of grain protein over time.

Future research

This research is part of a PhD project currently being undertaken by Mikaela Tilse at the Precision Agriculture Laboratory, The University of Sydney, titled 'Assessing yield, fibre, and grain quality variability in cropping systems through data science for improved management'. This research, alongside output from several GRDC-funded projects will be used in the future to better understand the drivers of grain protein content variability.

SoilWaterNow: Soil water nowcasting for the grains industry (GRDC Code UOS2002-001RTX) is a GRDC-funded project led by The University of Sydney which aims to predict soil water content in near-real-time within and between fields and at multiple depths in the soil profile.

Next Generation Machine Learning models for 3D soil-mapping applications (GRDC Code UOS2206-009RTX) is another GRDC-funded project led by The University of Sydney that aims to build and test machine learning models to map soil constraints and plant available water capacity across a range of environments in Australia's grain growing regions. This project also aims to develop constraint-limited plant available water capacity maps based on soil x crop dynamics.

The output from these projects may be useful as inputs within interpretive machine learning models to help understand and describe some of the factors that drive variability in grain protein content, including soil moisture dynamics. Overall, future work aims to better understand the drivers of grain protein content and the interactions between grain protein, soil water, and soil constraints.

Conclusions

In the absence of grain protein sensor data, a combination of on-farm and publicly available data layers can be used to build a predictive model to predict grain protein content. Model performance was moderate-to-good overall and the addition of at least some grain protein sensor data within a field improved model performance. Model quality improved when predictions were validated using 2FCV compared to LOFYOCV, and performance also improved when predictions were aggregated from a fine (30 m) resolution to management zones. Moving forward, future research will investigate the drivers of grain protein content within and between fields and seasons through the use of interpretive machine learning and outputs from current GRDC-funded projects led by The University of Sydney.

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Integrating soil moisture sensor technology into seeding equipment to optimise seeding depth and crop establishment

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Key words

seeding, emergence, in-furrow soil sensors, moisture sensors

GRDC code

SEN2312-001RTX

Take home message

- A common objective in seeding is to have all seeds placed into a uniform soil moisture profile to achieve a uniform emergence. This may involve scenarios involving both moisture seeking as well as dry sowing
- Traditional seeding equipment is generally focused on providing a seeding outcome where a consistent depth outcome is achieved
- Whilst acknowledging that uniform depth is a desirable outcome, it does not necessarily result in a uniform emergence outcome if there is soil moisture profile variability across a field
- The aim of this project is a semi-autonomous seeder that uses in-furrow soil sensors to determine the status of soil moisture, such that hydro-electric row units can be adjusted in real-time within field.

Introduction

Over the course of many years, manufacturers of seeding and tillage equipment have consistently endeavoured to introduce innovative solutions designed to address specific challenges encountered during the seeding process. These solutions encompass a range of features, including consistent depth, breakout, trash flow, and press wheel functions, among others. While these features are undeniably important, a limitation lies in their ability to deal and react to variabilities within the soil.

The evolving landscape of agricultural technology has witnessed significant progress in both proximal and remote sensing. These advancements hold the potential to offer valuable insights into areas where variability is occurring within soils, however they often require ground truthing to validate their findings or may overlook regions with alternate soil properties.

An alternate approach to address these challenges involves the integration of sensors directly into the in-furrow arrangement of the seeder. This strategic placement allows for the real-time mapping of soil properties as the seeder traverses a field. The utilisation of this data during the seeding process allows the potential for optimising seed placement in-field by enabling adjustments to various mechanical aspects of the seeder mechanism.

Non-uniform crop emergence

The occurrence of uneven crop emergence is often attributed to variability in soil moisture levels within the seed zone during or shortly after planting. The moisture present at seed depth might be sufficient for germination and emergence in certain sections of a field but insufficient in others.

When planting seed into dry soil, seeds may not germinate and emerge until a rainfall event occurs, which could be weeks after the initial planting. Consequently, a field may exhibit a mix of more and less established crop, with the discrepancy aligned with the duration from planting to the onset of rainfall.

Uneven emergence often leads to non-uniform maturity within a crop. The earliest emerging plants may reach maturity sooner than later-emerging plants This non-uniformity can complicate harvest timing and reduce overall yield.

Areas with delayed crop emergence may provide opportunities for weed growth before the crop canopy is established. Weeds can compete with crops for essential resources, further increasing the negative impact on crop yield.

In-furrow soil sensing

During the 2010’s deep seeding crops became common, partially due to seasonal conditions, and partially due to the increased production of chickpea, which can handle emerging from greater depths than many crops.

Whilst ‘moisture seeking’ was a proven method to improve crop establishment in marginal soil moisture conditions, it resulted in significantly higher fuel use, and was often related to structural fatigue of seeding equipment.

By embedding soil moisture sensors into an autonomous row unit with automatic depth control, a more optimised seed placement could potentially be achieved across an entire field, thus improving plant establishment, whilst potentially reducing fuel use in areas where soil moisture profiles were more favourable.

Technology trials

In the preliminary phases of implementing this technology, trials were initiated using a single-row unit mounted on a trailer (Figure 1). This experimental setup served as a platform for testing various sensor types and gaining insights into the operational requirements of the hydraulic control, software, and mechanical requirements for the effective functioning of the row unit.

The utilisation of a single-row unit provided a valuable testing ground for different sensor types. It facilitated a hands-on exploration of the hydraulic control system, allowing for a comprehensive understanding of its intricacies in ensuring the optimal performance of the row unit. This initial testing phase played a pivotal role in refining the technology and establishing a foundation for further advancements.

Figure 1. First single row trial unit.

Despite the informative nature of these trials, a limitation arose due to the generation of only a single data set from the soil sensor. This singular dataset presented challenges in comprehensively assessing the performance of the specific sensor type, especially in comparison to alternative sensor types. The absence of multiple datasets limited the ability to conduct robust comparative analyses, impeding a refined evaluation of each sensor's advantages.

In essence, the single-row unit trials, while instrumental in determining the functionality of the hydraulic control system and testing different sensor types, highlighted the need for a more comprehensive approach to data collection.

To overcome the limited testing capacity of the single row machine, a 3-row unit was constructed (Figure 2). The transition from a single row unit to three introduced a more complex requirement to the hydraulic control system and the control software. This sophistication was essential to ensure the seamless coordination and functionality of multiple row units simultaneously. The expanded setup not only allowed for a comprehensive evaluation of the hydraulic control software's adaptability but also enabled a concurrent assessment of different sensor types.

However, beyond a seeding depth of approximately 100 mm, ground slippage became significant, particularly as a conventional road-going vehicle was used as the driving source. This limitation posed a hurdle to achieving full optimal performance.

The incorporation of three row units outlined the interplay between hardware and software components. The hydraulic control system needed to navigate the complexities of managing multiple row units, ensuring uniformity in seeding operations while accommodating the nuances introduced by different sensor types. This phase of development served as a baseline for refining not only the mechanical aspects but also the software algorithms that controlled the system's responsiveness.

Despite the challenge posed by ground slippage, the utilisation of three row units presented a unique opportunity for comprehensive testing and refinement. The concurrent evaluation of different sensor types allowed for a better understanding of each sensor's strengths and weaknesses under field conditions. This process contributed to the improvement of the technology, bringing it closer to achieving the desired outcome of the product.

Figure 2. Second trial unit with 3 rows.

After the initial trailer arrangement, the machine was rebuilt onto a linkage frame (Figure 3). This adaptation not only allowed for better trials but also extended the operational capacity of the machine, enabling it to reach a maximum working depth of 250mm.

The mounting on a tractor allowed integration in the tractors hydraulic system. This integration not only streamlined the overall hydraulic functionality but also offered the advantage of freely adjustable flow rates. Moreover, the seamless connection to the tractor's hydraulic system ensured a readily available fluid source, eliminating the need for electronic on/off fluid control. This on-tap fluid availability increased the machine's efficiency, allowing for dynamic adjustments and responsive control during various phases of operation.

Within this refined setup, a comprehensive network of pressure and load sensors was strategically incorporated. These sensors were positioned to cover the entire row unit, capturing data across various seeding depths. This arrangement allowed for the measurement of force settings throughout the entirety of the row unit, offering a detailed understanding of the forces experienced at different depths during the seeding process.

The integration of pressure and load sensors enabled the quantification and analysis of forces exerted by the row unit at different seeding depths. This data set not only provided valuable insights into the machine's performance but also facilitated the fine-tuning of force settings to achieve optimal outcomes across different soil conditions.

Figure 3. Third trial unit with 3 rows on a linkage toolbar.

During product development we had made substantial progress in defining the mechanical, hydraulic, control software, and sensor components. However, a critical phase remained – validating the system's functionality at scale. The existing 3-row machine, while informative in early trials, had limitations in its hectare-per-hour rate and faced challenges in discerning significant changes in soil properties over small areas.

To address these limitations, a strategic decision was made to acquire an existing 12-meter seeder frame. This larger frame offered the potential to scale operations and rapidly evaluate the technology over more extensive areas. The frame was retrofitted with 36 row units spaced at 333 mm intervals (Figure 4).

A trial site was selected in Tullamore, central New South Wales, providing a diverse and representative location for testing. The 120-hectare site offering a suitable area to assess the system's performance under more realistic conditions.

Whilst the large-scale trials proved successful, it involved significant works in commissioning the machine, primarily involving changes to the operational software in modifying the routine on how the rows engage and disengage as required during the course of performing the seeding tasks. On top of this, was the various ancillary requirements of engaging the seed cart, and in-field guidance.

Figure 4. 12-metre-wide frame, with 36 rows fitted during the 2023 winter cropping trials.

What's next?

With an operational full-scale seeder in place, the validation and ROI works are the key priority.

During 2024, the key project objectives include:

- ISOBUS integration
  The seeder is currently operating under its own control suite, however upgrading to an ISOBUS control will not only simplify operation of the seeder but will potentially allow for an integrated semi-autonomous operation of the seeder with minimal user input. This development is aimed at allowing for both the current deskilling of the agricultural workforce and the future automation of both tractors and implements.
- New sensor development
  Currently working with a Sydney based university to improve the sensor array. This research is intended at improving both sensor accuracy and sensor wear resistance.
- Crop trials
  Increased cropping trials in a variety of zones, running in conjunction with standard seeding equipment to determine performance of the technology when compared to conventional seeders. These trials will allow the continued development and optimisation of the sensor technology, the automatic control of the seeder functions, and the simplification and refinement of the seeder user interface.

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Taking the lab to the field

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Key words

cereal grain moisture, cereal grain protein, grain quality, spectral models

Take home message

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

Background

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

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

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

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

The challenge

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

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

The science

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

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

Understanding the limitations of adoption

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

The opportunity presented across three areas:

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

Guiding principles

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

The solution needed to satisfy the constraints that producers faced.

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

Challenges to be overcome

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

This enabled Hone to:

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

Applications and outcomes

Cereal grain

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

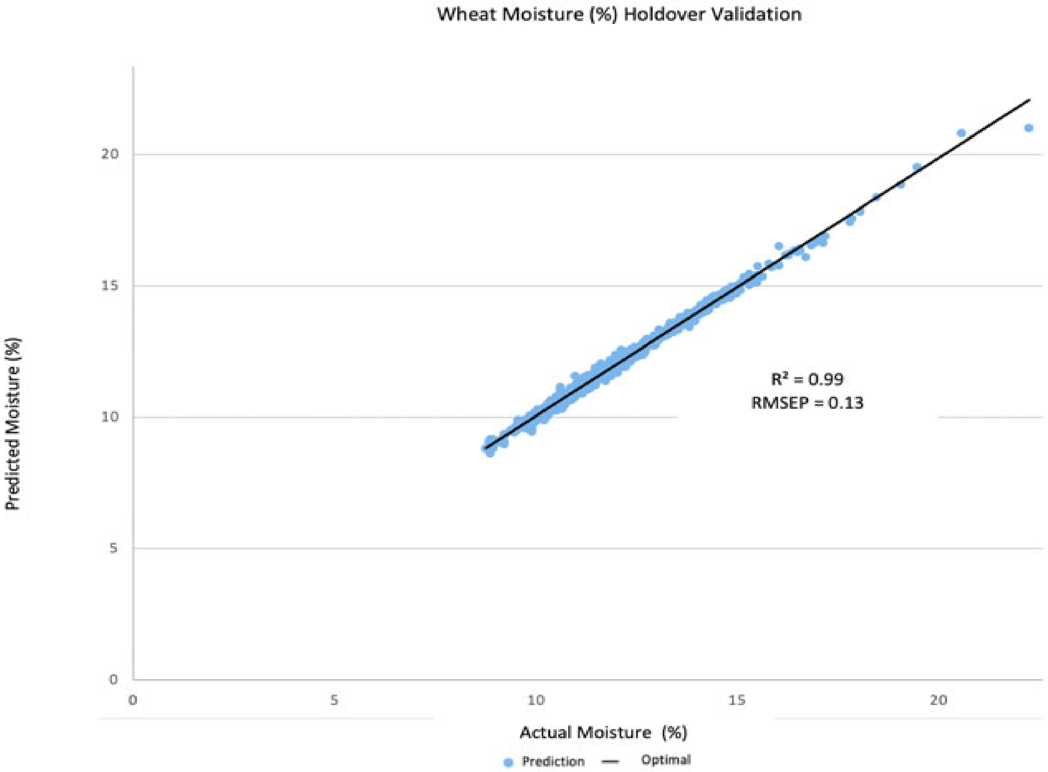

Figure 1. Wheat moisture predictive model.

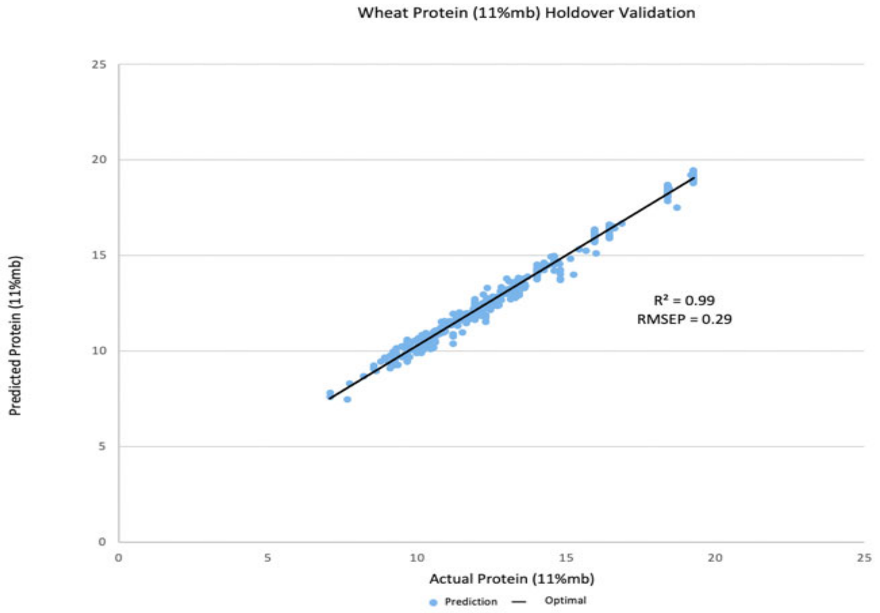

Figure 2. Wheat protein predictive model.

Feed grain

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

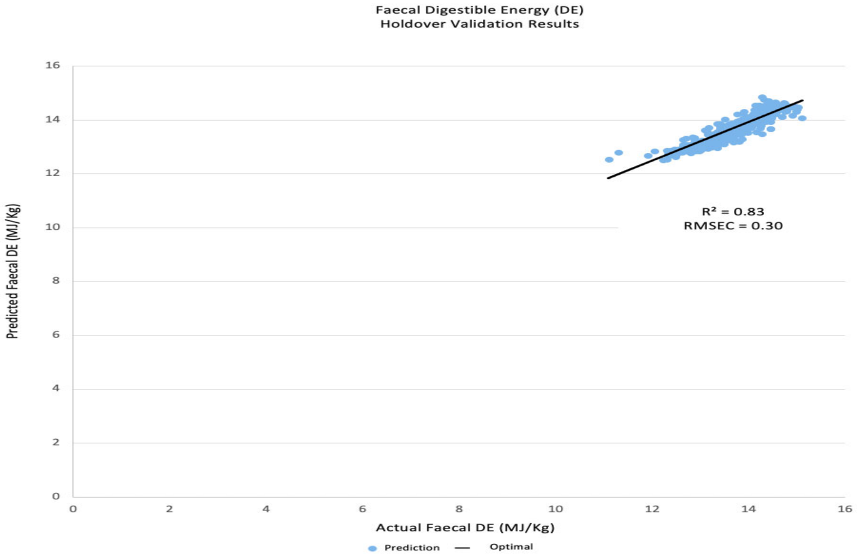

Figure 3. LHS; Faecal digestible energy (MJ/kg) cross validation results.

Economics

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

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

On-farm wheat segregation

Table 1. The annualised cost of the Hone Lab Red is $2450 (+GST) per annum, resulting in a nett ROI of over 70% per annum. The additional value of being able to assess cereal grain for feed quality will open further opportunities for producers and consumers of feed grain.

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

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Notes

The regional disease surveillance network: a BioScout endeavour

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Key words

BioScout, automated disease surveillance, disease management, disease surveillance network, SporeScout

GRDC code

BIS2305-001RTX

Take home message

- BioScout technology empowers proactive disease management by combining automated microscopy with machine learning to provide growers with near real-time airborne fungal data.
- Launching in 2024, Australia's first regional airborne disease surveillance network, in collaboration with the GRDC, will deploy BioScout units across three regions, offering valuable data on key threats until early 2026.
- Free access for GRDC-approved users until the end of 2025 provides an opportunity to leverage this novel resource and optimise disease management strategies.
- Register your interest to stay informed about network availability and contribute to shaping a future of informed and sustainable crop protection.

The disease problem

Australia's grain crops face substantial yearly losses due to diseases. The FAO (2019) estimates that plant diseases are responsible for 20 – 40% of crop losses on average, costing the global economy US$220 billion annually. In Australia, Murray and Brennan estimated back in 2009 that foliar fungal infections cost the grains industry over AUD 470 million annually despite spending around AUD 84.3 million on fungicides; these numbers are now likely much higher. Addressing these losses can boost crop production profitability by protecting yield while promoting sustainable practices without additional land clearing or inputs.

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

BioScout technology

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

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

- General rust (*Puccinia spp.)*
- Blackleg (Leptosphaeria maculans)

- General Alternaria (*Alternaria spp.)*
- Powdery mildew (*Blumeria graminis*)
- Botrytis (*Botrytis cinerea*)

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

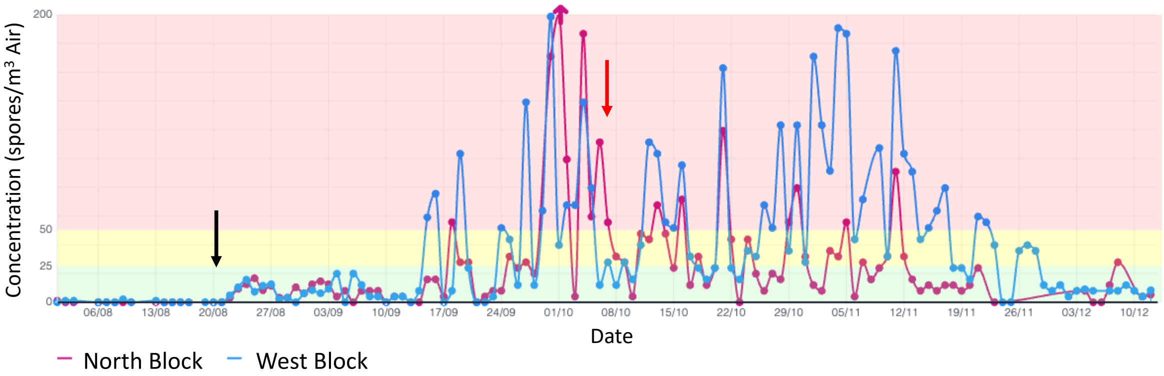


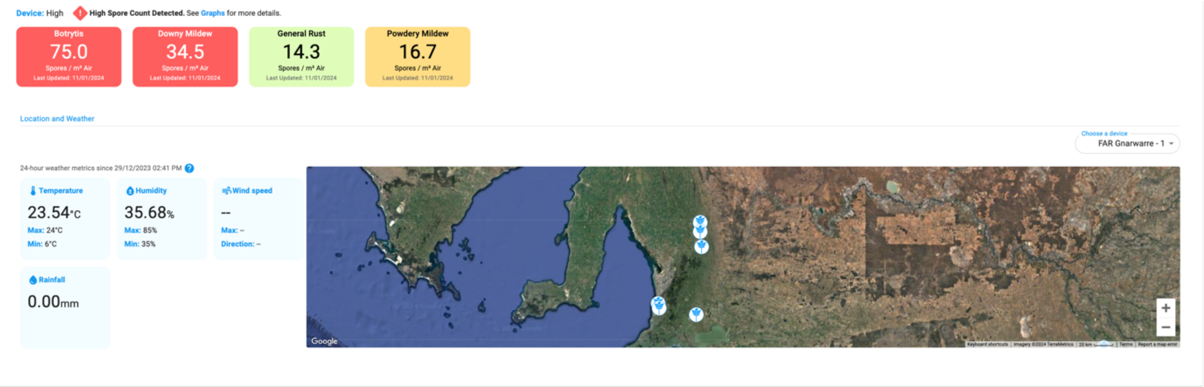
Figure 2. A graph from the BioScout dashboard displaying airborne concentrations of general rust detected through the SporeScouts during an outbreak. Two SporeScouts were placed at a site in Victoria from June to November 2023. North Block (pink line) and West Block (blue line) were located 776m and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

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

The regional disease surveillance network project

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

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



Device: High ! High Spore Count Detected. See Graphs for more details.

Botrytis	Downy Mildew	General Rust	Powdery Mildew
75.0	34.5	14.3	16.7
Spores / m³ Air	Spores / m³ Air	Spores / m³ Air	Spores / m³ Air
Last Updated: 11/01/2024	Last Updated: 11/01/2024	Last Updated: 11/01/2024	Last Updated: 11/01/2024

Location and Weather

Choose a device: FAR Gnarwarre - 1

24-hour weather metrics since 29/12/2023 02:41 PM

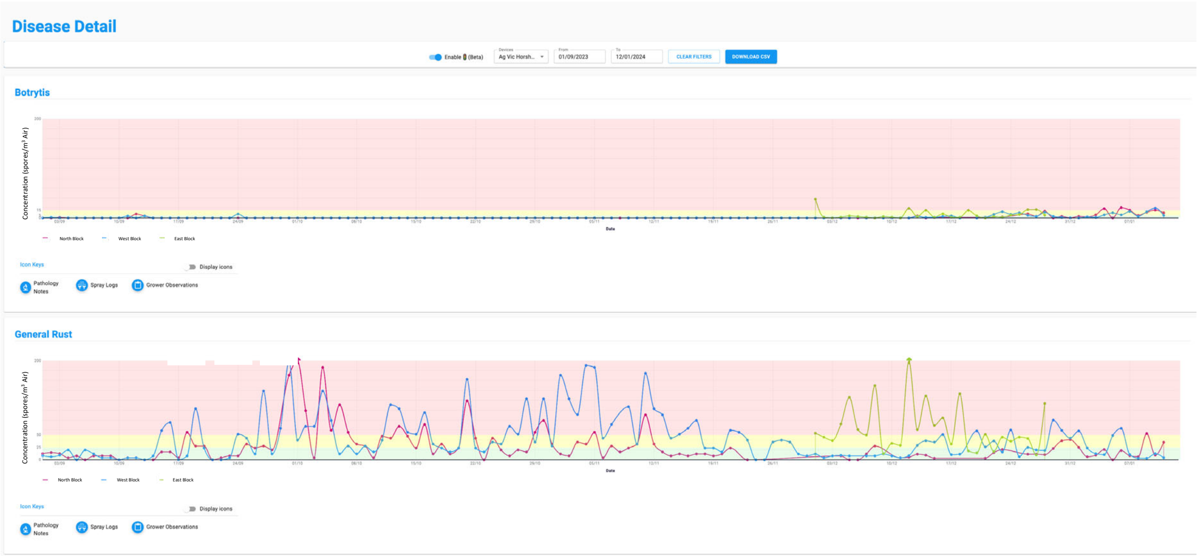
Temperature: 23.54°C
Max: 24°C
Min: 6°C

Humidity: 35.68%
Max: 85%
Min: 35%

Wind speed: --
Max: –
Direction: –

Rainfall: 0.00mm

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



Devices: Ag Vic Horsh..
From: 01/09/2023
To: 12/01/2024

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

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

Conclusions

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

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ConstraintID – Updates to enhance useability, accuracy and accessibility in the assessment of sub-soil constraints

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Key words

ConstraintID, sub-soil constraints, crop yield, decision support tool, remote sensing, FarmLab

GRDC code

UOQ1803-003RTX

Take home messages

- ConstraintID is a web-based tool that enables growers to use remotely sensed data to analyse past crop yields and present maps of subsoil constraints for comparison and amelioration. The data on these driving factors helps the user to interpret the variation shown by the remote-sensing data.
- Integrating this tool into FarmLab allows users to use their existing spatial data in the software to analyse and predict subsoil constraints, create management zones and variable rate application maps
- By integrating directly with soil testing labs, FarmLab allows soil test results to be analysed by the ConstraintID tool, further enhancing useability and helping users to target problem zones across their land.

Introduction

The ConstraintID tool, developed with funding from GRDC (GRDC Code UOQ1803-003RTX), has found a wide range of applications since its release in 2021. It offers growers an assessment of soil constraints across their paddocks using remotely sensed data and on-ground soil samples. ConstraintID has been integrated with FarmLab to provide a more streamlined user experience and enhanced analysis capabilities for assessing subsoil constraints. This integration offers several benefits:

- Better access to farm and paddock boundaries
- Direct integration with soil testing labs for seamless data ingestion
- Ability to analyze constraints alongside other soil performance drivers, such as fertility, carbon, and water holding capacity

Current format

In its current format, users define their paddock boundaries on Google Maps, triggering background spatial analysis on the server. The software processes a time-series of Enhanced Vegetation Index (EVI) satellite images, filtering out irrelevant data and stitching adjoining images when necessary. The result is a Crop Yield Index (CYI) representing vegetation levels across the paddock for each year.

In subsequent steps, users choose soil constraints for analysis and upload relevant test data. The software guides users in identifying data columns for each constraint. Paddock images displaying CYI for each year are presented, marked by the software to indicate typical cropping years. Users validate these markings, calibrating the analysis. The final step compiles selected cropping years into a paddock map of CYI values. A second image highlights consistently high (blue) and low (red) CYI regions, overlaying soil test readings for further analysis. This comprehensive process enhances decision-making in agriculture by providing insights into soil health and productivity.

Updates and integration with FarmLab Analytics

FarmLab developers integrated ConstraintID into the FarmLab Analytics platform, allowing users to generate custom reports that include ConstraintID analyses. FarmLab Analytics contains a series of 'widgets' that allow users to automatically generate reports using their remotely sensed data, terrain, soil models and soil test results. This was a logical place to host the tool as it gives users options to explore and compare subsoil constraints to other soil datasets at various depths. This integration has led to significant improvements in functionality and allows it to be used at scale across Australian cropping areas. Specific improvements include:

- Users can import their paddocks in KML or SHP file formats, eliminating the need to manually draw boundaries each time they run an analysis using the tool
- By integrating directly with soil testing labs, soil test results collected in FarmLab are automatically incorporated into the analysis
- The tool can be run efficiently on multiple farms simultaneously, reducing the amount of time an agronomist may need to run several reports or scenarios
- Results can be shared alongside other important production data, such as agronomic soil test results, historic NDVI changes, and other farm environmental data.

Future opportunities

FarmLab is exploring the following opportunities for ConstraintID, based on feedback from Beta testers:

- Stratification for soil carbon projects: recent research suggests a high correlation between subsoil constraints and low soil carbon stocks in cropping systems. ConstraintID could be valuable for identifying areas with high constraints and low carbon stocks, aiding in sample planning and carbon stock estimation for carbon offset projects.
- Loans and financial support for subsoil amelioration: an estimated 90% of Australian cropping land exhibits sub-soil constraints, which hamper yield by up to 20%. Across Australia's wheat industries, that's an unrealised production loss of $1.9 billion per annum.

Summary

ConstraintID is a valuable tool for assessing soil constraints in agricultural paddocks. Its integration with FarmLab has enhanced its functionality and user experience, making it more efficient and accessible. Future opportunities for ConstraintID include its potential application in soil carbon projects and financial support programs for subsoil amelioration.

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Being certain of uncertainty: Getting the most from weather and climate forecast models.

Jonathan How, Bureau of Meteorology

Key words

Bureau, forecasts, uncertainty, computer, models

GRDC code

AGI2206-002OPX

Take home message

- The Bureau of Meteorology's Agriculture Program has been engaging with the grains industry and responding to feedback from growers and advisers since 2017. Research and face-to-face engagement has shown that there is a need for insights into computer models, both short-term weather models, and long-term climate models
- With funding from Agricultural Innovation Australia, through investment from the Grains Research Development Corporation (GRDC) and other rural Research and Development Corporations (RDCs) via the Agri-Climate Outlooks (ACO) project, a dedicated service has been established which publishes region and commodity-specific forecasts on YouTube to assist with understanding of long-term outlooks beyond 7-days. . The Agriculture Program delivering the Agri-climate outlooks project aims to positively impact on-farm business management and grains-specific decisions such as autumn sowing
- The insights captured by the Agriculture Program and continued engagement with industry have shaped the decision support service to date. The case studies presented outline the value of drawing on the expertise of the Bureau, which in turn helps to ground-truth the long-term forecast for improved accuracy
- As growers and advisors plan for the upcoming autumn season, the Agriculture Program will continue to provide relevant insights that bridge the gap between short-term forecasts and long-term forecasts. We invite growers and advisors to keep up to date with the analysis of the forecasts, by subscribing to the grains climate video briefings (Bureau of Meteorology Agriculture YouTube playlist) and by getting in touch with the team via email at agriculture@bom.gov.au, or in-person at field days and seminars.

Background to computer models

Computer models are the main tool that meteorologists use to forecast weather and climate. They divide the atmosphere into grid boxes, both vertically and horizontally, in order to simulate the atmosphere and project forward in time. Computer models can provide forecasts within the next hours to days (**short-term models**) to weeks and months out with probabilistic scenarios (**long-term models**).

Today, there are many different computer models, each requiring immense supercomputing power. Some of the large meteorological agencies across the world produce their own models. Table 1 shows some of the major short-term and long-term computer models currently in operation, including the ACCESS Australian model. ACCESS stands for Australian Community Climate and Earth-System Simulator, and it is based on the UK Met Office's Unified Model.

Table 1. Comparison of different international computer models

Computer model	Horizontal resolution	Calculations per second (supercomputer)	Update frequency	Duration
Short-term models				
ACCESS-G[1] (Australia)	25km	1.6 petaflops**	Every 12 hours	10 days
ECMWF[2] (Europe)	9km	10 petaflops	Every 12 hours	10 days
US GFS[3] (USA)	28km	12.1 petaflops	Every 6 hours	10 days
UKMO Unified Model[4] (UK)	17km	14 petaflops (soon 60 petaflops)	Every 12 hours	3 days
Long-term models (Probabilistic output)				
ACCESS-S[5] (Australia)	60km	1.6 petaflops	Daily to weekly	Weeks to seasons ahead
ECMWF Long-term[6] (Europe)	36km	10 petaflops	Once a month-every 3 months	7 months-13months
US NCEP[7] (USA)	56km	12.1 petaflops	Once a month	3 months – 9 months
UKMO Long-term[8] (UK)	25-130km	14 petaflops (soon 60 petaflops)	Once a month	2 – 6 months

** petaflop - a unit of computing speed equal to one thousand million million (10^{15}) floating-point operations per second.

Information sourced from respective webpages, as detailed below:

[1] ACCESS information http://www.bom.gov.au/australia/charts/about/about_access.shtml Accessed December 2023

[2] ECMWF information: https://www.ecmwf.int/en/research/modelling-and-prediction Accessed Dec 2023

[3] US GFS information: https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.ncdc:C00631. Accessed Dec 2023

[4] UKMO information: https://www.metoffice.gov.uk/research/approach/modelling-systems/unified-model/weather-forecasting Accessed Dec 2023

[5] ACCESS-S information: http://www.bom.gov.au/climate/ahead/about/model/access.shtml#:~:text=ACCESS%E2%80%93S%20produces%20rainfall%20and,range%20of%20possible%20future%20scenarios. Accessed Dec 2023

[6] ECMWF Long range information: https://www.ecmwf.int/en/forecasts/documentation-and-support/long-range#:~:text=Our%20long%2Drange%20(seasonal),resolution%20of%20around%2036%20km. Accessed Dec 2023

[7] NCEP model information: https://www.ncei.noaa.gov/products/weather-climate-models/climate-forecast-system Accessed Dec 2023

[8] UKMO long range information https://www.metoffice.gov.uk/research/climate/seasonal-to-decadal/gpc-outlooks/user-guide/index Accessed Dec 2023

Results

The Agriculture Program has recently increased its service to the agriculture sector with investment in the Agri-Climate Outlooks (ACO) project from the agriculture industry and other RDCs, including GRDC. Research conducted by the Agriculture Program has found that there is a need for insights into computer models, both short-term weather models, and long-term climate models. These insights can provide additional perspectives when making risk management and high-value decisions.

The meteorologists in the Agriculture Program, through understanding the physics of the atmosphere and the complexity of computer models, aim to provide insights that connect the physical interactions of the atmosphere to modelled scenarios. In doing this, they provide targeted insights to inform high-value decisions.

This is demonstrated in a specific NSW case study from November 2023 (see below). This case study demonstrates the limitations of using one source without meteorological analysis or understanding of the biases within the computer modelling systems for weather and climate risk assessment.

Which computer model performs best, and why do they tell different stories?

There is no one computer model that can be definitively described as being 'the best'. Each model has its own limitations and biases which in turn affect its accuracy. This is true for both short-term and long-term models. In a perfect world, a computer model would simulate the atmosphere and ocean perfectly, with observations feeding in from every point on earth. This would require computing power and resources well beyond our current capabilities. Instead, computer models use approximations, while other factors come into play. These factors can include:

- Grid box size and model resolution, as shown in Table 1
- Geographic region, including topography and representation of the land
- Initial conditions used
- Timeframe for forecast
- Equations used to represent atmospheric processes
- Computing power and availability of resources

Based on these factors, models can produce different outcomes for the same weather or climate events. Different models and resources will be covered in more detail during the presentation.

Case study: Storm outbreak across eastern Australia – November 2023

The Agriculture Program attended the Cropping Solutions Seminar in Narrabri in July 2023. Through conversations with growers and advisers at the seminar and on the ground, staff learned that Yr.no is a popular online resource for grain growers in New South Wales as it provides an 'exact' expected rainfall amount up to 10 days ahead. However, there is not a widespread understanding of how these forecasts are produced, nor of the computer models behind the forecast, which can limit their effectiveness in decision making.

An example of this came from canola growers near Narrabri who relied on this online source of information for a rainfall forecast more than 7 days in advance. These growers made decisions to sow 1,000 ha of canola based on this one rainfall forecast. As the day of the forecast rainfall approached, the rainfall expectation fell dramatically (from over 60 mm to just 2 mm) and this resulted in significant losses due to non-viable crops.

In contrast, the Bureau's 7-day forecast uses a blend of computer models that have been analysed by meteorologists, and so the rainfall forecast shows a probable range rather than one single rainfall amount. Beyond 7-day forecasts, the Bureau's ACCESS-S climate model displays long-term forecasts that show rainfall totals for a given level of chance, and various other displays for example, the chance of exceeding a certain rainfall amount over 3 days. Long-term forecasts are probability-based and are designed to be used as one of several planning tools within risk management and decision-making. The greatest benefits of using Bureau long-term forecasts will accrue from use over several seasons or years. The meteorologists in the Agriculture Program use a range of long-term forecasts that include other international models as part of the analysis to provide a forecast beyond 7 days.

To demonstrate the limitations of using one source without meteorological analysis or understanding of the biases within the computer modelling systems for weather and climate risk assessment, a case study was developed that investigated the effectiveness of forecasts from Yr.no, in November 2023. This was to demonstrate how one model forecast can change significantly over time, and therefore not provide the best decision outcome if used in isolation without long term analysis and verification to confirm the model simulation.

In late November 2023, several surface troughs combined with tropical moisture to produce rain and storms over eastern Australia, peaking on 24–25 November. An analysis of forecasts displayed on Yr.no captured how the forecasts changed at Dubbo and Tamworth, and was then compared to observed rainfall amounts.

Forecast on Yr.no

Figure 1 shows how the forecast for 25 November evolved at Dubbo and Tamworth between 20 November (5 days before the storm event) to the day prior.

At Dubbo (top line) the forecast indicated more than 20 mm until 24 November, at which point the forecast fell to 10 mm. Similarly in Tamworth (bottom line), the forecast rain amount dropped in the lead up to 25 November.

The reason why the Yr.no forecast jumped around is because thunderstorms are localised events and are spatially much smaller than the grid resolution of many models. Computer models only give the forecast for a point location based on how the model has resolved precipitation at that grid point. However, actual observed rain may form 5 or 50 km away. A computer model should be viewed as simulating the environment.

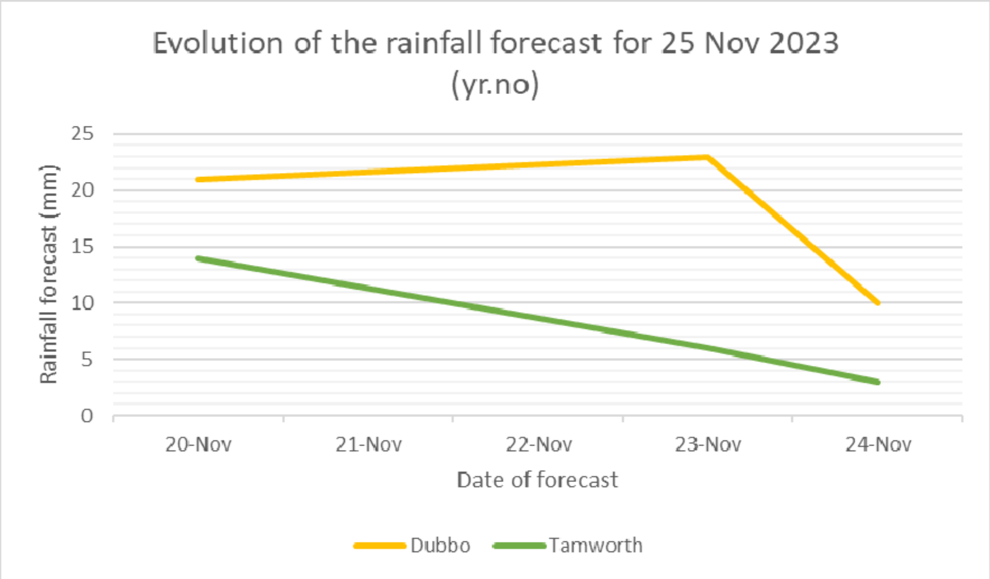

Figure 1. Evolution of the forecast at two different locations on yr.no (taken from yr.no between 20 and 24 November 2023)

Bureau of Meteorology forecast

The grains climate video update (November Grains Climate Outlook), released on 8 November 2023, discussed the increased risk of rain and storms across eastern Australia more than 2 weeks in advance, during the second half of the month, due to surface troughs and moisture from the north. This included annotations within the video which helped to explain the outlook and provide context. Specifically, the video stated that "the inland trough over inland parts of Queensland and NSW… [would] lead to an increase in shower and thunderstorm activity. Figure 2 shows a screenshot lifted from this video.

This video update went further and compared both the Australian ACCESS-S climate model, as well as the international range of long-term climate models. By doing this, the Agriculture Program provided a scientifically rigorous method of analysis, in addition to a meteorologist's understanding of the interactions of weather systems, such as airmass evolution and surface low pressure troughs.

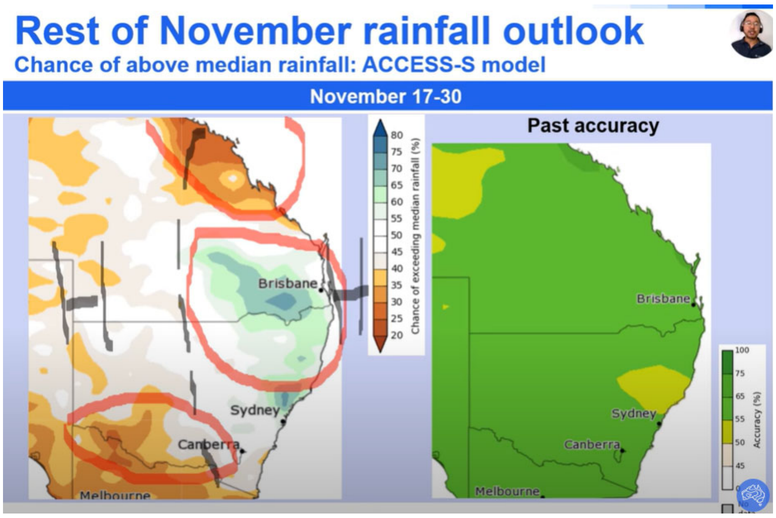

Figure 2. Grains video briefing screenshot from 8 November 2023 (Bureau of Meteorology Agriculture YouTube)

Rain observations

Rain observations from 25 November 2023 were as follows:

- Dubbo 0.2 mm
- Tamworth 31 mm

Thunderstorms developed during the day and swept over parts of the Murray-Darling Basin. The Bureau issued Severe Thunderstorm Warnings for broad areas of NSW. Figure 3 below demonstrates how some locations received high totals, for example Wellington, NSW (38mm) while others nearby received very little, for example Dubbo (0.2mm), which is 46 kilometres from Wellington.

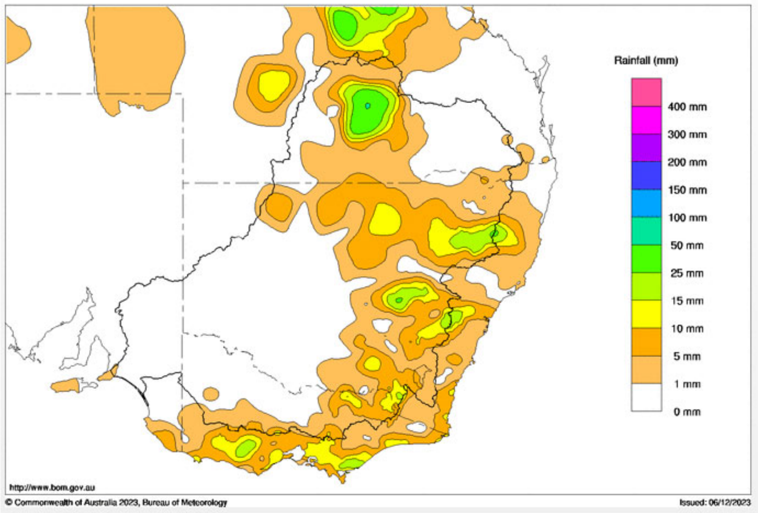

Figure 3. 24-hour rainfall totals for 25 November 2023 (observations taken from www.bom.gov.au)

Findings and conclusion

There are many computer models and resources available to growers and advisers today. Some of these can be popular as they provide the information that growers seek. Over-reliance on resources that provide a quantitative numerical forecast outcome based on one model only, without analysis or verification, can increase the error in decision assessment or risk analysis. This is demonstrated in the above example of canola sowing in northern NSW, and the case study of the outcome from the popular website, yr.no.

To gain a fuller perspective on weather and climate for risk management decisions, it is important to consider additional analysis, rather than to rely on one resource. The Bureau uses a blend of computer models to provide a rigorous analysis, and weather-dependant organisations are encouraged to use a range of sources as well. In particular, the Bureau's Agriculture Program staff can provide insights that connect the physical interactions of the atmosphere to modelled scenarios, with the objective of providing the best information to support weather dependant agriculture businesses to understand weather and climate-related risk scenarios. The role of meteorologists is to understand the complex science of weather and climate and provide additional information to support on-farm high-value decisions.

The Agriculture Program will continue to engage with the agriculture industry in 2024 to provide direct, relevant weather and climate analysis and insights. Staff will support research to understand model bias, verification, and model physics in international climate models where appropriate. Growers and advisors are invited to keep up to date with the analysis and the long-term forecast, by subscribing to the Grains Climate Outlook video briefings, and by contacting the team via email at agriculture@bom.gov.au, or in-person at field days and seminars.

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https://www.youtube.com/playlist?list=PLbKuJrA7Vp7mdHq2Mal0tglzznaZNbHUq

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Yr.no. Linked accessed 20-25 November 2023 https://www.yr.no/en

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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.

The Bureau of Meteorology, in partnership with Agricultural Innovation Australia (AIA) are delivering the 4-year ACO project, which involves collaboration across 10 rural Research and Development Corporations. This includes the Grains Research Development Corporation (GRDC). This project will help to deliver improved seasonal climate and water outlooks for use by the agricultural sector, and create value by helping producers make better, and more informed decisions.

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

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Keywords

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

Take home message

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

Background

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

WeedErase and Weed Seed Destroyer

Global Neighbor, Inc. (https://g-neighbor.com/) is a startup based in Ohio who have developed a weed and weed seed control approach based on heat from the combination of 440 nm wavelength blue light and mid-wave infra-red (MWIR) wavelengths. The blue light at high intensity, 30 times sunlight, damages photosynthetic systems (chloroplasts), as evidenced by blackened leaves. MWIR which is not present in sunlight, penetrates the soil to damage weed roots. This technology is currently only commercially available as the handheld WeedErase® system for home garden use.

Further research has found that the combination of high intensity blue light and MWIR can be effective at killing weed seeds. Global Neighbor, Inc. is now pursuing the use of this approach for targeting weed seeds during harvest. Preliminary studies have shown that complete control of weed seeds in chaff can be achieved within a few seconds exposure. Global Neighbor, Inc. are pursuing this opportunity with a development labelled the Weed Seed Destroyer (WSD). This technology is still very much under development, with prototype systems being produced for benchtop as well as field testing.

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

Electrical weeding

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

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

Weed recognition technologies

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

Evaluation of gametocides to prevent weed seed production

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

Allelopathic weed control and biological nitrification inhibition

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

Conclusion

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

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Where AI adds value to agronomic and crop decision-making now, and where might this technology be in 5 years?

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Key words

AI, agronomy, technology, decision making, artificial intelligence

Take home message

- Artificial intelligence (AI) will add value to different agronomic decisions differently
- Prioritise quality-assuring yield and management data from on-farm experiments to help enable AI in agronomy
- Expect some AI-enabled beta (test) agronomy products from GRDC projects to be available in 2024 and keep an eye on the May-June Groundcover supplement for more information.

Background

GRDC has a significant portfolio of R&D in AI in agronomy. The intent of this paper is to provide a practical and non-exhaustive overview of where AI currently adds value to agronomic decision making and where the technology is likely heading in the Australian market in the near to midterm based on scientific, commercial, and regulatory factors.

This paper is brief and qualitative in nature because a Groundcover supplement scheduled for release in May-Jun 2024 will discuss this subject in more depth, along with results from GRDC's broader portfolio in 'on-farm' applications of digital agriculture and automation.

Where does AI add value to agronomic decision making?

AI is likely to add value to different agronomic decisions differently. That's a key message from this paper. A helpful way to think through the contribution to AI in agronomic decision making is in one of three categories:

1. Informing decisions
2. Guiding decisions
3. Prescribing decisions

This is not meant to be used as a formal or fixed distinction, but to provide some guard rails for understanding how AI can add value to decision making now and into the future.

Where does AI add value now?

Informing decisions

Some forms of AI are adept at retrieving, synthesising, and summarising vast amounts of information. Large Language Models (LLMs) such as Chat GPT by Open AI, Bard by Google, and Llama 2 by Meta AI are popular examples. For example, sourcing information on the optimum planting time for a specific variety in your location, its disease ratings, and its certifications to inform variety selection. Most LLMs have multi-model capabilities, meaning they can ingest and analyse multiple types of input data such as text, images, numerical data, etc. The capabilities of LLMs are evolving rapidly and their future influence on agronomic decision making could be profound. For now, they're worth experimenting with to make the job of sourcing and synthesising information much easier, but note they have biases, errors, and their terms of use need to be carefully understood.

Guiding decisions

Many agronomic decisions can be guided by access to good data, as in accurate biophysical data provided at the right spatial resolution in a user friendly and cost-effective manner at the right time. For example, information on the flowering time of a given variety for a given location and emergence date; the PAWC and depth to constraints across a paddock; plant available water at *x* depth in *y* paddock or zone; spatial distribution of weed emergence in fallow and to some extent, in-crop, etc. These are all examples of current capabilities enabled by the coupling of AI with relevant domain expertise.

Sometimes the influence of AI is easily apparent, but often it's used 'behind the scenes' within a broader workflow for sourcing, processing, and analysing multiple sources of data. Here are some examples of AI at work across the GRDC portfolio developing agronomic data layers to guide decision making (Table 1). Note this is a just a snapshot and by no means an exhaustive list.

Table 1. Examples of how AI is used to create insightful agronomic data that can guide decisions.

GRDC project code	Domain	Use-case	Example of how AI adds value
UOM1806-001RTX	Crop phenology	Predicting variety-specific flowering time	To predict parameters required for APSIM Next Gen to simulate flowering time using genetic data
UOS2205-006RTX	Frost and heat (Abiotic stress)	Predicting yield loss from frost and heat events in major crop types	To develop analytics methods that use historical precision ag, crop physiological, environmental, and remotely sensed data to predict the impacts of frost and heat events at different stages of development in different crop types and environments
UOS2206-009RTX	PAWC and soil constraints	Mapping spatial variations in PAWC and the depth to soil constraints	To develop analytics methods that use soil sampling data, soil surveys, environmental and remotely sensed data in combination with digital soil mapping techniques to map spatial variations in PAWC across a paddock and map the 'effective' rooting depth based on the depth to soil constraints.
UOS2002-001RTX	Plant available water (PAW)	Mapping and monitoring plant available water at different depths in the profile and across zones	To develop analytics methods that use soil sampling data, soil surveys, environmental and remotely sensed data (optical and microwave) in combination with soil water balance models to estimate the PAW content at different depth profiles at different points in time across a farm, paddocks, or zones in a paddock
BCS2307-001RTX	Weed management	Mapping post-emergent weeds for site-specific herbicide applications	To detect the location of weeds from drone-based imagery for input into sprayers with section control or individual nozzle control for site-specific application of post-emergent herbicides
DFL2304-001RTX	Disease management	Detecting the occurrence of foliar diseases	To analyse satellite imagery for the purpose of mapping the incidence of crop foliar diseases to inform fungicide management

A few of these projects are just getting started, but many will have initial protypes/beta products made available in the spring of 2024 following 4-6 years of applied research and development and ongoing engagement with growers and agronomists across Australia. Keep an eye on the May-Jun Groundcover supplement for more information.

Prescribing decisions

This is where AI in agronomy is most frequently hyped and perhaps most infrequently realised. A pertinent example is with mid-season nitrogen decisions in winter cereals across Southern Australia. It can be a complex decision given there are multiple variables interacting in different ways across different sites and seasons. Nonetheless, AI can have significant, strategic impacts in prescribing a course of action, but there's often a requirement to couple large volumes of quality on-farm data with relevant domain expertise, precision agriculture technologies, and a long-term outlook. The experience with the Future Farm project (CSP1803-020RMX) is a good example.

Working with leading growers across Australia to implement and sample large-scale strip trials and analyse multiple data layers in different ways, the team developed a method to predict the economically optimum N-rate that more than halved the recommendation error associated with a simplified mass balance approach (Colaço *et al., 2024*). See Figure 1 for a summary figure sourced from Colaço *et al., 2024*. This method is being evaluated further at scale in multiple crop types and environments with growers across Australia in partnership with a private company. While the results are very impressive, the requirement for data is intensive and the approach is contingent on implementing N-rich and N-nil strips using precision agriculture technology.

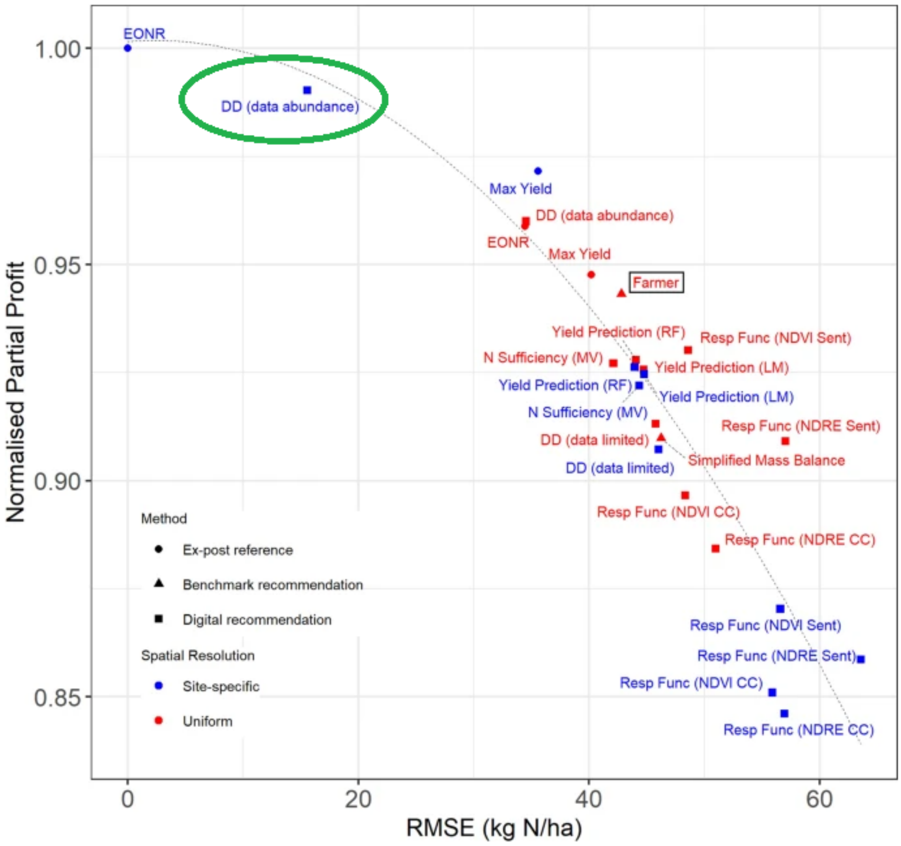

Figure 1. Error by profit biplot showing the average results of various N recommendation methods across 21 large scale on-farm trials in Australia, sourced directly from Colaço *et al.,* (2024). The RMSE stands for root mean squared error is a measure of accuracy. The lower the RMSE the better. Normalised partial profit is a relative measure of how profitable the N recommendation was. The higher the better. The method circled in green is the best-performing one and enabled by AI. Again, see Colaço *et al.,* (2024) for more information.

In summary, AI for prescribing complex decisions is doable and very powerful, but it's not easy. A key enabler of this approach is collated on-farm data and easy to use digital tools for collating yield and agronomic management data as well as results from large-scale on-farm experiments like strip trials. There are prior, powerful examples of this at work.

The power of on-farm experimentation for enabling AI in agronomy

For example, Bayer's Fieldview^{TM} platform has a powerful set of predictive agronomic tools for corn growers in the US. Fieldview provided digital tools for growers to implement simple strip trials and collect yield data from those strips alongside relevant agronomic management information. Aggregating that on-farm data at scale and combining it with their in-house small-plot database, genetic insights, and data science expertise provided an opportunity to build, test, and refine powerful predictive agronomic models that are both scalable and locally accurate. A blog post from the Climate Corporation (Bayer's Fieldview) back in 2018 provides a simplistic overview of the power or digital tools in the context of AI and agronomy (Eathington, 2018). For a more revealing description that highlights the power of collated on-farm data and on-farm experiments, it's worth reading through a patent filing from the Climate Corporation titled Digital modelling and tracking of agricultural fields for implementing agricultural field trials (Climate Corp, 2020).

Of course, many growers and agronomists already implement and learn from many types of OFEs. But quality assuring the yield data collected from those OFEs, collating it alongside management information, and creating a networked database of OFEs for analysis is often the missing piece. That's often key to realising the power of AI in agronomy. In addition to supporting product development in AI in agronomy, OFE provides a powerful basis to support peer-to-peer learning and fostering of farmer-researcher relationships (Lacoste *et al.,* 2022).

Digital tools are key facilitating both shared discovery between growers, agronomists, and researchers and collection of the quantitative geospatial data required to power AI-based agronomic models. There are many products available in the Australian market to help Australian growers implement and collect geospatial data from on-farm experiments, such as PCT Agcloud's strip trial tool and the Field Trial Module from SMS Advanced by AgLeader®. There are also different methods available to analyse treatment responses from large-scale on-farm experiments (e.g., Lawes et al., 2012 and Rakshit et al.) and published examples of the potential value of OFEs in different domains (Yan *et al.,* 2002; Virk and Witcombe, 2008; Kandel *et al.,* 2018).

The impact of commercial drivers and market structure

While there's significant potential for AI in agronomy, commercial drivers often restrict the pace of development of AI in agronomy in the Australian market. Australia is a relatively small market on the global stage for digital agronomic analytics products and services. That mitigates the private investment into developing and scaling new innovations in AI and agronomy. While Australia has some excellent precision ag analytics companies operating in our market, the business case for investing in advanced agronomic analytics products for wheat, barley and canola in Australia often doesn't stack up the way it does for say corn and soy growers in North and South America.

Where might this technology be in 5 years-time?

While this is difficult to predict given the pace of technological progress and some uncertain regulatory issues related to generative AI, there are some general observations worth noting:

Expect new AI-enabled products and services to hit the market from GRDC investments

GRDC has been investing in high-value use cases in agronomy and AI in multiple areas. By focussing on the high-value use-cases with a long-time horizon, GRDC's partners have able to couple their domain expertise in crop physiology, agronomy, soil science, nutrition, abiotic stress, and other areas to develop new products and innovations in AI and agronomy. We're excited to see many of them hit the paddock in and around spring 2024. Keep an eye on the May-Jun 2024 Groundcover supplement for more details on those projects, and where we're heading with our 'Grain Automate' program of RD&E that's focussed on machine autonomy and intelligent systems; areas heavily enabled by AI.

Expect data from on-farm experiments to have a strong influence in AI and agronomy

Modern machine capabilities and data analytics tools make it easier than ever to implement large-scale on-farm experiments (OFEs) using precision agriculture tools. OFEs provide a rich basis of quantitative data across sites and seasons to help train and calibrate AI-based products for sub-paddock scale applications. As we head toward leveraging the power of AI for more complex agronomic decisions, OFEs are likely to be a linchpin in developing those products and services, and in helping growers and agronomists build confidence in those products.

Expect LLMs to advance rapidly barring regulatory and legal constraints

The AI arms race among big tech companies such as Microsoft, Google, Meta (Facebook) is accelerating the pace at which AI tools become available to a wide breadth of users. At Agritechnica last year Bayer and Microsoft announced an update to Microsoft Azure Data Manager for Agriculture that included news of large language model APIs in Azure Data Manager for agriculture (Thomas, 2023). LLMs are also making coding tasks more accessible to non-software engineers, opening possibilities to easily automate bespoke data and/or agronomic analysis tasks, and many other applications.

GRDC's investment strategy in AI and agronomy

GRDC has been focussing on high value use-cases that require complex science and commercial innovation to bring to market. That often involves investing upstream in applied R&D where the power of AI can be combined with relevant domain expertise, and where we can partner with companies that work closely with growers and agronomists to develop user-friendly AI products and services that really meet the need on-farm. We're excited to see the fruits of that long-term strategy deliver benefits on-farm and at scale in 2024 and beyond.

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