WAGGA WAGGA
NSW
WEDNESDAY 14 &
THURSDAY 15
FEBRUARY 2024

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

GRDC™
GRAINS RESEARCH
& DEVELOPMENT
CORPORATION

grdc.com.au

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: Wednesday 14 February 2024

9am registration for a 10am start, finish at 5:20pm

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)*
11:05 am	GHG calculators for your grain farming business	***Ben White*** *(Kondinin Group)*
11:30 am	Securing access to nitrogen for food production, a GHG perspective	***Rob Norton*** *(Norton Agronomic)*
12:05 pm	*PhD Presentation*: Fertilise the farming system not just the crop if you want to build soil organic matter. The impact of nutrient stoichiometry on carbon sequestration in dispersive subsoils	***Andrew Regan*** *(UNE)*
12:20 pm	Lunch	
1:20 pm	Concurrent session 1 – *See concurrent sessions for details*	
3:05 pm	Afternoon tea	
3:35 pm	Concurrent session 2 – *See concurrent sessions for details*	
5:20 pm	Close	
7:00 pm	Networking dinner & drinks at the Thirsty Crow Brewery, 153 Fitzmaurice St, Wagga Wagga *Courtesy of AGT & Syngenta*	

Day 2 Program: Thursday 15 February 2024

7:30–8:20am early risers session. Day sessions 8:30am start, finish at 3:00pm

Time	Topic	Speaker(s)
7:30 am	EARLY RISERS DISCUSSION SESSION Risks and rewards of running higher N budgets	***John Kirkegaard*** *(CSIRO),* ***Mathew Dunn*** *(NSW DPI)* ***& 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	Where AI adds value to agronomic and crop decision-making now, and where might this technology be in 5 years?	***Liam Ryan*** *(GRDC)*
2:00 pm	The Cool Soil Initiative: A farmer-focused, scalable framework for emission reporting through the supply chain	***Fionia McCreadie*** *(Cool Soils)*
2:25 pm	Bridging the sustainability divide: Challenges and opportunities in key markets for Australian grain	***Chris Carter*** *(AEGIC)*
3:00 pm	Close	

Location & timing of concurrent sessions

	Joyes Hall (Live streamed)	Venue 2	Venue 3
Day 1 – Session 1	Farming systems, dual purpose crop economics & the genetics of heat stress	Cereal diseases	Pot pouri
Day 1 – Session 2	Cereal diseases	Farming systems, dual purpose crop economics and the genetics of heat stress	Pot pouri
Day 2 – Session 3	Weeds	New tech & start-ups	Slugs, climate forecasts & crop weather services
Day 2 – Session 4	New tech & start-ups	Weeds	Slugs, climate forecasts & crop weather services

(Agenda subject to change)

Concurrent Sessions – DAY 1

Farming systems, dual-purpose crop economics and the genetics of heat stress (Sessions 1 & 2)

Session Time		Topic and Speaker(s)
1 Live stream	**2**	
1:20 pm	3:35 pm	Heat stress & harvest heroes: Cultivating tolerance in wheat through innovative breeding to enhance grain fill ***Rebecca Thistlethwaite*** *(Uni of Sydney)*
1:50 pm	4:05 pm	Farming systems – profit over time & risk –Exploring N legacy impacts in different farming systems ***John Kirkegaard*** *(CSIRO)*
2:25 pm	4:40 pm	Revisiting the economics of dual-purpose crops under current meat & wool prices ***John Francis*** *(Agrista)*

Cereal diseases (Sessions 1 & 2)

Session time		Topic and Speaker(s)
1	**2** Live stream	
1:20 pm	3:35 pm	Rust management issues in 2024 ***Mumta Chhetri*** *(Uni of Syd PBI)*
1:50 pm	4:05 pm	Septoria tritici management in 2024 ***Brad Baxter*** *(NSW DPI)*
2:20 pm	4:35 pm	Strategies to reduce losses from crown rot • performance of Victrato® in wet and dry seasons • strategies to reduce inoculum load • resistance and stewardship for Victrato®. ***Steven Simpfendorfer*** *(NSW DPI)*

Pot pouri (Sessions 1 & 2)

Session time		Topic and Speaker(s)
1	**2**	
1:20 pm	3:35 pm	The long & the short of it: How longer hypocotyls could improve canola establishment ***Matt Nelson*** *(CSIRO)*
1:50 pm	4:05 pm	RLEM & resistance: the latest in best practice management & new decision-aid tools ***James Maino*** *(Cesar)*
2:20 pm	4:35 pm	Sensors, automation, data & ag tech case study: setting the farm up for the future using lidar technology to reduce waterlogging ***Jay Carrol*** *(Civil Ag Design Moree)*
2:45 pm	5:00 pm	Comparing the effect of weed seed impact mills on the weed seed bank ***Ben White*** *(Kondinin) &* ***John Broster*** *(CSU)*

Concurrent Sessions – DAY 2

Weeds (Sessions 3 & 4)

Session Time		Topic and Speaker(s)
3 Live stream	**4**	
8:30 am	10:45 am	Novel weed control technologies under development in the US for HWSC & controlling weeds post-em ***Mike Walsh*** *(CSU)*
9:00 am	11:15 am	Resistance management strategies for glyphosate resistant weeds; finessing pre-em herbicides & getting the early post-em space right ***Chris Preston*** *(Uni of Adelaide)*
9:45 am	12:00 pm	Panel discussion: Chemical & cultural options to manage glyphosate resistant ryegrass, glyphosate resistant & susceptible sow thistle & paraquat resistant fleabane ***Greg Condon*** *(Grassroots Agronomy),* ***Barry Haskins*** *(AgGrow Agronomy),* ***Craig Warren*** *(Nutrien Temora)*

New tech & start-ups (Sessions 3 & 4)

Session time		Topic and Speaker(s)
3	**4** Live stream	
8:30 am	10:45 am	Integrating soil moisture sensor technology on sowing equipment to optimise seeding depth & establishment ***David Finlay*** *(MPT)*
8:45 am	11:00 am	Using guided work instructions for on-farm maintenance, operation & repair ***Nick Walker / Liam Scanlon*** *(Hindsite Industries)*
9:00 am	11:15 am	A handheld lab for better infield decision making ***Peter Johnston*** *(Hone Ag)*
9:15 am	11:30 pm	Robust remote area connectivity solutions ***Dan Winson*** *(Zetifi)*
9:30 am	11:45 am	Automated agricultural disease detection ***Edward Gubbins*** *(BioScout)*
9:45 am	12:00 pm	Manage environmental data such as soil tests for fertiliser budgets, or developing carbon offset projects ***Sam Duncan*** *(Farmlab)*

Slugs, climate forecasts & crop weather services (Session 3 & 4)

Session time		Topic and Speaker(s)
3	**4**	
8:30 am	10:45 am	Slugs – why did they appear in 2023 & are they likely to persist? How do new slug products perform in wet conditions & on other establishment pests & how do you determine when it's economic to treat? ***Michael Nash*** *(What Bugs you)*
9:00 am	11:15 am	Climate services for cropping – historical climate data & future projections for growing season rainfall, frost risk, heat risk at flowering & soil moisture by region for medium to longer term farm planning ***Sigrid Tijs*** *(BOM)*
9:30 am	11:45 am	Weather predictions, risk & decision making. Perspectives on making better decisions on risk management from weather & seasonal forecasts. ***Claire Yeo*** *(BOM)*

Live stream of the event

In addition to being run as a face-to-face Update, the Joyes Hall sessions will be live streamed for online viewing.

Those who register for the live stream (free), receive a link to the live stream close to the event and a link to the online proceedings. Not all concurrent sessions will be run in Joyes Hall, so not all sessions will be live streamed. Please refer to above agenda.

Register for the livestream at https://icanrural.com.au/updates.html

Contents

Compiled by Independent Consultants Australia Network (ICAN) Pty Ltd.
PO Box 718, Hornsby NSW 1630
Ph: (02) 9482 4930, Fx: (02) 9482 4931, E-mail: northernupdates@icanrural.com.au

ɸ Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.
® Registered trademark

General plenary - Day 1

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

Warwick Badgery[1], Aaron Simmons[2], Richard Eckard[3], Peter Grace[4]

[1] NSW Department of Primary Industries, Orange Agricultural Institute, 1447 Forest Rd, Orange, NSW, 2800
[2] NSW Department of Primary Industries, Muldoon Street, Taree, NSW, 2430
[3] School of Agriculture and Food, The University of Melbourne, Parkville, VIC, 3010
[4] Centre for Agriculture and the Bioeconomy, Queensland University of Technology, Brisbane, QLD

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.

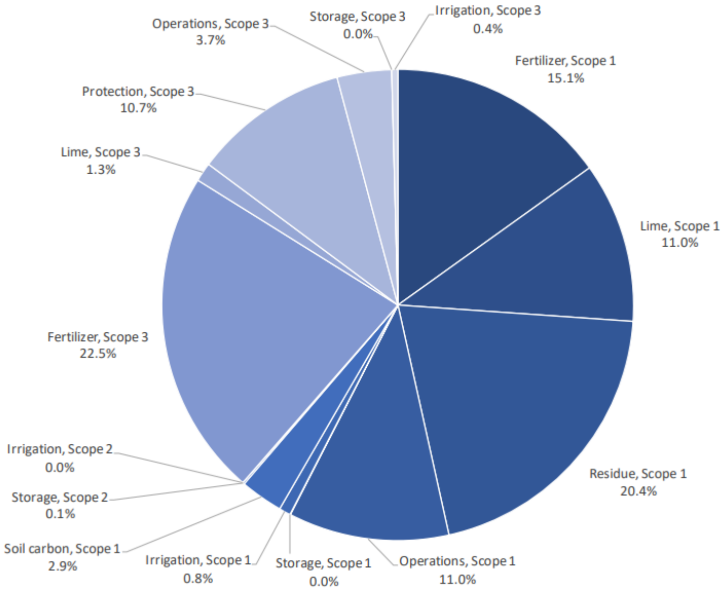


Figure 1. Contribution of emissions sources for the Australian grain sector (From Sevenster *et al.,* 2022). Scope 1 - Direct emissions from the company's operations; Scope 2 - Indirect energy emissions; and Scope 3 – Other indirect emissions.

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.

Contact details

Warwick Badgery
NSW DPI
Ph: 0427 274 034
Email: warwick.badgery@dpi.nsw.gov.au

GHG calculators for your grain farming business

Ben White, Kondinin Group

Contact details

Ben White
Kondinin Group
Email: ben@kondinin.com.au

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]

[1] Associate Professor, The University of Melbourne, & Norton Agronomic
[2] Soil Water and Nutrients Consulting, & School of Agriculture and Food Sciences, The University of Queensland
[3] School of Biology and Environmental Science, Queensland University of Technology
[4] Fertilizer Australia
[5] Grower Relations Manager – North, Grains Research and Development Corporation

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).

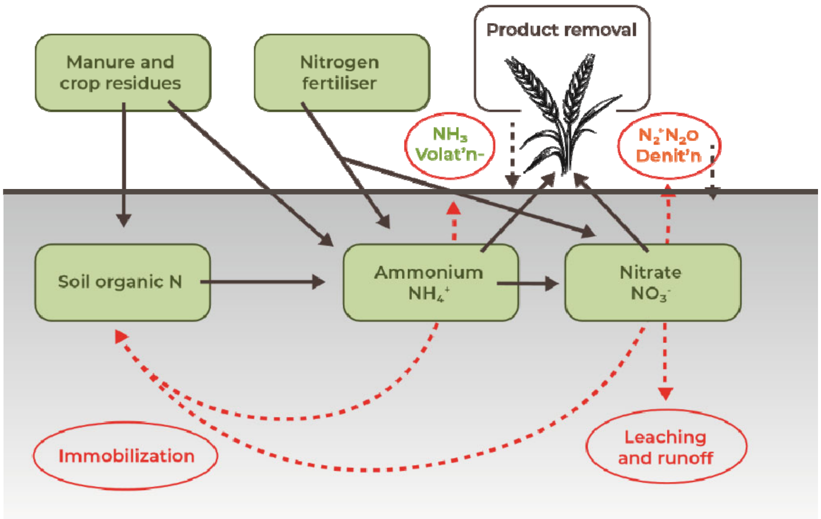


Figure 1. A simplified nitrogen cycle showing the inputs and pools of nitrogen, along with loss and transfer pathways in red dashed lines (International Plant Nutrition Institute). (Volat'n = volatilisation; Denit'n = denitrification). Gaseous N can redeposit.

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).

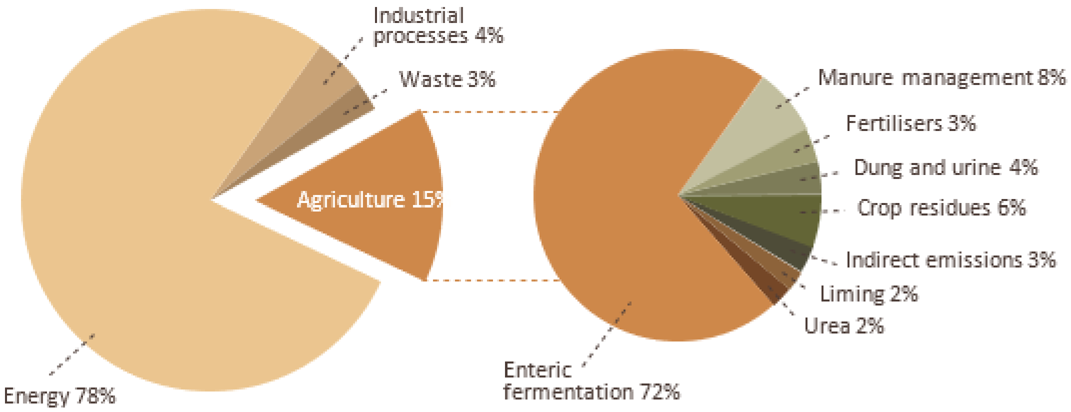


Figure 2. Total greenhouse gas (GHG) emissions for Australia by United Nations Framework Convention on Climate Change, net of Land Use, Land Use Change and Forestry sector (left) and the breakdown of agricultural emissions by IPCC source.

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.

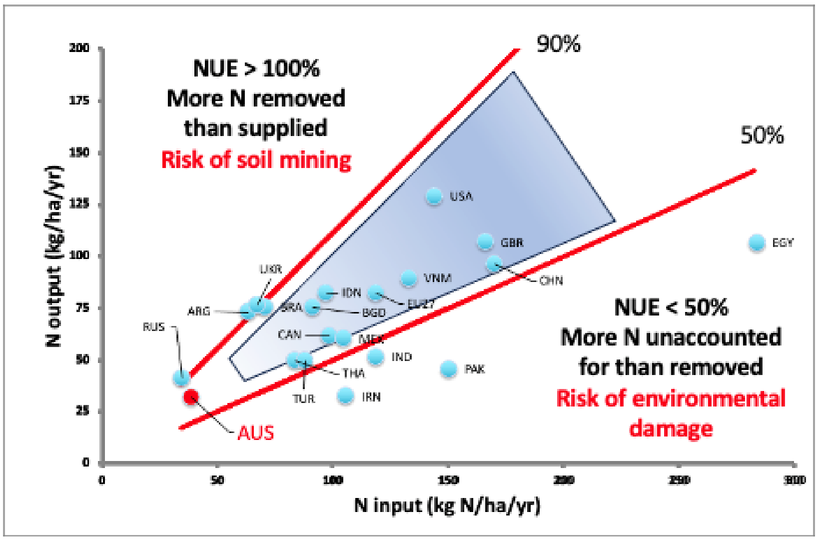


Figure 3. NUE (partial nutrient balance for N) for cereals, graphed as the output (removal) of N against the fertiliser input N. The thick red lines show values of NUE according to the relation between inputs and outputs. Biological N fixation and manure use are not considered in this example. The 'safe' 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.

References

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

Brill R, Moodie M, Street M, Obrien B, Price T, Morris B, Haskins B and Whitworth R (2023) Pulse performance in regionally relevant environments. GRDC Update Paper 14 February 2023. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2023/02/pulse-performance-in-regionally-relevant-environments

Deloitte Access Economics (2023) Carbon border adjustment mechanisms: Implications for Australian Agriculture. Agrifutures Australia. https://agrifutures.com.au/product/carbon-border-adjustment-mechanisms-implications-for-australian-agriculture/

French R, Schultz J (1984) Water use efficiency of wheat in a Mediterranean-type environment. I. The relation between yield, water use and climate. Australian Journal of Agricultural Research 35, 743-764.

Grace P, de Rosa D, Shcherbak I, Strazzabosco A, Rowlings D, Scheer C, Barton L, Wang W, Schwenke G, Armstrong R, Porter I and Bell M (2023) Revised emission factors for estimating direct nitrous oxide emissions form nitrogen inputs in Australia's agricultural production systems: a meta-analysis. Soil Research 62, SR23070. doi.org/10.1071/SR23070

Harries M, Flower KC, Renton M, Anderson GC (2022) Water use efficiency in Western Australian cropping systems. Crop and Pasture Science 73, 1097-1117.

Norton R, Gourley C, Grace P and Kraak J (2023) Nitrogen Fertiliser Use and Greenhouse Gases - An Australian Assessment: Challenges and Opportunities. Fertilizer Australia, Canberra, ACT https://fertilizer.org.au/news-events-and-publications/fertilizer-australia-white-paper

Norton R, Bruulsema T, Robert T, Snyder C. 2015 Crop nutrient performance indicators. Agricultural Science, 27 (2), 33-38.

Peoples MB, Bowman AM, Gault RR, Herridge DF, McCallum MH, McCormick KM, Norton RM, Rochester IJ, Scammell GJ, Schwenke GD. (2001) Factors regulating the contributions of fixed nitrogen by pastures and crop legumes in different farming systems of eastern Australia. Plant and Soil, 228 (1):29-41.

Sadras V and Rodriguez D (2007) The limit to wheat water-use efficiency in eastern Australia. II. Influence of rainfall patterns. Australian Journal of Agricultural Research 58(7) DOI:10.1071/AR06376

Sevenster M, Bell L, Anderson B, Jamali H, Horan H, Simmons A, Cowie A, Hochman Z (2022) Australian grains baseline and mitigation assessment. https://grdc.com.au/__data/assets/pdf_file/0031/572449/Paper-Sevenster-Maartje-GHG-footprint-Grains-February-2022.pdf

Contact details

Rob Norton
Email: robnorton001@gmail.com

® Registered trademark

Fertilise the farming system not just the crop to build soil organic matter – the impact of nutrient stoichiometry on carbon sequestration in dispersive subsoils

Andrew Regan[1]; Chris Guppy[2],Brian Wilson[2], John Kirkegaard[3], Alan Richardson[3]

[1] UNE/CSIRO
[2] UNE
[3] CSIRO

Key words

soil carbon, carbon sequestration, stoichiometry, nutrition, microbes

GRDC code

CSP2302-011RTX

Take home messages

- Recent research found a novel method to increase soil C in cropping systems by adding nutrients (N, P, S) to incorporated crop stubble at the theoretical rate required by soil microbes for growth
- The practice has produced variable results and has not been tested specifically on sodic soils which could benefit significantly from improved carbon sequestration
- Our research demonstrates that soil C losses could be reduced, rather than significant soil C sequestered by supplementary nutrients added to stubble on a dispersive soil which was accompanied by improved aggregate stability
- A new GRDC funded project led by CSIRO seeks to verify the soils and strategies where post-harvest fertiliser applications to crop residues can increase soil C.

Background

Sequestering carbon in agricultural soils improves crop productivity and contributes to offsetting greenhouse gas emissions (Lal, 2011). The balanced application of N, P and S in combination with stubble incorporation into topsoil is a novel strategy to increase soil C in cropping systems (Kirkby *et al.,* 2016; Kirkegaard, 2023). The stable form of soil C (mineral-associated organic C (MAOC)) was found to have a specific C:N:P:S ratio of 10,000:833:200:143. Therefore, applying fertiliser to crop stubbles to achieve the microbial demand for these nutrients has potential to improve stabilisation of soil C.

A common misconception is that nutrients are lost/wasted when applied to soil in the fallow period however ‘fertilising the system’ meets the microbial demand for nutrients when stubble is decomposing which can result in greater stabilisation of C and the nutrients later become available to the crop. This concept requires further research to determine the soils/environments, seasonal conditions, and timing where it is beneficial and economical.

Study one – PhD project (2019-2025)

A PhD project aimed to build on previous research by exploring this input strategy in a dispersive subsoil. Dispersive subsoils benefit from the application of organic matter (Uddin, *et al.,* 2022) so it is possible that dispersion could be further reduced by stubble incorporation and the co-application of nutrients.

Incubation 1 – Short-term study

Method. The study comprised a laboratory incubation experiment to assess the impact of stubble, stubble quality and supplementary nutrients (N, P, S) on microbial activity and soil C changes. Two sorghum stubble of different quality (C:N ratio of 36 and 43) were applied to soil at an equivalent rate of 4 t/ha. Nitrogen was applied to each at three rates; Control (0 kg N/ha), half rate required to balance the stoichiometry (55 kg N/ha) and full rate (110 kg N/ha). Sulfur alone (20 kg S/ha), and sulfur plus phosphorus at 30 kg/ha were added to both the half N and full N treatments to determine the value of providing S and P in addition to N.

The incubation experiment was run for 8 weeks in 70 ml jars each containing 25 g of soil in cabinets at 22°C. During the course of the experiment hourly CO_2 respiration was recorded over the full 8-week period and at the end of the experiment samples of soil were taken to measure changes in soil C fractions including total organic C (TOC), mineral-associated organic C (MAOC), particulate OC (POC) and recalcitrant OC (ROC) using a mid-infrared spectrometer.

Results. The pattern of respiration over the course of the 8-week period is shown in Figure 1 for the control and the average of both of the residue treatments (very little difference between stubble types). The application of stubble increased respiration by soil microbes and under the higher N rate soil respiration was increased (Figure 1). When the stubble and N were supplemented with S alone there was a small and transitory reduction in respiration during the first week, while S and P generated a small increase in respiration.

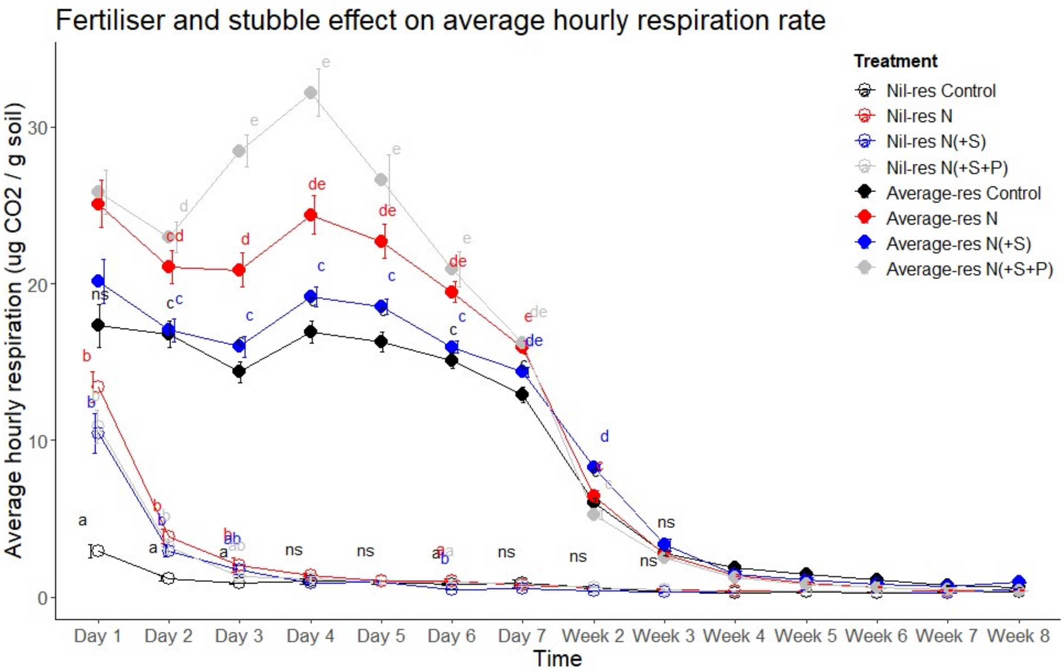


Figure 1. The effect of stubble and fertiliser treatment addition on average hourly respiration rate during the 8-week incubation.

The application of stubble appeared to increase soil C fractions (Figure 2) but only the MAOC and ROC fractions had significant increases (Figure 2B, D). It seems likely much of the added stubble C was consumed and respired as CO_2. Under the higher N rate soil respiration was higher (Figure 1) but a similar amount of MAOC was stabilised (Figure 2B). When N was supplemented with S and P there was no significant change in soil C fractions despite the transitory changes in respiration.

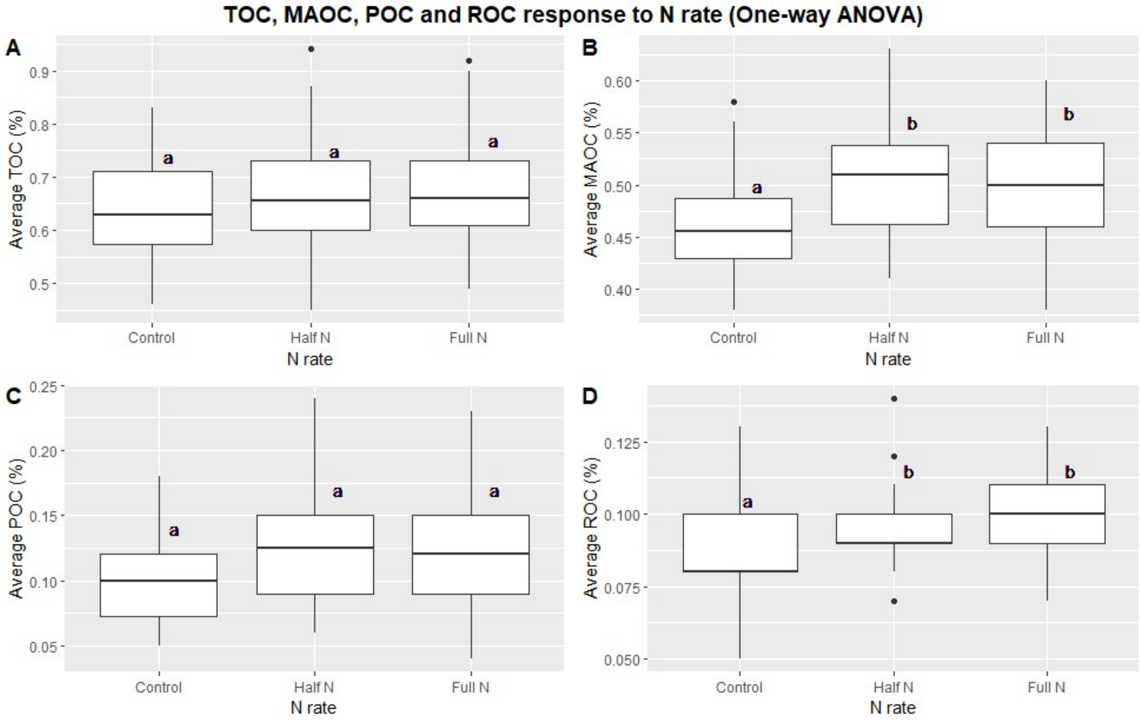


Figure 2. Changes in soil C fractions in response to added stubble and nitrogen

Incubation 2 – Longer-term effects on aggregate stability

Method. The experiment involved a 6-month incubation designed to investigate the impacts of similar treatments to those in Incubation 1 on the longer-term soil structural stability. Treatments were applied to 70 ml containers with 25 g soil and treatments identical to those in Incubation 1. Stability was assessed at the end of the incubation by measuring (1) Spontaneous turbidity, which is a measure of the physicochemical stability of a soil; (2) Mechanical turbidity, which incorporates kinetic energy into the measurement, simulating the action of raindrop impact; and (3) Zeta potential, which integrates the important role of cation valence and ionic strength (salinity) on aggregate stability. The higher in magnitude the zeta potential the greater the soils tendency to disperse.

Results. Spontaneous turbidity (ST) declined by 60% with the addition of stubble in the absence of nutrients with little difference between stubble types (Figure 3). Nutrients alone reduced ST to an even greater degree than stubble with the full N (+S or S+P) treatment generally providing the greatest reduction in turbidity with or without stubble.

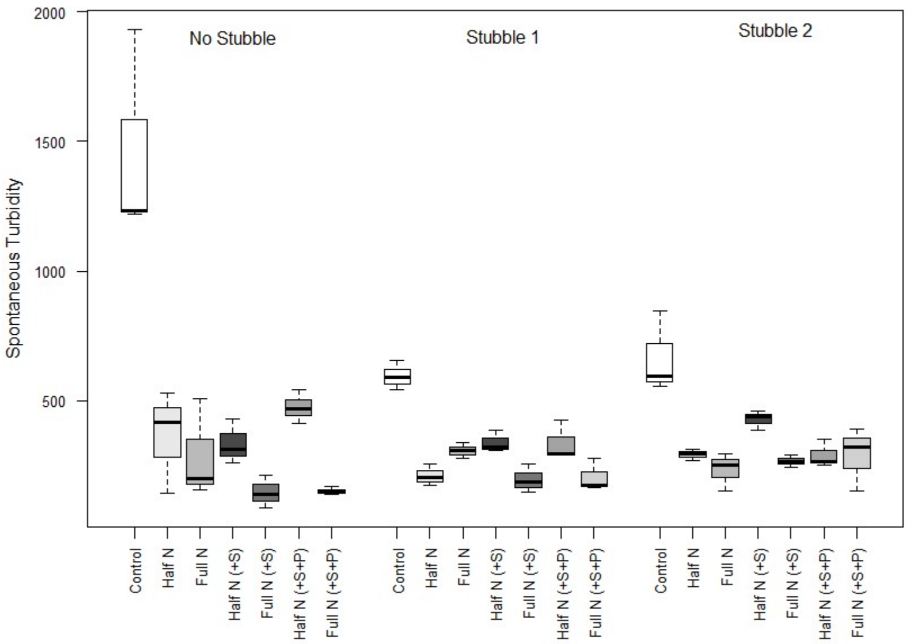


Figure 3. Effect of stubble and nutrient treatments on spontaneous turbidity after 6 month incubation of a dispersive soil.

Similar trends were observed for mechanical turbidity although stubble alone had less effect while the effect of the full N rate, with or without S and P was exceptional, reducing turbidity to zero (Figure 4).

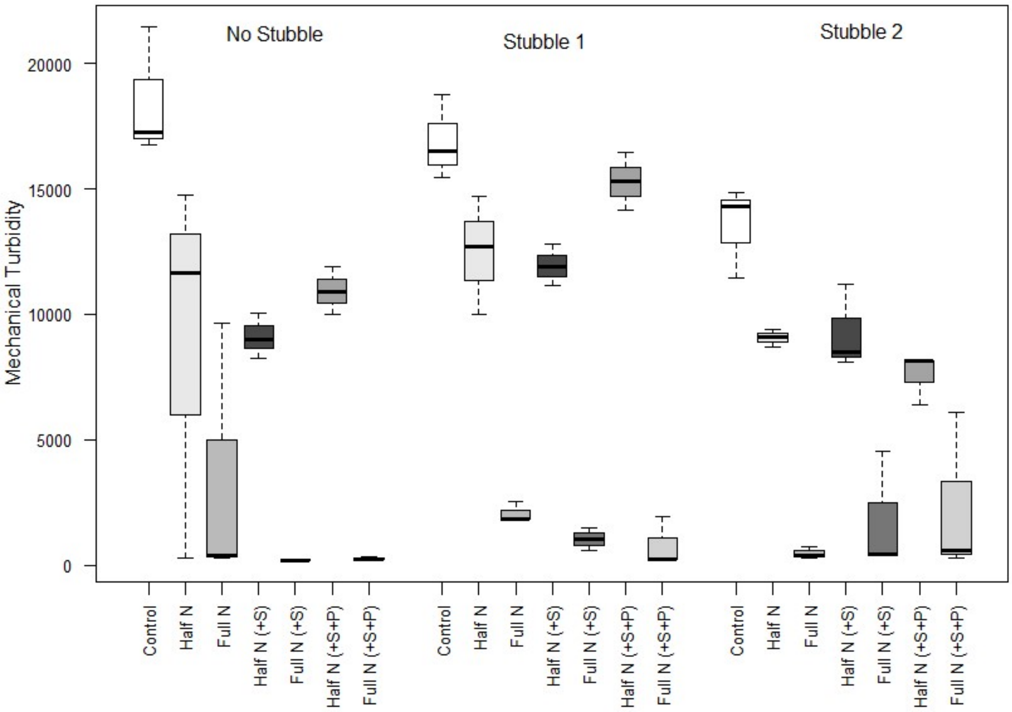


Figure 4. Effect of stubble and nutrient treatments on mechanical turbidity after 6 month incubation of a dispersive soil.

Discussion

The incubation studies have demonstrated that both stubble retention and N, P and S supplied as fertiliser increased microbial respiration and prevented C losses in a dispersive subsoil under laboratory conditions. The results coincided with improved aggregate stability, which suggests this management practice may be an effective tool on other dispersive soils and in a field setting. The results suggest stubble quality can affect decomposition and C content so testing of stubble may be required to establish appropriate fertiliser rates rather than relying on generalised assumptions. The impact of N rate appeared to have a greater effect than S and P, but this may change depending on initial soil S and/or P content. Dispersion processes are highly sensitive to ionic strength, a soil chemist's term for salinity. This is part of the reason small rates of gypsum can reduce dispersion before they have fully dissolved. In this study, fertiliser application itself, particularly N increased soil ionic strength enough to limit dispersion significantly. In incubation studies, the applied fertiliser is contained. However, these effects, if not stabilised through the incorporation of the added N into organic matrices, will be short-lived as the fertiliser leaches through field soil.

Study two – New GRDC project (2023–2027)

A national-scale field project has been established to build on significant national and international research demonstrating the importance of nutrient supply (NPS), not just C, in the correct ratios to build and maintain soil organic matter (SOM) in productive agricultural systems.

The initial proof-of-concept conducted at CSIRO was confirmed in recent experiments (Kirkby *et al.,* 2016; Sevenster *et al.,* 2020; Kirkegaard *et al.,* 2023) where a long-term trend of declining SOM under no-till farming was arrested and reversed within 5 years by adopting novel nutrient supply strategies.

This field-based proof-of-concept in a long-term tillage experiment at Harden NSW, showed significant increases in SOM could be achieved in productive and profitable systems by adopting this approach – however further refinements to nutrient timing, rates, formulations, and delivery may provide further improvements to reduce risk of C loss, increase profit and avoid nutrient loss.

This project will assess 10 different nutrient supply strategies in fully replicated (4) on-farm field experiments, starting January, 2023 at 8 sites on contrasting soils and environments across Australia including Narrabri NSW (black soil); Young NSW (granite/red brown); Corowa NSW (red brown); Wimmera VIC (grey clay);Keith SA (alkaline loam); Tarlee SA (red brown); Cuballing WA (sand over gravel); Moora WA (deep sand). The treatments include different levels of incorporation, granular and liquid fertiliser and comparison of fertiliser applied to the stubble or to the crop.

Baseline sites with replicated experiments have been established and baseline soil C sampling done in 2023 along with on-farm strip trials. The sites will be managed through a 5-year crop sequence with treatments applied to stubble annually. At the conclusion of the 5-yr experimental period, the data collected on crop productivity, gross margins, and changes in soil C from small plot and paddock strips will be used to develop cost-benefit analysis including sensitivity analysis with respect to C, fertiliser and grain prices.

References

Kirkby CA, Richardson AE, Wade LJ, Conyers M and Kirkegaard JA (2016) Inorganic Nutrients Increase Humification Efficiency and C-Sequestration in an Annually Cropped Soil, PLoS One, 11(5), https://doi.org/10.1371/journal.pone.0153698Kirkegaard, 2020).

Kirkegaard JA, Richardson AE, and Kirkby CA (2023) Fate and Cost Effectiveness of Soil Carbon Sequestered Using Supplementary Nutrients Applied to Crop Residues Under Field Conditions, Nutrient cycling in agroecosystems 143

Lal R (2011) Sequestering carbon in soils of agro-ecosystems, Food policy, Vol.36 (1), p.S33-S39

Sevenster M, Luo Z, Eady S, Grant T (2020) Including long-term soil organic carbon changes in life cycle assessment of agricultural products, Int J Life Cycle Assess 25, 1231–1241 (2020). https://doi.org/10.1007/s11367-019-01660-4

Uddin S, Williams SW, Aslam N, Fang Y, Parvin S, Rust J, Van Zwieten L, Armstrong R, Tavakkoli E (2022), Ameliorating Alkaline Dispersive Subsoils with Organic Amendments: Are Productivity Responses Due to Nutrition or Improved Soil Structure? Plant and soil 227

Acknowledgements

Supervisors: Chris Guppy and Brian Wilson. With assistance from John Kirkegaard and Alan Richardson at CSIRO.

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

Contact details

Andrew Regan
UNE / CSIRO
School of Environmental & Life Sciences, UNE
Ph: 0427 872 329
Email: aregan3@myune.edu.au

Concurrent session: Farming systems, dual purpose crop economics and the genetics of heat stress

---

Heat stress and harvest heroes: cultivating tolerance in wheat through innovative genetic breeding for enhanced grain fill

Rebecca Thistlethwaite[1], Anowarul Bokshi[1], Reem Joukhadar[2], Daniel Tan[1], Josquin Tibbits [2], Darshan Shama[3], Matthew Hayden[2,] Dini Ganesalingam[4], Dion Nicol[3], Richard Trethowan[1]

[1] The Plant Breeding Institute, The University of Sydney
[2] Agriculture Victoria
[3] Department of Primary Industries and Regional Development, WA
[4] Intergrain Pty Ltd

Key words

heat stress, heat tolerance, wheat, grain filling, trait stability, genetics

GRDC code

UOS2202-001RTX

Take home message

- This research tackles the threat of rising temperatures to wheat production, focusing on the vulnerability of the critical grain fill growth stage during milk and dough development
- Elevated daytime temperatures shorten the grain-filling period, while high night-time temperatures disrupt respiration, induce rapid maturity and compromise photosynthesis
- This project involves an adaptive approach towards screening for heat tolerance, rigorous phenotyping, creating new heat-tolerant varieties, and deepening genetic understanding to equip wheat growers with genetic tools to remain productive when faced with extreme temperatures during the growing season
- Tolerant commercial varieties like LRPB Hellfireⓓ, LRPB Flankerⓓ, and LRPB Reliantⓓ express small yield variability in various conditions, and the genetic stability of Maceⓓ and Scepterⓓ indicates consistent yield performance
- Imported and locally developed genetic material in Australia demonstrates promising potential as a robust defense against extreme heat events
- A deeper understanding of leaf waxiness (glaucousness) in environments like Kununurra, predicted to occur in the future, can expedite the identification of wheat lines with superior heat tolerance.

Rationale behind research

As climate change intensifies, extreme heat events are becoming more frequent, posing a significant threat to wheat production. Wheat is particularly sensitive during the grain fill (milk and dough) growth stage, and extreme heat during this period can severely impact both crop yield and quality. Such heat events disrupt the translocation of nutrients and the synthesis and deposition of starch, negatively affecting kernel size.

Daytime high temperatures during grain fill can impact a wheat plant though:

- **Reduced grain filling duration**–- elevated daytime temperatures shorten the critical grain-filling period, limiting the wheat plant's ability to store nutrients and resulting in lower yield.
- **Kernel weight reduction** – elevated daytime temperatures during grain filling significantly reduce the weight of individual wheat kernels, impacting overall yield and quality.

Night-time high temperatures during grain fill can impact a wheat plant by:

- **Impairing respiration** – night-time high temperatures interfere with the plant's respiration, hindering the efficient use of stored sugars for grain development, affecting overall quality and yield.
- **Inducing senescence** – prolonged exposure to high night-time temperature causes premature aging in wheat plants, shortening the grain-filling period and impacting final yield.
- **Compromising photosynthesis** – elevated night-time temperature disrupts the balance between photosynthesis and respiration, reducing the plant's ability to produce and store energy, further contributing to reduced grain quality and yield.

Combating increasing temperatures across Australia

To ensure wheat producers across Australia can combat rising temperatures, our research employs a multi-stepped approach:

1. Screening for heat tolerance: genotypes are assessed under high temperature environmental conditions using a three-tiered technique. This involves a combination of large-scale field trials where a staggered time of sowing approach is used to induce a natural heat stress. A small subset of the most promising genetic material is further assessed under controlled conditions such as in-field controlled environment chambers and standard glasshouse facilities.
2. Phenotyping and validation: the performance of 200 of the most promising lines is evaluated at key sites across Australia in conjunction with Intergrain's Multi-Environment Trial (MET) network, considering phenology, UAV imagery, yield, grain weight, and screenings.
3. Creating new genotypes: crosses among lines with high genetic potential are conducted, contributing to ongoing efforts to develop heat-tolerant wheat varieties.
4. Genetic understanding: by 2025, we aim to figure out the unique code (haplotype structure) in wheat's genetic makeup, which acts like a special pattern to help understand how different traits for heat tolerance are connected in the DNA.

What did well under high temperature stress in 2022 and 2023?

Building on the findings of the GRDC funded initiative US00081, which initially focused on heat tolerance during anthesis, the current pre-breeding project extends its scope to scrutinize grain filling more closely. By leveraging the successful three-tiered phenotyping technique developed in the previous project, we can effectively assess the performance and physiological responses of wheat genotypes in hot environments. Unlike traditional single-tiered approaches conducted in controlled environments like a glasshouse, this research prioritises field conditions for assessment. Wheat varieties that exhibited success in the field were further evaluated in both glasshouse and in-field controlled environment chambers for a comprehensive analysis.

In 2022, a mild year, trials nationwide experienced minimal heat stress, except for Kununurra. In contrast, 2023 proved to be a challenging year, characterised by elevated temperatures and prolonged periods of high temperature during grain filling across the country. This resulted in a discernible impact on harvest yields. Table 1 illustrates the temperature variances for each year in relation to their respective harvest yields for Narrabri in north-west NSW. The average yield decrease in the challenging year (2023) amounted to 1.8 t/ha, while in the favorable year it was 1 t/ha (2022).

Table 1. Planting dates, average trial yield (t/ha), and maximum and minimum in-season temperatures for each time of sowing (TOS) at Narrabri in 2022 and 2023

Year	TOS	Planting date	Max in-season temperature (°C)	Min in-season temperature (°C)	Average trial yield (t/ha)
2022	1	27/05/2022	32.8 on 27/11	-2.1 on 10/07	6.8
	2	19/07/2022	33.8 on 19/11	-1.6 on 19/07	5.8
2023	1	30/05/2023	32.4 on 2/10	-3.5 on 20/07	4.6
	2	19/07/2023	36.8 on 13/11	-3.5 on 20/07	2.8

Table 2 illustrates the yield decline between normal and late planting for current commercial lines at Narrabri, NSW. Lines with a low yeild reduction between years, such as Valiantⓟ, Rockstarⓟ, Maceⓟ and Scepterⓟ showcased their versatility and ability to withstand different years and envirnoments under stress while maintaining yield stability.

Table 2. Yield reduction (t/ha) between normal and late planting and yield stability (YS) ranking across years for current commercial lines at Narrabri, NSW in 2022 and 2023

Genotype	Yield reduction (t/ha)		YS Rank
	2022	2023	
Valiant CL Plusⓟ	2.13	1.21	1
Rockstarⓟ	2.17	1.95	2
Maceⓟ	1.66	1.56	3
Scepterⓟ	1.45	1.48	4
Borlaug 100ⓟ	1.67	1.89	5
Catapultⓟ	1.21	1.75	6
Cutlassⓟ	1.08	1.90	7
Suntopⓟ	0.93	1.89	8
Sheriff CL Plusⓟ	1.31	2.28	9
Coolahⓟ	0.13	1.15	10
Condoⓟ	0.60	1.74	11
Vikingⓟ	0.49	1.68	12
Beckomⓟ	1.10	2.45	13
LRPB Stealthⓟ	0.49	1.89	14
Havocⓟ	0.47	1.99	15
LRPB Hellfireⓟ	-0.35	1.31	16
Sunchaserⓟ	0.30	2.09	17
Vixenⓟ	0.64	2.43	18
LRPB Flankerⓟ	-0.19	1.60	19
Sunmaster	1.17	3.20	20
LRPB Reliantⓟ	-0.56	1.69	21
LRPB Mustangⓟ	0.52	2.98	22

The use of Intergrain's MET network is crucial for assessing the heat tolerance of wheat varieties because it provides a comprehensive evaluation across diverse environmental conditions. Table 3 depicts the best-performing wheat varieties across 24 locations in 2022. This extensive trial network considers variations in temperature, precipitation, and other environmental factors, providing a more realistic representation of the challenges faced by wheat crops in various regions.

Table 3. The yield performance based on average ranking (Av rank) of 14 candidate lines with high Genomic Estimated Breeding Values (GEBVs) for heat tolerance across all trial sites for each state and the 24 sites nationally in Intergrains (IG) multi-environment trials, and at 3 times of sowing (TOS) at Kununurra in 2022 expressed as % Sunmasterⓓ (best performing check nationally in IG's 2022 MET).

Genotype	Average yield ranking					Yield at Kununurra (% Sunmasterⓓ)			
	NSW	SA	VIC	WA	All sites	TOS1	TOS2	TOS3	Average all TOS
	4 sites	4 sites	5 sites	11 sites	24 sites				
ZWB11-132	8.4	11.0	9.8	10.1	9.8	130.8	108.4	141.8	127.0
ZWB13-171	5.6	5.8	6.2	9.3	7.5	123.7	111.3	138.9	124.6
ZWB13-261	12.7	19.0	17.2	11.5	14.5	117.3	108.6	145.8	123.9
PBI17N008-0N-0N-35N	9.2	11.3	6.6	10.7	10.0	115.0	112.5	131.3	119.6
ZWW11-061	8.4	13.8	12.2	8.9	10.6	115.4	98.7	140.9	118.4
ZWB13-238	13.4	14.0	14.8	13.6	13.7	112.4	101.8	139.4	117.9
Maceⓓ	10.7	5.3	16.8	9.8	11.1	111.5	106.0	136.0	117.8
Vixenⓓ	9.9	7.8	12.2	8.2	9.8	98.3	106.4	146.2	117.0
PBI17N006-0N-0N-96N	7.9	11.0	6.0	9.8	8.9	114.8	103.2	131.0	116.3
ZWW10-069	10.0	12.8	9.2	12.4	11.5	115.5	110.2	121.9	115.9
ZIZ12-045	6.4	13.0	8.0	11.1	9.8	122.4	103.1	118.7	114.7
PBI17N015-0N-0N-55N	9.3	10.8	7.4	8.5	8.9	111.6	105.8	125.7	114.4
ZWB12-009	8.2	9.5	5.6	9.3	8.1	106.1	113.0	123.0	114.0
PBI19N007-0N-6N	15.0	13.8	15.2	16.8	16.2	106.0	106.0	129.5	113.8
PBI17N009-0N-0N-46N	5.9	3.8	5.0	10.1	7.0	111.0	94.4	123.7	109.7
Scepterⓓ	10.5	5.3	10.4	7.3	8.3	101.2	97.7	105.4	101.4
Sunmasterⓓ	4.4	2.0	4.8	6.2	4.8	100.0	100.0	100.0	100.0

Exploring the impact of night-time temperatures on wheat, especially during critical growth stages like grain filling, is a crucial avenue for further investigation. This is a key time when plants recover, gearing up to combat high daytime temperatures. Plants photosynthesize during the day to produce energy, and at night they respire to rest. Figure 1 depicts the impact on yield when this process is disrupted, removing the opportunity for recovery during the night. Treatments were administered during the milk (Z75) and dough (Z83) growth stages, maintaining temperatures 5°C above the ambient temperature for five consecutive nights. Most genotypes tended to be more susceptible to heat at the milk stage when the translocation of nutrients and starch building is at its highest. Interestingly, those tolerant to the milk treatment stage were not as tolerant at the dough stage, indicating the presence of distinct genetics influencing both stages. The average overnight temperature for the milk and dough growth stage treatments were 22°C and 18°C, respectively.

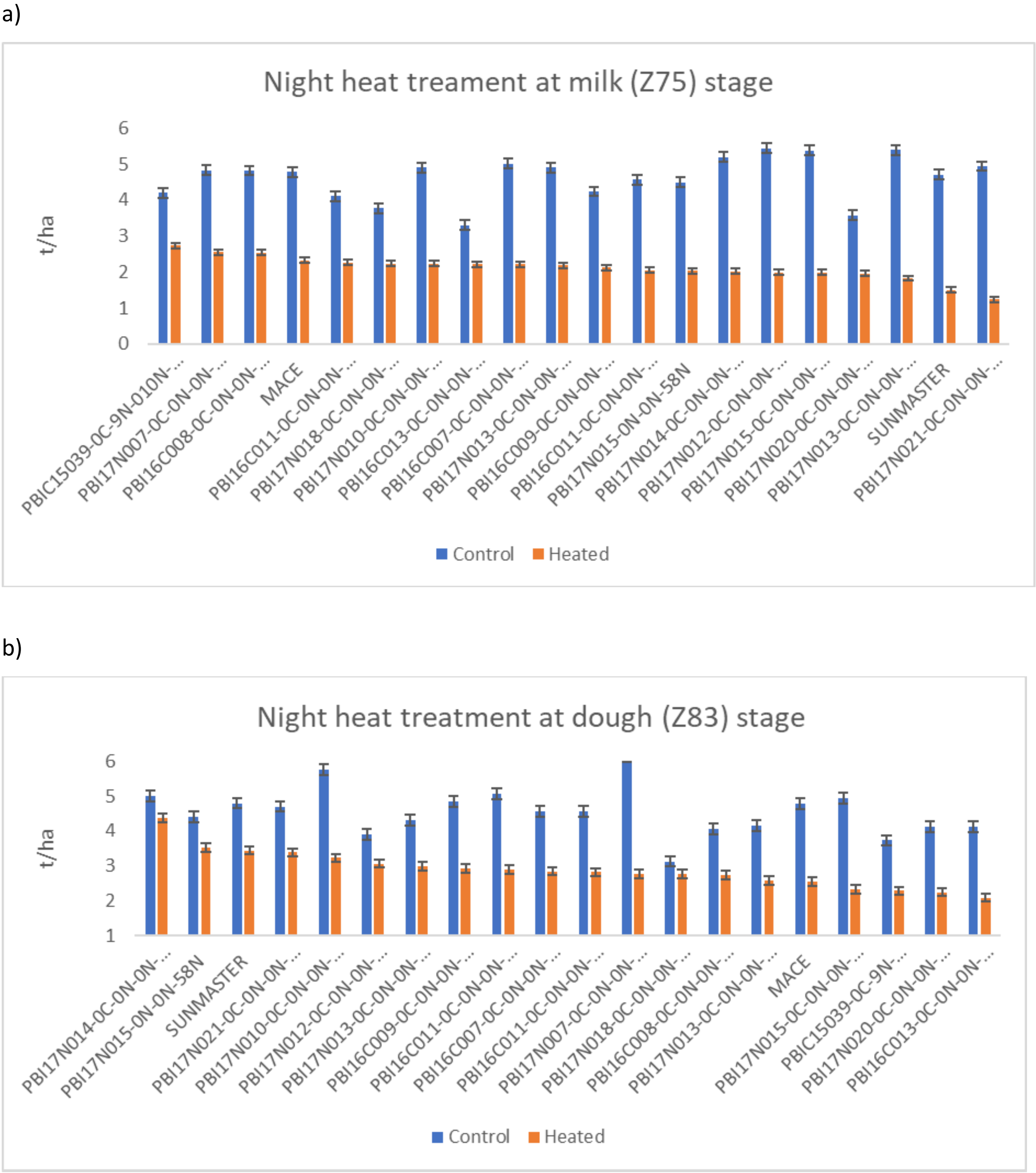


Figure 1. The grain yield (t/ha) for night-time heat treatment of 18 breeding lines, Mace⟠, and Sunmaster⟠ at the a) milk (Z75) and b) dough (Z83) growth stages in Narrabri during 2023. Genotypes are ranked from highest to lowest yield based on performance under heat treatment. Vertical error bars represent the standard error.

Understanding the genetic basis of heat tolerance in wheat is essential for the development of sustainable and commercially viable cultivars by plant breeders. Figure 2 presents a focused exploration of Quantitative Trait Loci (QTL) associated with grain yield, as identified through a Meta-Genome Wide Association Study (MetaGWAS) analysis. Notably, the Manhattan plot reveals significant spikes on chromosomes 3A and 4A, indicating specific genomic locations strongly linked to heat tolerance. On the x-axis, each point corresponds to a genomic location, on different chromosomes. The y-axis shows the statistical significance of associations between genetic markers and heat tolerance.

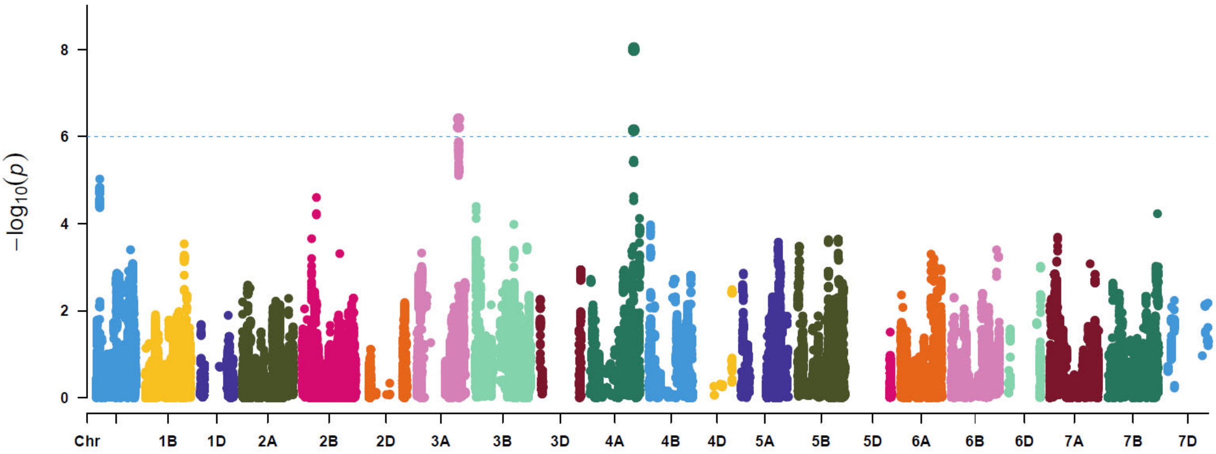


Figure 2 Manhattan plot showing the significant grain yield QTL detected with the MetaGWAS analysis that uses the late time of sowing (TOS2) in all environments. The x-axis indicates genomic locations on different chromosomes, while the y-axis represents the statistical significance of associations between genetic markers and heat tolerance.

This MetaGWAS emphasises regular sowing times across diverse environments, enhancing the robustness of its findings. Each point on the plot corresponds to a unique genomic location, strategically chosen to highlight regions of the genome influencing grain yield. By incorporating data from various environments, the analysis provides comprehensive insights into genetic markers that play a pivotal role in influencing grain yield under different conditions, all while maintaining adherence to standard sowing times. The specific identification of QTLs on chromosomes 3A and 4A suggests targeted regions for further investigation, contributing valuable knowledge to the development of heat-tolerant wheat cultivars.

Significance of the research for growers across Australia

1. With the escalating impact of climate change, more frequent extreme heat events pose a threat to wheat production. Understanding how wheat responds is essential for plant breeders to provide growers with genetically resilient varieties for a sustainable future.
2. The research has a direct impact on crop yield, aiding growers to optimise yield under challenging climatic conditions by identifying wheat genotypes that are heat tolerant during the grain filling growth stage(s).
3. Beyond quantity, the research is focused on enhancing wheat quality, ensuring the new genotypes identified maintain or improve quality attributes.
4. Equipped with insights into heat-tolerant wheat varieties that are currently available, growers can make informed decisions about resource allocation, optimising inputs like water and fertiliser.
5. Recognizing the risk extreme temperature events pose to crop production, the implementation of heat-tolerant varieties identified through this research acts as a vital risk mitigation strategy for growers.

6. Contributing to the development of wheat varieties that withstand challenging conditions, the research safeguards the economic sustainability of wheat growers through improved yield and higher-quality crops.

In summary, this research addresses the practical needs and challenges of wheat growers in Australia, providing solutions to enhance both the quantity and quality of yield, ensuring the sustainability and profitability of their operations in a changing climate.

Acknowledgements

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

Contact details

Dr Rebecca Thistlethwaite
University of Sydney International Centre for Crop and Digital Agriculture
12656 Newell Highway Narrabri NSW 2390
Ph: 0403 525345
Email: rebecca.thistlethwaite@sydney.edu.au

Professor Richard Trethowan
University of Sydney Plant Breeding Institute
107 Cobbitty Road Cobbitty NSW 2570
Ph: 02 9351 8860
Email: richard.trethowan@sydney.edu.au

® Registered trademark

ⓓ Varieties displaying this symbol are protected under the Plant Breeders Rights Act 1994.

Farming systems profit and risk over time: exploring the N legacy impacts on profit in different farming systems

John Kirkegaard[2], Mathew Dunn[1], Tony Swan[2], Jeremy Whish[2], Xiaoxi Li[2], Mehrshad Barary[1], Russell Pumpa[1], Kelly Fiske[1]

[1] NSW Department of Primary Industries
[2] CSIRO Agriculture and Food

Key words

risk, water use efficiency, early sowing, nitrogen, diversity, legumes

GRDC codes

CFF00011, CSP2110-004RMX

Take home message

- A range of different systems were profitable and had similar average annual gross margin over 6 years, but differed significantly in variability and return on investment (ROI)
- Despite being the most profitable at only two of the four sites, Diverse systems involving grain legumes with a low N strategy had consistently higher ROI than Baseline cereal-canola systems
- Reduced N inputs to legumes and to cereal and canola crops following legumes were more important economically than yield benefits following the legumes, which were rare
- Fababean was more profitable than lupin and had a greater legacy on subsequent crops
- Issues related to nitrogen supply (costs and response) underpin most of the productivity and profitability differences observed between the systems.

The Southern Farming Systems Project – a brief description

The southern NSW farming systems project was established in 2017 after 12-month consultation period and extensive literature review demonstrated a significant gap in profitability and rainfall efficiency ($/ha/mm) of current cropping systems (i.e. actual *vs* potential) despite good agronomy of individual crops. The average annual gross margin of the best 3-4-year sequences was often ~$400/ha higher than the worst, and $150 to $250/ha higher than the common 'Baseline' sequences. Research sites and simulation studies were established to investigate strategies to increase the conversion of rainfall to profit across a crop sequence while managing weeds, diseases, soil fertility and risk.

Four sites covered soil and climate variability across southern NSW at Greenethorpe, Wagga Wagga and Condobolin (high, medium and low rainfall sites on red acidic loam soils), and a 4th site on a sodic clay vertosol at Urana. At each site, the 'Baseline' system (sequence of canola-wheat-wheat or canola-wheat-barley; timely sown in late April-early May; and with a conservative decile 2 N strategy) was compared with a range of other systems that varied in (i) crop diversity (inclusion of legumes), (ii) sowing time (early and timely) and (iii) N strategy (conservative decile 2 and optimistic decile 7) (Table 1). Management protocols for all other input and management decisions (e.g. tillage and stubble management; variety choice; herbicide, fungicide and pesticide applications) were agreed by the project team using a consensus approach of best practice that was continually reviewed.

Table 1. Selected systems common to most sites including different crop sequence, time of sowing and N strategies. Early-sown (March) treatments included winter grazed crops at Wagga and Greenethorpe. Diverse systems including a legume are shown in grey.

System	Crop sequence	Sowing time[1]	N strategy[2] (Decile 2 or 7)	Grazing
Baseline	Barley[3]-canola-wheat	Timely	2, 7	No
Intense Baseline	Canola-wheat	Early, Timely	2, 7	Yes
Diverse low value	(Faba/lupin)-canola-wheat	Timely	2, 7	No
Diverse high value	(Lentil/chickpea)-canola-wheat	Early, Timely	2	No
Diverse mix	Vetch-canola-wheat	Timely	2	No
Continuous wheat	Wheat-wheat-wheat	Timely	2, 7	No
Fallow	Fallow-canola-wheat	Early, Timely	7	No

[1] Early sowing= from March 1 if grazed, April 1 if un grazed; Timely sowing = late April to mid-May

[2] The N strategies (decile 2 or decile 7) apply top-dressed N each year in July to cereals and canola assuming the season will finish as either decile 2 (lower yield and less N) or decile 7 (higher yield so more N). N requirement is adjusted in each treatment to account for soil N measured pre-sowing, so carry-over 'legacy N' from previous seasons (fertiliser or legume N) means less N will be required for the current crop and so the value of legacy N from fertiliser or legumes is captured in the lower input costs.

[3] At Greenethorpe, a 2nd wheat crop replaced the barley

Seasonal conditions at the sites during the 2018-2023 seasons

The 2018 and 2019 seasons were dry (decile 1-2), the 2020 to 2022 were wet (decile 7-10) while the 2023 season was closer to long-term average (decile 5-6), except at Urana (decile 8) (Table 2).

Table 2. Rainfall (+irrigation) at the experiment sites from 2018 to 2022 and the long-term median (LTM) rainfall and the decile for that season (brackets).

Site	2018	2019	2020	2021	2022	2023	LTM
Greenethorpe	359 (2)	353 (2)	726 (10)	943 (10)	875 (10)	590 (5)	579
Wagga Wagga	403 (3)	320 (2)	557 (8)	757 (10)	886 (10)	559 (6)	526
Urana	276 (1)	222 (1)	488 (6)	564 (9)	968 (10)	552 (8)	449
Condobolin	218+120 (1)	162+118 (1)	685 (9)	806 (10)	958 (10)	474 (6)	434

Brief background to the outcomes so far

Phase 1 (2018-2020)

In Phase 1, the outcomes for the different systems were highly influenced by the two consecutive dry seasons (see Kirkegaard *et al.,* 2021). The key outcome for grain-only systems for phase 1 was that at all sites, the diverse systems that included a legume, and with a decile 2 N strategy were more profitable than the *Baseline* system, were less risky, had stable or declining weed and disease burdens, and lower average input costs. Simulation also predicted these results to be robust for a range of seasons modelled over the longer term. In mixed (grazing crop) systems, the most profitable systems involved early sown grazed crops (wheat-canola) with a higher N fertiliser strategy (decile 7).

Phase 2 (2021-2023)

The effect of the 3 consecutive wet seasons (2020 -2022) on these early results were considered in detail in (Kirkegaard *et al.*, 2022, 2023). The wet conditions provided opportunities to lift yield and profitability, capitalise on higher N strategies and earlier-sown crops, but also increased the risks of disease, lodging, grain quality reduction and reduced the timeliness of operations. Grain legumes can suffer significant yield losses to disease and lodging and/or significant costs for multiple fungicide applications. Consequently, during these wet seasons, the Baseline and Intense Baseline systems with more canola and higher N supply performed well in terms of profit but had lower return on investment, while some systems with legumes (e.g. chickpea) performed poorly.

As a consequence, after 5 years, the diverse systems with grain legumes and decile 2 N strategy remained the most profitable at two sites (Urana and Greenethorpe), while the *Baseline* and *Intense Baseline* were more profitable at Wagga and Condobolin, but with greater risk.

Profit and risk after 6 years (2018-2023)

Effect of diversity and N strategy in timely-sown grain-only crops

A summary of outcomes for selected timely-sown grain-only systems across all sites is provided in Table 3, with a focus on the effect of crop diversity, and nitrogen strategy. The systems are arranged in Table 3 for each site in order of increasing crop diversity (Continuous wheat = 100% cereal, Baseline systems = 66% cereal, Intense Baseline = 50% cereal, Diverse = 33% cereal). For the diverse systems, the most profitable of the legume sequences was used in each case.

Profitability is represented by average annual $GM (2018-2023), risk by both the variability (standard error) of annual $GM, and the profit/cost ratio (ROI). The average annual N applied as fertiliser (kg/ha/yr) is also shown in Table 3, as N fertiliser was a significant cost driver.

At the two sites (Wagga and Greenethorpe) where continuous wheat systems were included, they had significantly lower $GM than the Baseline systems although the variability in $GM was also relatively low (Table 3). The ROI was also relatively low compared to the Baseline at Wagga Wagga but similar at Greenethorpe, perhaps reflecting the lower level of N applied at Greenethorpe. At Wagga, the average $GM of continuous wheat system was responsive to higher N in the decile 7 treatment (extra 56 kg N/ha/yr), but this did not match the profitability or ROI of the more diverse systems with lower N.

Intensifying the Baseline systems by moving to Intense canola-wheat (C-W) systems reduced average $GM at Wagga Wagga and Urana while increasing the $GM at Greenethorpe and Condobolin. At all sites, the variability in $GM was increased, while ROI was either reduced (Wagga Wagga, Urana) or unchanged. Average N supply increased at all sites in the Intense Baseline system, most notably at Greenethorpe with minor increases at the other sites (Table 3). Increasing N supply to the Intense Baseline systems (average increase 40-60 kg/ha/yr) had most impact on $GM at Urana (+$164), smaller effects at Wagga Wagga and Greenethorpe (~+$50/ha) and a small reduction at Condobolin. The additional income barely covered the higher N costs, with ROI declining or remaining relatively unchanged and variability in $GM generally increasing.

The diverse system with low N was the most profitable system at Urana, matched the most profitable at Greenethorpe, but was less profitable than the Baseline at Wagga and Condobolin. However, the Diverse systems consistently had the highest ROI at all sites by a significant margin, This was partly related to the much lower average annual N required (40-50 kg/ha/yr less) in those systems. The variability in $GM was similar or lower than Baseline at Wagga and Condobolin but higher at Greenethorpe and Urana – possibly reflecting the variable performance of the legumes across the years with respect to yield and price compared to canola, wheat and barley.

Table 3. Average gross margins ($/ha/yr) and variation (standard error) in gross margin for timely-sown, grain-only systems at four experimental sites over 6 years (2018-2023). Profit/cost ratio ($GM/$Variable costs) are shown as a measure of return on investment and risk. The average annual N application as fertiliser (kg N/ha/yr) to each system is also shown. N2 and N7 refer to the decile 2 and decile 7 nitrogen strategies.

System	**Crop sequence**	**Average annual gross margin (GM) ($/ha/yr)**		**Variability in gross margin (Std. Err.) ($/ha/yr)**		**Profit/Cost ratio (ROI)**		**Average N applied (kg/ha/yr)**	
		N2	**N7**	**N2**	**N7**	**N2**	**N7**	**N2**	**N7**
Wagga Wagga									
Cont. wheat	W-W-W	652	732	86	129	0.94	0.91	77	133
Baseline	C-W-B	902	944	116	121	1.11	1.06	97	143
Int. Baseline	C-W	767	819	143	143	0.87	0.9	103	144
Diverse	Lu-C-W	802	-	97	-	**1.20**	-	54	-
Greenethorpe									
Cont. wheat	W-W-W	953	-	96	-	**1.47**	-	47	-
Baseline	C-W-W	1108	1130	131	159	1.42	1.32	77	119
Int. Baseline	C-W	1163	1219	198	222	1.37	1.33	88	135
Diverse	Fa-C-W	1179	-	172	-	**1.46**	-	40	-
Urana									
Baseline	C-W-B	816	-	109	-	1.12	-	72	-
Int. Baseline	C-W	682	847	115	163	0.91	0.98	78	137
Diverse	Fa-C-W	992	-	130	-	**1.38**	-	29	-
Condobolin									
Baseline	C-W-B	781	-	127	-	1.14	-	67	-
Int. Baseline	C-W	826	809	153	158	1.15	1.08	74	116
Diverse	Lu-C-W	730	-	127	-	**1.31**	-	42	-

In summary, while the most profitable diverse systems have matched the average profit of the Baseline and Intense Baseline systems at some but not all sites, the consistent benefit is the increased ROI of the Diverse systems at all sites, partly related to the reduced requirement for N fertiliser. Economic responses to increased N fertiliser were relatively small with lower ROI. There are a few exceptions to this. The N7 Int. Base at Urana was quite a bit more profitable ($165/ha) than the N2 and has a higher profit/cost ratio. This was also the case at Wagga Wagga, however not as pronounced.

The Diverse systems involving chickpea/lentil matched the profit of the system involving fababean at Urana, but were less profitable by $145/yr. at Condobolin (*cf* lupin), $90 at Greenethorpe (*cf* fababean), and $37/yr at Wagga (*cf* lupin). The chickpea was especially affected by waterlogging and cold conditions in 2022, and by the need for repeated fungicide sprays for Ascochyta in 2020 and 2021.

Effect of earlier sowing in grain-only crops

Recent research has demonstrated that earlier sown crops selected to flower within the optimum flowering window can have a grain yield and water-use efficiency advantage over timely-sown crops especially when stored subsoil water is available (Flohr *et al.,* 2020). They also provide grazing opportunities on mixed farms. However early sown crops may leave a legacy of drier and lower N subsoils which can reduce the growth of following crops in a sequence. Consequently, the effect of earlier sown crops on the profitability of the system was of interest in this project.

At 3 of the 4 sites (not at Greenethorpe), we could make direct comparisons of grain-only systems that differed only in the sowing time of the wheat and canola crops (Table 4).

The benefit of early-sown wheat and canola in the Diverse N2 system was significant at Condobolin where it added $139/yr to the average annual $GM and this was mostly driven by the higher yield of the earlier-sown wheat and canola. At Wagga, a smaller benefit was achieved by sowing early in the Diverse N2 system, but not in the N7 system, because the additional cost of the increased N applied was not recovered. At Urana in the Intense Baseline canola-wheat system there was only marginal benefit from sowing earlier in the N2 system and reduced profit at N7, similar to the Wagga observation.

In summary the value of earlier-sown crops is dependent on the site and the system (both crop sequence and N strategy) but can provide a significant boost to the profitability of the system in the medium term.

Table 4. Effect of wheat and canola sowing times in selected systems at three sites on the average annual gross margin from 2018-2023.

Site	**System**	**Average annual gross margin ($/ha/yr)**		
		Timely sown	**Early sown**	**Difference**
Condobolin	Diverse N2 (Le/Ch-C-W)	585	724	+139
Wagga	Diverse N2 (Le/Ch-C-W)	765	786	+21
	Diverse N7 (Le/Ch-C-W)	748	609	-139
Urana	Int. Baseline N2 (C-W)	682	695	+13
	Int. Baseline N7 (C-W)	847	775	-72

N legacy impacts on profit

The effect of N legacies at the experimental sites have been reported at previous Updates by Swan *et al.,* (2022) and Dunn *et al.*, (2023). In exploring the value of N legacies from legumes on following crops and on the profit and risk of the systems there are several questions that can be considered.

1) Is there a legacy of higher soil mineral N in the soil after legumes compared to non-legumes?
2) How much less fertiliser was applied to the system as a result?
3) Was there a yield increase in following crops?
4) Did (1)-(3) contribute to increased profit and reduced risk?

In answer to (1) Table 5 summarises the soil mineral N in the soil prior to the canola crops following wheat or barley crops in the Baseline systems and following legumes (lupin or fababean) in the Diverse systems (as previously shown in Table 3). Except in the flood year at Condobolin (2022), a legacy of higher mineral N following the legumes was observed at all sites and in all seasons, with an additional average pre-sowing mineral N of 26, 98, 48 and 42 kg N/ha at Wagga, Greenethorpe, Urana and Condobolin respectively. This would have reduced the N applied to reach the target yield in the canola crops within those systems each year. In addition to the higher N in the soil prior to the canola, there was also higher N in the soil prior to the subsequent wheat crops which averaged

+27, +50, +16 kg N/ha at Wagga, Greenethorpe and Urana while there was 10 kg N/ha less prior to wheat at Condobolin (data not shown). Though it is difficult to attribute this legacy specifically to the legume due to the differences in top-dressed N and N removal by the canola crops, the overall effect was to reduce the average annual application of N fertiliser to the Diverse system by 43, 37, 43, and 25 kg N/ha/yr (as shown previously in Table 3).

Table 5. Mineral N in the soil prior to sowing canola following barley or wheat in the Baseline systems and following fababean or lupin in the Diverse systems at the four sites. Note all crops in 2018 (Yr 1) followed wheat so no legacy effects existed in that year.

System	**Crop sequence**	**Mineral nitrogen in soil prior to canola (kg N/ha)**					
		2019	**2020**	**2021**	**2022**	**2023**	**Mean**
Wagga Wagga							
Baseline	B-**C**-W	47	81	91	91	47	**71**
Diverse	Lu-**C**-W	78	67	114	128	154	**97**
Greenethorpe							
Baseline	W-**C**-W	217	180	109	127	58	**136**
Diverse	Fa-**C**-W	260	264	339	233	133	**234**
Urana							
Baseline	B-**C**-W	45	84	66	47	45	**57**
Diverse	Fa-**C**-W	101	106	123	112	133	**105**
Condobolin							
Baseline	B-**C**-W	53	64	15	11	132	**52**
Diverse	Lu-**C**-W	133	146	48	2	190	**94**

With respect to (3), any yield benefit following the legumes in the subsequent canola crop cannot necessarily be attributed to the extra N measured pre-sowing, because the canola crops were top-dressed to a decile 2 yield target according to the N available at sowing. Indeed, the N applied to the canola crops was reduced on average by 18, 58, 41 and 27 kg N/ha at Wagga, Greenethorpe, Urana and Condobolin respectively following the legumes in the Diverse systems. This represented a cost saving, but had an equalising effect on N supply, although additional N may have mineralised after sowing following the legumes, to provide an additional N benefit for the following crop. As the higher soil N legacy persisted to the subsequent wheat crops, there was also around 20 kg N/ha less N applied to the wheat crops on average in the Diverse systems. These N savings were significant but were small compared to the reductions in N applied to the legume crops themselves (<5 kg N/ha applied) compared to barley or wheat (50 to 100 kg N/ha applied) which were 86, 47, 62 and 50 kg N/ha at Wagga, Greenethorpe, Urana and Condobolin respectively.

There was little overall yield benefit measured in the canola crops following the legumes in the Diverse systems at the 4 sites (+0.3 t/ha at Urana only) or in the subsequent wheat crops (+0.3 t/ha at Greenethorpe only) (data not shown). Consequently, except for these two cases, little of the economic benefits within the Diverse systems have arisen from higher yields and income in the canola or wheat crops following the legumes in the Diverse systems.

In assessing the impact of legacy N on profit and risk, it is useful to examine the overall performance of the different crops in the sequence across the 6 years in light of the impacts on N inputs (Table 6). At Wagga, despite the N legacy effects of the lupin reducing the overall N inputs, the lower profitability of the lupin itself (average yield 3.1 t/ha) compared with the barley (average yield 6.0 t/ha) in the system was the major driver of the lower $GM of the Diverse system (Table 6). A somewhat similar outcome occurred at Condobolin, although the boost in canola $GM offset the lower profitability of the lupin compared with the barley. The fababean in the Diverse system at Greenethorpe (average yield 4.4 t/ha) and Urana (average yield 4.7 t/ha) were as profitable or significantly more profitable than the wheat (average yield 5.4 t/ha) or barley (average yield 6.2 t/ha) in the Baseline systems at those sites, and there were also higher $GM in the following canola and wheat crops following the fababean.

In summary, the reduced N fertiliser input costs in the Diverse systems due to low N applied to the legume crops and reduced N applied to subsequent canola and wheat crops due to legacy N has contributed to the $GM of the Diverse systems much more than increased yield of subsequent crops following the legumes. Urana is the exception to this. The increased yield and profit ($257/ha for canola) following fababeans have been quite pronounced. However the lower profitability of lupin compared to barley has eroded that economic advantage at Wagga and Condobolin, while the higher profitability of fababean has added to the economic advantage at Greenethorpe, and especially at Urana.

Table 6. Average annual 6-yr gross margins for individual crops in the grain-only Baseline N2 (barley-canola-wheat) and Diverse N2 (legume-canola-wheat) systems from 2018 to 2023.

System	**Crop sequence**	**Average annual $GM ($/ha/yr) 2018-2023**			
		Cereal/Legume	**Canola**	**Wheat**	**Mean**
Wagga Wagga					
Baseline	B-C-W	1103	838	764	901
Diverse	Lu-C-W	800	812	794	802
Greenethorpe					
Baseline	W-C-W	1094	1034	1195	1107
Diverse	Fa-C-W	1058	1228	1252	1179
Urana					
Baseline	B-C-W	1089	475	884	816
Diverse	Fa-C-W	1301	732	942	992
Condobolin					
Baseline	B-C-W	818	771	752	780
Diverse	Lu-C-W	604	834	752	730

Do legacies occur with higher fertiliser strategies?

At two sites (Wagga and Greenethorpe) Baseline systems were included with both decile 2 and decile 7 strategies (see Table 3). The question arises as to whether there is evidence that the higher N applied each season to the N7 treatment that is not used by the crop, carries over to subsequent crops in the same way that legume N carries over.

At Wagga there was an average of +17, +32 and +27 extra kg N/ha/yr measured pre-sowing in the N7 compared to the N2 prior to the canola, wheat and barley respectively, an average of +25 kg N/ha for the system. This compares with an extra 50 kg N/ha/yr applied to the N7 treatment (Table 3). At Greenethorpe there was an average of +37, +102 and +6 extra kg N/ha/yr measured pre-sowing in N7 compared to N2 prior to the canola, wheat 1 and wheat 2 crops respectively. This compares with an extra 41 kg N/ha/yr applied in the N7 treatment (Table 3). This suggests that a significant portion of the increased N applied that may not be utilised by the crops can carry over as legacy N within the system, although in this case it has only generated a small increase in $GM but a lower ROI within the systems (Table 3). A more complete N balance will be carried out to provide more detail on the fate of the applied N in terms of offtake, changes in soil organic matter or N losses.

Whole-farm and business considerations

The results at the four sites demonstrate that a range of different systems with relatively small differences in average annual gross margin over 6 years can be quite profitable but may differ in performance in different seasons (wet, dry) and have different risk profiles. This reminds us that different systems may suit specific businesses depending on a range of factors other than the agronomic management - many of which cannot be measured in these small-scale experiments but must be considered when making decisions to integrate grain legumes into the business. For example, it is likely that to ensure the best outcome from grain legumes that some storage capacity may be required on farm, the capacity to handle the inoculation process in a timely and effective manner, and careful and timely application of fungicides in wetter seasons. These will generate labour peaks and demand on machinery that must be considered. Enterprises with significant areas of legume-based pastures may find that these can perform much the same function of organic N supply, disease and weed management as that played by grain legumes in the systems reported here and are suited to phased rotation with more intensive cereal-canola systems. The choice of legume is also clearly important based on those best adapted to specific paddocks.

Never-the-less, the emerging data from these systems experiments demonstrate the importance of fully assessing the value of grain legumes in different systems beyond their performance in individual years, as much of the benefit derives from legacy effects, input savings and more even performance across seasons. These are difficult to assess without longer-term side-by-side comparisons and supporting data to understand the mechanisms behind the responses.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC and NSW DPI, the author would like to thank them for their continued support. The authors would like to especially thank Warakirri Cropping “Karoola Park” and Rod and Nick Kershaw “Iandra Pastoral” for their support and co-operation in hosting the Urana and Greenethorpe field experimental sites. The authors would also like to acknowledge the contributions of Graeme Sandral for his role as site leader during the first two and a half seasons of the project. We also thank Chris Baker (Baker Ag Advantage), Tim Condon (Delta Agribusiness), Greg Condon (Grassroots Agronomy), Heidi Gooden (Delta Agribusiness), Peter Watts (Elders), Rod and Nick Kershaw (Iandra), John Stevenson (Warakirri Cropping) and John Francis (Agrista) for the many useful discussions in their role on the project advisory committee.

References

Kirkegaard J, Dunn M, Swan T, Whish J, Pumpa R, Fiske K (2023) Farming systems profit and risk over time: the impact of three wet consecutive seasons. GRDC Updates Wagga Wagga 2023. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2023/02/farming-systems-profit-and-risk-over-time-the-impact-of-three-wet-consecutive-seasons

Dunn M, Kirkegaard J, Swan T, Whish J, Pumpa R, Fiske K (2023) Legacy effects and the value of legumes in the farming system after three consecutive wet seasons. GRDC Updates Wagga Wagga 2023. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2023/02/legacy-effects-and-the-value-of-legumes-in-the-farming-system-after-three-consecutive-wet-seasons

Kirkegaard J, Swan T, Dunn M, Sandral G, Whish J, Berary M, Reardon D, Woodsford-Smith A, Friske K, Pumpa R (2022) Farming systems performance at a 'macro' scale: effects of management strategies on productivity, profit, risk, WUE GRDC Update Wagga Wagga 2022. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/02/farming-systems-performance-at-a-macro-scale-effects-of-management-strategies-on-productivity,-profit,-risk,-wue

Swan T, Dunn M, Kirkegaard J, Goward L, Leighton E, Sandral G, Hunt J, Bullock M, Pumpa R, Fiske K, Woodford-Smith A, Reardon D, Barry M, Burns H (2022). What is the N legacy following pulses for subsequent crops and what management options are important to optimise N fixation? GRDC update, Wagga Wagga 2022. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/02/what-is-the-n-legacy-following-pulses-for-subsequent-crops-and-what-management-options-are-important-to-optimise-n-fixation2

Kirkegaard J, Swan T, Dunn M, Sandral G, Whish J, Leighton E, Reardon D, Bullock M, Friske K, Pumpa R (2021) Managing water and N across years and crop sequences to drive profit. GRDC Updates Wagga Wagga 2021. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2021/02/managing-water-and-n-across-years-and-crop-sequences-to-drive-profit

Flohr BM et al., (2020) Deep Soil Water-Use Determines the Yield Benefit of Long-Cycle Wheat. *Frontiers in Plant Science* 11, 548 doi: 10.3389/fpls.2020.00548.

Contact details

John Kirkegaard
CSIRO Agriculture and Food
Canberra
Ph: 0458 354 630
Email: john.kirkegaard@csiro.au

Practicalities and economics of integrating dual purpose crops into the whole of farming operation in the medium rainfall zone

John Francis, Agrista

Key words

dual-purpose crops, grazing crops, whole farm profitability

GRDC code

CFF00011

Take home message

- There is no one size fits all approach to the integration of dual-purpose crops into a farming system. The value of the integration will depend on several factors including the existing system and the existing skill base. Following are some tips that may assist in successful implementation to ensure that dual purpose crops are an enduring part of the farming system
- Extracting value from dual purpose crops at a whole farm level requires optimising not only the grazing crop but also the other parts of the farming system
- Don't underestimate the investment in skills required to make some of the changes. Start small to build confidence as this will minimise risk and build skill over time
- Whole farm feed budgeting prior to making systems changes will assist in understanding the extent of the capital requirements for the additional livestock and the stocking rates necessary to deliver profitability improvements
- If feed budgeting skills can be learned and perfected through exposure to dual purpose crops and then applied to other parts of the farm, then there is the potential for improvement in whole farm profit.

Introduction

The GRDC farming systems project has compared the performance of crop sequences over the 2018 to 2020 growing seasons to account for legacy effects of one crop to the next. This has helped to move thinking beyond individual crop performance within any year to rotation performance across years. Further insights will be delivered with GRDC's investment into the second three-year phase which will run from 2021 to 2023.

The introduction of dual-purpose crops has the potential to increase whole farm profitability where the per hectare returns exceed those of the existing enterprises and their introduction doesn't erode the profits of the existing system. The aim of this paper is to demonstrate some of the factors that will influence the financial performance of dual-purpose crops. Dual purpose crops will have a greater chance of being an enduring part of the system if there is general understanding of the success factors prior to implementing change.

This paper will take a theoretical approach and combine it with case studies to demonstrate some of the practical issues associated with integrating dual purpose crops into the whole farm system. The value created, or destroyed, as a result of the integration of dual-purpose crops into the system is dependent on a range of factors including skills, management, the existing system and the extent to which it is already optimised.

This paper will also address the methodology for assigning a value to the grazing component of dual-purpose crops and consider some of the issues associated when scaling up from experimental components to an integrated whole farm system.

Play to your strengths

Decisions around farming systems changes should have some element of weighting on financial performance however there are a range of other factors that are also important. The financial performance resulting from production delivered in farming systems experiments is highly dependent on the management applied to the plots. This is entirely appropriate as the aim of these experiments is to measure the effect of an experimental treatment or test a hypothesis which is usually easier if all other management factors are optimised.

Not all farm business managers have the same level of skill across their enterprise mix. Farm performance analysis often shows that in mixed enterprise farms some business operators consistently perform better in one enterprise than another irrespective of commodity price differences. There is little data showing why this occurs, but the speculation is that passion or natural preference for one enterprise over another plays a role in this outcome. This passion leads to a greater skill development in the preferred enterprise at the cost of skill development in another enterprise and that just exacerbates the relative difference in performance.

A case in point is a producer in a 600-millimetre mixed farming area of southern NSW with 15 years of farm production and financial performance data. The highest return and best use for their farmland is dryland cropping with livestock enterprise returns being the next most appropriate use based on the resource base. Despite this, the farm manager has exceptional livestock performance due the skills built in this enterprise, the desire to manage livestock and his implementation of a livestock system that matches feed supply with feed demand and the timing of offtake of trading livestock coinciding with the decline in feed quality.

For this particular producer, over the last 15 years the per hectare financial returns of dual-purpose crops, inclusive of the value of grazing income, have rarely exceeded those of the chosen livestock enterprise. While farm performance data suggests this is not reflective of similar farms in the area, it reflects the management and skill sets of this individual manager. Despite these results, the manager was an early adopter of dual-purpose crops and continues to grow them for the role they play in reducing the weed seedbank prior to sowing long term perennial pasture.

For every manager with strengths in livestock management skills and weaknesses in crop management skills there will be another with strengths in crop management skills and weaknesses in livestock management skills. There is real value in identifying the weakness and establishing the cost of that weakness prior to executing a change in system, as the investment in a system change requires appropriate skill sets. Capital investment without the necessary skill sets is likely to be insufficient.

The key point here is that some farm managers have strengths and skills that need consideration when deciding about which farming system to implement. The financial performance delivered in a research trial may never be achieved on some farms because the effort and discipline required to build the management skills to deliver the same results exceeds the marginal reward when compared to the alternative.

What do you give up and what do you gain?

Studies of human behaviour, psychology and mental processes have shown that we value a loss and a gain of the same magnitude differently. The value that we place on loss is far higher and has a far greater impact than the value we place on gain. In fact, some studies have shown that we fear loss nearly twice as much as we value gain. Given this, it is important to quantify the value of any potential downside as well as the frequency of occurrence of that downside.

The vast weight of research data involving dual purpose crops suggest that, provided a few simple grazing rules are followed, there is no marginal cost of foregone grain yield of moving from a grain only system to a dual-purpose cropping system. In other words, yields of grazed crops are not significantly dissimilar to yields of ungrazed or grain only crops. This suggests that there is little risk from the grain income side of introducing a dual purpose crop, but there may be perceived risk on the grazing side.

The risks in introducing a grazing enterprise to a system where there was previously no livestock include:

1. Biosecurity risk. The introduction of weed seeds in the livestock themselves.
2. Labour risk. The time taken to manage the grazing livestock erodes some value elsewhere on the farm.
3. Management risk. The skills haven't been developed so there are unknown elements that could induce cost.
4. Capital risk. There is more capital required for the outlay of the livestock however this needs to be tempered with the extremely low probability that it would be completely lost.
5. Production and price risk due to a lack of skill. The combination of these doesn't combine to deliver the outcome necessary to generate an adequate return.

These risks need to be considered against the reward which is the additional income that can be generated from the grazing. It is also worth noting that many of these risks can be dealt with by taking a pro-active management approach to minimise their impact.

What base are you coming from?

An important step in establishing the value of any systems change is to first consider the status quo or base case. This is important because the value of a change in system depends in part on the existing system and its performance. When assessing the integration of dual-purpose crops into an existing farming system, there will be several factors that require consideration which are outside of the production and financial performance demonstrated in research trials.

These include, but are not limited to:

- Skills
- Human resources
- Capital requirements
- Land class suitability.

The extent of the change in technical skills, labour requirements and capital investment when integrating dual purpose crops into a farming system, previously devoid of this enterprise will differ depending on the existing enterprise mix. Table 1 shows that a mixed grain and livestock business will experience only small changes in skills, labour and capital investment when integrating dual purpose crops into the system. By comparison, the changes are large if moving from a livestock or grain only enterprise mix.

Table 1. The extent of the change in skills, labour and capital investment to integrate grazing of dual-purpose crops will differ depending on the existing enterprise mix.

Current enterprise	Change in skills, labour & capital investment
Mixed grain and livestock enterprise	Small
Livestock only enterprise	Large
Grain only enterprise	Large

Allocating grazing value to crops

The allocation of the value of grazing to a dual-purpose crop is necessary to account for the multiple streams of income (grain and grazing) that can be provided by the crop. There can be complexity associated with the allocation of the net value of grazing to dual purpose crops. Simplification sometimes results in miscalculation of the true value of the grazing resulting in erroneous values that can influence decision making. This can have major consequences where implementation is heavily dependent on financial performance.

Market value of feed

To assess performance at an enterprise level it is necessary to place a market value on the production generated by the dual-purpose crop. The market value of the grain is easily estimated as it is a simple calculation of yield by price. There is more complexity associated with the calculation of the value of grazing biomass because the value differs depending on how that biomass is used. The biomass can be used for trading livestock, creating value internally through utilisation in existing livestock enterprises or by agisting external livestock.

The value of a livestock trade allocated to a dual-purpose crop can be calculated as the net value or proportion of net value created by the trade. This is calculated as sales less purchases less all associated enterprise costs. If the trade occurs over a period which is longer than the dual-purpose crop grazing period, then the appropriate proportion of net earnings generated by the crop should be allocated.

The value of external agistment allocated to a dual-purpose crop is dictated by the price paid by the market. When feed is abundant the value may be low and when feed is in short supply the value increases. The range is usually around $0.50 cents to $2.00 per DSE per week.

The value to existing livestock enterprises of using a dual-purpose crop can be allocated in one of two ways. The first is to assign the market value of agistment as if the feed were to be sold as external agistment. The second is to establish the value generated from the use of the feed internally. The latter is far more difficult to calculate because splitting the costs and benefits of different components of a breeding unit is not straightforward.

In any livestock breeding enterprise, there are usually several income streams. These include trading livestock sales, cull and surplus female sales, bull, ram or wether sales and wool sales. The largest of the livestock income streams is usually the livestock trading component typically made up of young livestock such as lambs, hoggets, steers or heifers. In a breeding enterprise, the production of these trading livestock is dependent on a female breeding animal. This breeding animal incurs most of the enterprise cost and consumes around 75 percent of the total feed of the breeding and trading unit combined. Allocation of the trading income to the dual-purpose crop without either attribution of the cost of carrying the breeder or allocation of a purchase price of the lamb therefore results in unrealistically high values accrued against the dual-purpose crop.

Allocating a livestock trading enterprise value to a grazing crop

Where feed utilisation levels of fifty percent or above are achieved on pastures in the farming system then the inclusion of a livestock trading enterprise can be an effective means of utilising the additional feed supplied by the dual-purpose crop. To achieve feed utilisation levels of fifty percent or above, it is necessary to manage a livestock system that matches feed supply with demand. Typically, in a breeding operation, this means timing operational activities with high energy demand such as lambing, calving to coincide with the highest energy supply and ensuring trading livestock are sold as energy supply declines rapidly.

Where a trading enterprise is introduced for the sole purpose of generating revenue from the grazing crop, then the allocation of trading enterprise net earnings to the crop is relatively straight forward. The net earnings, or margin on the trade consists of sales less purchases less operational costs. It is generally not necessary to allocate any overhead costs to this trade unless it consumes a large proportion of the total labour use on farm. If a portion of the time spent by the trading livestock occurs off the crop, then the net earnings can be allocated on a pro-rata basis.

It appears to be a reasonably common industry practice to allocate the income of a livestock trading enterprise to the dual-purpose crop irrespective of the way the crop feed is utilised. This can be problematic as it may result in skewed results that aren’t truly reflective of the value at a whole farm level.

Industry practice appears to involve an estimation of grazing income, based on the estimation or measurement of weight gained on the crop by livestock, multiplied by a sales value per unit of weight gained. Some potential issues associated with the use of this methodology follow.

1. If the business is a breeding business and doesn’t have a trading enterprise, then it is possible that this method will overestimate the value of income.
2. There is no allocation of the value of any enterprise costs associated with the trade. If the trade was conducted purely for the consumption of the crop-supplied feed then the costs will include freight to farm, induction costs (animal health treatments including drench and vaccine), shearing and crutching costs and transaction costs including commissions, transaction levies and freight costs.
3. There is no allocation of the financial impact of mortality rate on income. At a financial level, mortality is accrued as foregone income by multiplying only those livestock sold by the value per head. Per hectare calculations derived from per head performance multiplied by stocking rate will need to account for mortality. This means that some per hectare calculations will be based on the number of livestock purchased and some on the number of livestock sold with the difference between the two being mortality.
4. Trading gains or trading losses are not allocated where income is calculated as sales value per unit of weight multiplied by weight gained.

Two components to a livestock trade

There are two components in a livestock trade that contribute to the margin net of costs. An explanation of these components follows.

1. The trading margin – calculated as the difference between buy and sell price.
2. The weight gain margin. The value of every unit of liveweight gain multiplied by the price per unit of liveweight gain at the point of sale. This must account for mortality as dead livestock tend not to put on a lot of weight.

The trading margin (difference in the buy and sell price) only applies to the weight purchased. When there is a positive price differential between the sell and buy price (i.e., the sell price exceeds the buy price) every kilogram purchased makes money. When there is a negative differential between the sell and buy price (i.e., the sell price is lower than the buy price) every kilogram purchased loses money. The weight gain margin is the value of every kilogram added after purchase.

It is the sum of the two that matters (i.e., makes the net income) – not one or the other in isolation. Some high-profile livestock producers have self-promoted their grazing and trading results on social media showing only the value of total weight at sale. In a livestock trading enterprise this gives an incomplete picture as it doesn't declare the value at purchase or the enterprise cost.

Many livestock trading enterprise managers conduct their risk analysis and trade margin calculations based on there being an adequate margin over the volume traded rather than ensuring the buy and sell price being the same. That is, they tend to accept that the sell price might be lower than the buy price because they think that the value of the weight that they gain at a lower price (than the buy price) will more than compensate for the lower price at sale. This mentality is not captured where trading income is calculated as sales price by weight gained.

The assignment to grazing crops of the value of livestock weight gain multiplied by the sales value per kilogram is only appropriate if the buy and sell price in a trade is exactly the same and mortality rate equates to zero. This however only accounts for the income in the trade and without the cost associated with the trade it overestimates the net margin associated with crop grazing.

Tables 2 and 3 provide examples of the calculations that are used to estimate grazing income on dual purpose crop. The methodology used in Table 1 potentially overestimates the value of the grazing contribution as it doesn't account for costs or trading gains or losses. The methodology in Table 3 more accurately values the grazing contribution to the crop as it accounts not only for the value of the weight gain but also for trading gains or losses, mortality and operating costs. The examples apply to a lamb trade however the principles apply equally to any livestock enterprise.

Table 2. Weight gain margin approach to valuation – does not account for costs or trading gain/loss

Biomass available for grazing (kg DM/ha)	3,800
Utilisation	75%
Feed conversion efficiency (kg DM/kg lwt)	8.3
Yield (cwt:lwt)	50%
Sale price ($/kg cwt)	$6.25
Carcase weight gained (kg cwt/ha)	171
Gross value of weight gain ($/ha)	$1,069

Table 3. Net margin approach to valuation – accounts for costs trading gain/loss and mortality

Buy to sell price disparity	**0%**
Gross value of weight gain ($/ha)	$1,069
Mortality adjusted value of weight gain ($/ha)	$1,035
Trading gain/loss ($/ha)	$0
Enterprise & transaction costs ($/ha)	$436
Net margin on trade ($/ha)	$599
Bottom line relative to headline	56%

Table 4 shows the assumptions that drive the outputs shown in Tables 2 and 3.

Table 4. Assumptions driving production and financial outputs.

Assumption	**Metric**
Mortality rate for period	1%
Induction & enterprise costs ($/head)	$8
Sales costs (commissions/fees/freight)	7%
Buy to sell disparity	0%
Yield (lwt to cwt)	50%
Sale price ($/kg cwt)	$6.25
Feed conversion efficiency	8.3
Crop area	250
Target sale weight (kg cwt/head)	22

Figure 1 shows that the weight gain margin method for valuing grazing to crops is insensitive to price disparity. This results in over estimations of net grazing value except where sell to buy price disparity exceeds 10 percent. The magnitude of the outcome of this analysis differs based on the selling price which in this example is $6.25 per kilogram carcase weight (lamb).

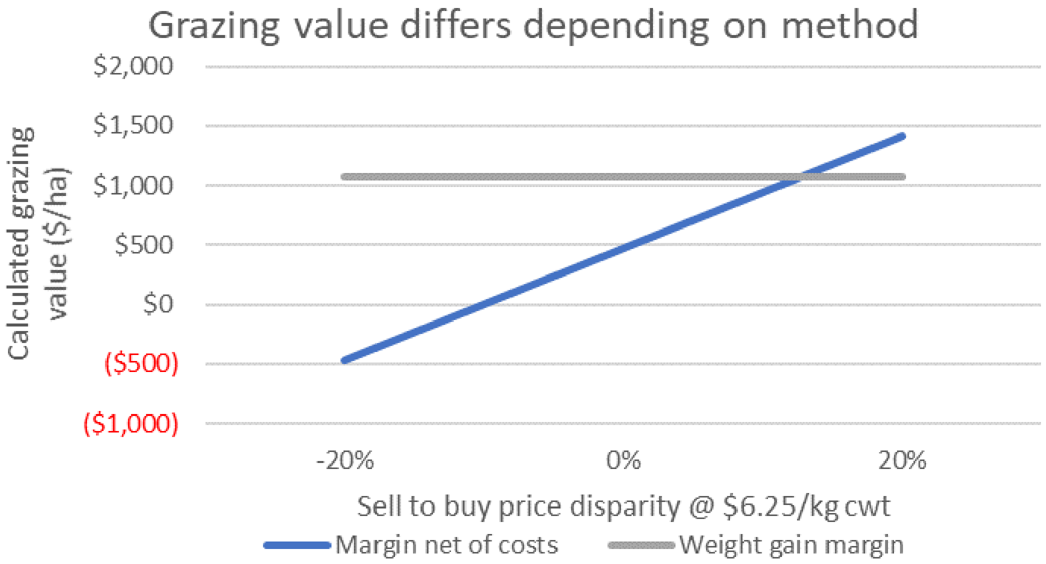


Figure 1. The weight gain margin method of grazing valuation is insensitive to trading gains or losses and ignores costs.

Shuffling the deck chairs or capturing the value? A case study demonstrating the difference

Farming systems trials have shown that dual purpose crop profits are highest where grain yield is optimised and vegetative crop biomass is well-utilised. Several research studies have concluded that the additional value generated through the inclusion of dual-purpose crops to the farming system adds considerably to whole farm profitability.

While farm benchmarking data shows that there are individuals who are able to capture the benefits of including dual purpose crops into their systems there are as many who generate no additional value. Individual farm benchmarking data sets have been examined to explore these issues and gain some understanding of why the additional return from dual purpose crop inclusion is not being delivered across the farm.

Table 5 shows two farming systems. The first three columns represent a livestock only system while the next three represent a system with 80% of the total farm area as pasture with the remaining 20 percent as dual-purpose crop (DP crop). The type of livestock enterprise, the time of lambing and calving and the time of turnoff of trading livestock are all important but they are not drivers of the outcome in the context of this analysis.

Table 5. Biomass production calculations for two systems – one livestock only, the other includes 20 percent dual purpose crop

	Livestock 100% Dual purpose crop 0%			**Livestock 80% Dual purpose crop 20%**		
	Pasture	**DP crop**	**Total**	**Pasture**	**DP crop**	**Total**
Enterprise (% total area)	100%	0%		80%	20%	
Area (ha)	1000	0	1,000	800	200	1,000
Biomass grown (kg DM/ha)	7,366	0	7,366	7,366	3,980	6,689

Figure 2 shows the stocking rate by systems component of the two farming systems. The grey line represents the monthly stocking rate, expressed in DSE per hectare, on pasture of the livestock only system. The dark blue bars represent the monthly stocking rate on the 80-pasture area while the light blue bars represent the monthly stocking rate on the 20 percent dual purpose crop area.

Figure 2 Shows the value of dual purpose crops is short duration grazing during Autumn and mid winter.

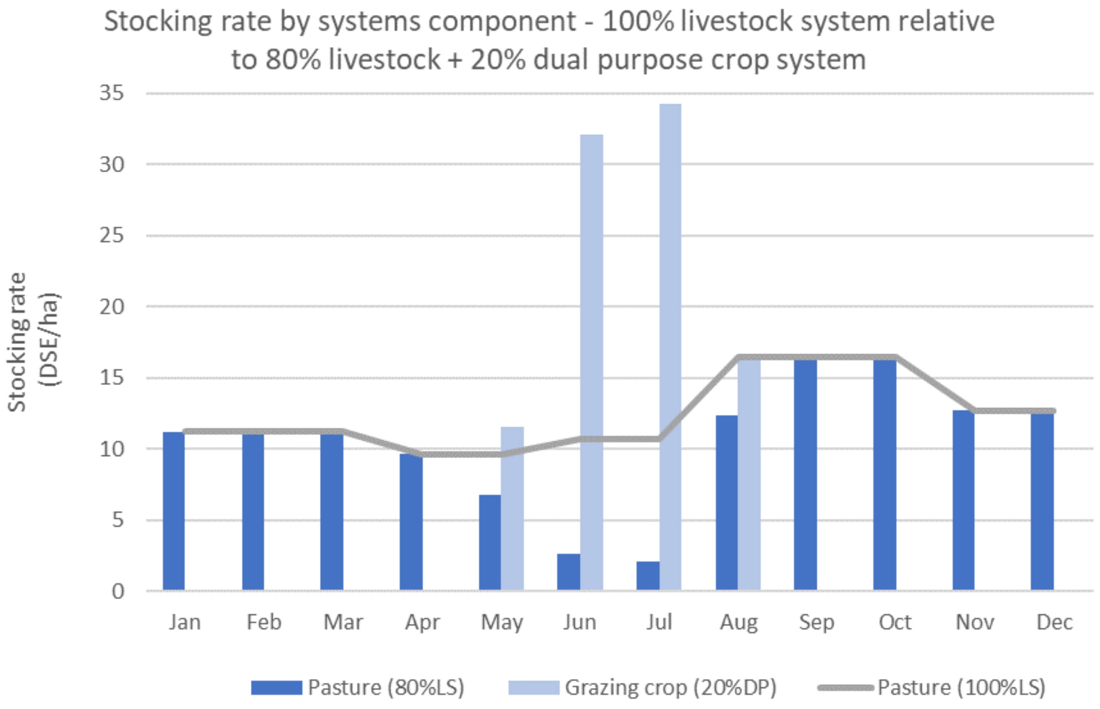


Figure 2. Stocking rate by month for a 100% livestock system vs an 80% livestock + 20% dual purpose crop system.

Table 6 shows stocking rate per hectare by component (pasture and crop) and by farming system. It also shows opening and closing annual biomass per hectare as well as feed utilisation levels. Feed utilisation is calculated as intake divided by feed grown. The closing crop biomass and the utilisation levels in the crop demonstrate that the additional feed supplied by the dual-purpose crop has been very well utilised. The issue however is that the lower mid-winter stocking rate in the pasture, shown as the dark blue bars in Figure 2, has reduced the average annual stocking rate on the pasture.

This reduction in average annual pasture stocking rate in the mixed livestock crop system has led to a reduction in feed utilisation demonstrated by the utilisation rate and the lower average annual stocking rate when compared with the livestock only system. If the pasture system was achieving a stocking rate of 12.5 DSE per hectare prior to introducing dual purpose crop it should be achieving the same stocking rate afterwards. Instead, the stocking rate on pasture declined.

At a whole farm level this means that the 9,980 DSE managed in the pasture and dual-purpose crop system represent 80 percent of the 12,430 DSE managed in the livestock only system. Given the pasture area in the pasture crop system represents 80% of the pasture area in the livestock only system this stocking rate should have been achieved in the absence of the dual-purpose crop and the 1,580 DSE in the dual-purpose crop should have been additional livestock. In other words, the grazing crop has added no marginal grazing value at a whole farm level.

This doesn't mean that the dual-purpose crop hasn't paid for itself, but it does mean that there is no additional grazing value added as a result of dual-purpose crop inclusion. The contribution of grain typically dwarfs the contribution of grazing to dual purpose crop income so there may still be value in adding dual purpose crops to the enterprise mix but their value isn't optimised. This is covered in more detail in Table 6.

Why is it so? For those that don't keep good livestock production records or differentiate pasture stocking rates from crop or whole farm stocking rates then it is possible that this issue isn't even known. It is plausible that the extremely high stocking rates on the crop, where the majority of livestock graze during a period that is conventionally difficult to manage and which accounts only for the minority of total grazed area, are causing misjudgements about the whole farm stocking rate. This is why recording stocking rate by area grazed is particularly important.

Dual purpose crops can provide potential benefits beyond production and its value. In cases where dual purpose crops are grazed with trading livestock, producers have been forced to become more skilled at feed budgeting. Many managers, because of growing dual purpose crops, are very attuned to crop growth rates, wastage rates, livestock intake and the factors that influence these.

In some cases, these feed budgeting skills have delivered improvements in feed utilisation in pasture systems as these managers become more confident in their ability to manage the livestock pasture interface. In some cases, the value of the improvements to the other parts of the farming system, depending on its scale may be greater than the value of the introduction of the dual-purpose crops to the system.

Table 6. Stocking rate per hectare by component (pasture and crop) and by farming system and opening and closing annual biomass per hectare as well as feed utilisation levels for 100% livestock system vs. an 80% livestock and 20% dual-purpose crop system. Dual purpose crop biomass is well utilised but pasture utilisation decreases.

	Livestock 100% Dual purpose crop 0%			**Livestock 80% Dual purpose crop 20%**		
	Pasture	**DP crop**	**Total**	**Pasture**	**DP crop**	**Total**
Opening biomass (kg DM/ha)	2,500			2,500	1,230	
Closing biomass (kg DM/ha)	2,526			2,884	508	
Average annual stocking rate	12.43		12.43	10.5	7.9	10.0
Utilisation rate	49%			42%	58%	
Farm stocking rate DSE	12,430		12,430	8,400	1,580	9,980

The impact on financial performance of two systems and three scenarios is presented in Table 7. The first column represents an efficient livestock only business (LS OPT). The next three columns represent the enterprise components of an 80% pasture base and 20% dual purpose crop system (LSC SUB) with pasture utilisation compromised or sub optimally stocked. The rightmost three) columns represent the enterprise components of an 80% pasture base and 20% dual purpose crop system (LSC OPT) with pasture utilisation and stocking rate optimised.

The value of the biomass in a dual-purpose crop represents only a small proportion of the total value of the crop. The majority of the total enterprise earnings are in grain production.

Table 7, which is an extension of Table 6, shows the difference in financial performance between enterprise components and between systems with sub optimal and optimal feed utilisation. In the system with sub optimal pasture utilisation the livestock (August lambing wool flock) are agisted onto the crop at a value of $1 per DSE per week. This is shown as crop grazing income at a gross level or Agistment/grazing margin at a per hectare level. This equates to $68 per hectare.

This agistment income is then seen as an expense in the livestock enterprise. When spread over all the livestock it equates to approximately $1.40 per DSE. The gross overhead costs allocated to the livestock enterprise decline from $310,000 to $250,000 but this equates to no net change on a per DSE basis. This is demonstrated in the cost per DSE which is $25 for the LS OPT and LSC SUB systems. Profits per DSE decline from $45 per DSE in the LS OPT system to $44 per DSE in the LSC SUB system due to the additional cost of the agistment onto the crop.

In the system with optimal pasture utilisation (LSC OPT), crop biomass is utilised with a livestock trade rather than the existing wool flock. The average annual stocking rate on the crop equates to 7.9 DSE per hectare but unlike the pasture, which is grazed year-round, it has been derived from short duration high intensity grazing for only a proportion of the year.

The number of livestock grazed on pasture increases relative to the LSC SUB system to reflect the per hectare stocking rate of the LS OPT system. This equates to 9,980 DSE. All of the expenses associated with the trade have been deducted so the net earnings of the trade are what is shown as the grazing margin. This means that there is no cost to be accrued against the existing livestock enterprise. The overhead cost base of the existing livestock enterprise is maintained at $25 per DSE which delivers the same profit per DSE.

The assumptions for the trade are shown in Table 8. The margin for the livestock trade ($308 per hectare) compared with the agistment income reflects the higher risk in this enterprise.

The grain income is assumed to be $1,238 per hectare which is higher than the average of the three-year grain income in the farming systems trial to attempt to reflect less volatility. The outcome of the analysis is highly sensitive to the value of the grain income per hectare. This reinforces the message around the importance of skills. Croppers know how much timeliness and management skill contributes to attaining the production while others may be less aware.

Per hectare comparisons

Livestock/pasture enterprise returns

The LS OPT system delivers operating profit or EBIT of $560 per hectare. The LSC SUB system delivers EBIT of $544 per hectare from the livestock due to additional agistment costs associated with grazing the dual-purpose crop. The LSC SUB system has maintained the 12.4 DSE per hectare stocking rate on the pasture by agisting on the crop which adds no value at a whole farm level.

The LSC OPT system generates the same return as the LS OPT system per hectare as the stocking rate per hectare on pasture has remained the same, but the additional feed produced by the crop is consumed using a livestock trading enterprise. At a gross level, profits have declined but only by the proportion of area sown to crop.

This means that there is no marginal cost associated with the crop as it has been grazed with trading livestock.

Crop enterprise returns

The LSC SUB system generates operating profit or EBIT of $555 per hectare in profit primarily due to low agistment income of only $68 per hectare when compared to the LSC OPT system. The LSC OPT system has higher grazing income because the net returns of trading (after costs) in this example are higher than the value attributed to agistment. The LSC OPT system generates $796 in EBIT per hectare which weights the whole farm EBIT per hectare up. This demonstrates that the value of the dual-purpose crop comes from creating additional value from the crop grazing.

Bottom line

The bottom line (EBIT) is demonstrated by the column titled ‘Whole farm.’ This is the aggregation of the enterprise contribution of income, expenses and profits within each system and scenario. The LSC SUB system generates less return to the whole business relative to the LS OPT system not because the grazing crop didn’t deliver solid production and financial performance but because that performance came at the cost of optimising the performance in the livestock system.

The LSC OPT system generated more profit across the whole farm because the stocking rate in the pasture system was maintained and the crop profits were higher than the livestock only system.

The returns of both the LS SUB system and the LS OPT system are highly sensitive to grain production, pasture feed utilisation (stocking rate) and agistment or grazing returns.

In this case study the livestock system generates the majority of the whole farm profit so it is critical that per hectare performance is maintained in this enterprise to ensure that whole farm profit isn’t eroded with the inclusion of a dual purpose cropping system.

The key message associated with this whole farm analysis is that without good records it is difficult to establish the value contributed by dual purpose crops at a whole farm level. Without recording whole farm stocking rate and taking it further to understand stocking rate per pasture and crop hectare it is impossible to establish the contribution of different enterprises to the whole farm performance. A good starting point for those looking to compare the value of dual purpose crops with alternative enterprises is to have good farm records to allow for the analyses to be conducted.

Table 7. Where whole farm grazing is optimised there is a greater business case to introduce dual purpose grazing crops. The difference in financial performance between enterprise components and between systems with sub optimal and optimal feed utilisation

System	**LS OPT Livestock Optimal SR**	**LSC SUB Internal agistment onto crop Sub optimal pasture stocking rate**			**LSC OPT Trade livestock onto crop Optimal pasture stocking rate**		
	Pasture	**Pasture**	**Crop**	**Whole farm**	**Pasture**	**Crop**	**Whole farm**
Stocking rate (AADSE)	12,425	8,400	1,580	9,980	9,980	1,580	11,560
Area (ha)	1,000	800	200	1,000	800	200	1,000
Gross profit ($/DSE)	$95	$95			$95		
Enterprise expenses ($/DSE)	$25	$25			$25		
Agistment expenses ($/DSE)		$1					
Overhead expenses ($/DSE)	$25	$25			$25		
EBIT ($/DSE)	**$45**	**$44**			**$45**		
Gross profit grain ($/ha)			$1,238			$1,238	
Agistment/grazing margin ($/ha)			$68			$308	
Gross profit ($/ha)	$1,180	$1,185	$1,305	$948	$1,185	$1,546	$1,257
Enterprise expenses ($/ha)	$311	$329	$450	$340	$312	$450	$340
Overhead expenses ($/ha)	$311	$312	$300	$310	$312	$300	$310
EBIT ($/HA)	**$559**	**$544**	**$555**	**$547**	**$561**	**$796**	**$608**
Gross profit livestock ($)	$1,180,419	$948,100		$948,100	$948,100		$948,100
Gross profit grain ($)			$247,500	$247,000		$247,500	$247,500
Crop grazing income ($)			$13,543	$13,543		$61,650	$61,650
Component gross profit ($)	**$1,180,419**	**$948,100**	**$261,043**	**$1,209,143**	**$948,100**	**$309,150**	**$1,257,250**
Enterprise expenses ($)	$310,637	$249,500	$90,000	$339,500	$249,500	$90,000	$339,500
Agistment grazing expense ($)		$13,543		$13,543			
Overhead expenses (4)	$310,637	$249,500	$60,000	$309,500	$249,500	$60,000	$309,500
Total operating costs ($)	**$621,273**	**$512,543**	**$150,000**	**$662,543**	**$499,000**	**$150,000**	**$649,000**
EBIT ($)	**$559,146**	**$435,557**	**$111,043**	**$546,600**	**$449,100**	**$159,150**	**$608,250**

It is possible to calculate the minimum per hectare profits from the dual-purpose crop enterprise required to break even with the LS OPT system. Deduct the whole farm livestock enterprise EBIT in the LSC SUB and LSC OPT systems from the LS OPT system and dividing that figure by the crop area.

For example, the LSC SUB system compared to the LS OPT system: $559,146-$435,557 = $123,589 ÷ 200 = $617 per hectare.

For example, the LSC OPT system compared to the LS OPT system: $559,146-$449 100 = $110,046 ÷ 200 = $550 per hectare.

This approach can be used in forecast budgets to assist in decisions.

Table 8. Livestock (lamb) trading assumptions

Livestock trade assumptions	
Weight gain (kg/head/day)	0.275
Yield (cwt to lwt %)	46%
Feed adjustment period (days)	10
Sale weight (kg cwt/head)	21
Sale weight (kg lwt/head)	45.7
Purchase weight (kg lwt/head)	29.2
Price in ($/kg cwt)	$8.00
Price in ($/head)	$107.28
Price out ($/kg cwt)	$8.50
Price out ($/head)	$178.50
Sales cost ($/head)	$12.50
Enterprise costs ($/head)	$8.00
Total cost ($/head)	$20.50
Net margin ($/head)	$50.73
Net margin ($/ha)	$398
Net margin ($ gross)	$61,650

What this means to you

There is no one size fits all approach to the integration of dual-purpose crops into a farming system. The value of the integration will depend on several factors including the existing system and the existing skill base. Following are some tips that may assist in successful implementation to ensure that dual purpose crops are an enduring part of the farming system.

1. Extracting value from dual purpose crops at a whole farm level requires optimising not only of the grazing crop but also the other parts of the farming system.
2. Don’t underestimate the investment in skills required to make some of the changes. Start small to build confidence as this will minimise risk and build skill over time.
3. Whole farm feed budgeting prior to making systems changes will assist in understanding the extent of the capital requirements for the additional livestock and the stocking rates necessary to deliver profitability improvements.
4. Where there is opportunity for feed budgeting skills learned as a result of exposure to dual purpose crops to be implemented to other parts of the farm there is massive opportunity for improvements in whole farm profitability.

Acknowledgement

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

Contact details

John Francis
Agrista
192 Dukes Road, Lake Albert
Ph: 0427 259 005
Email: john@agrista.com.au

Concurrent session: Cereal diseases

Cereal rust update 2024

Robert Park[1], Mumta Chhetri[1], Yi Ding[1], Brad Baxter[2], Hari Dadu[3]

[1] The University of Sydney
[2] NSW Department of Primary Industries, Agricultural Institute, Wagga Wagga
[3] Agriculture Victoria, Horsham

Key words

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.

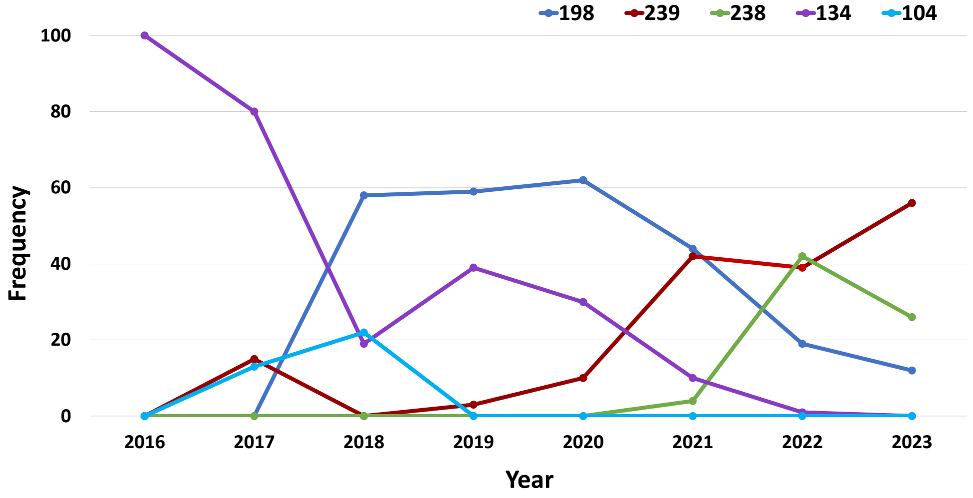


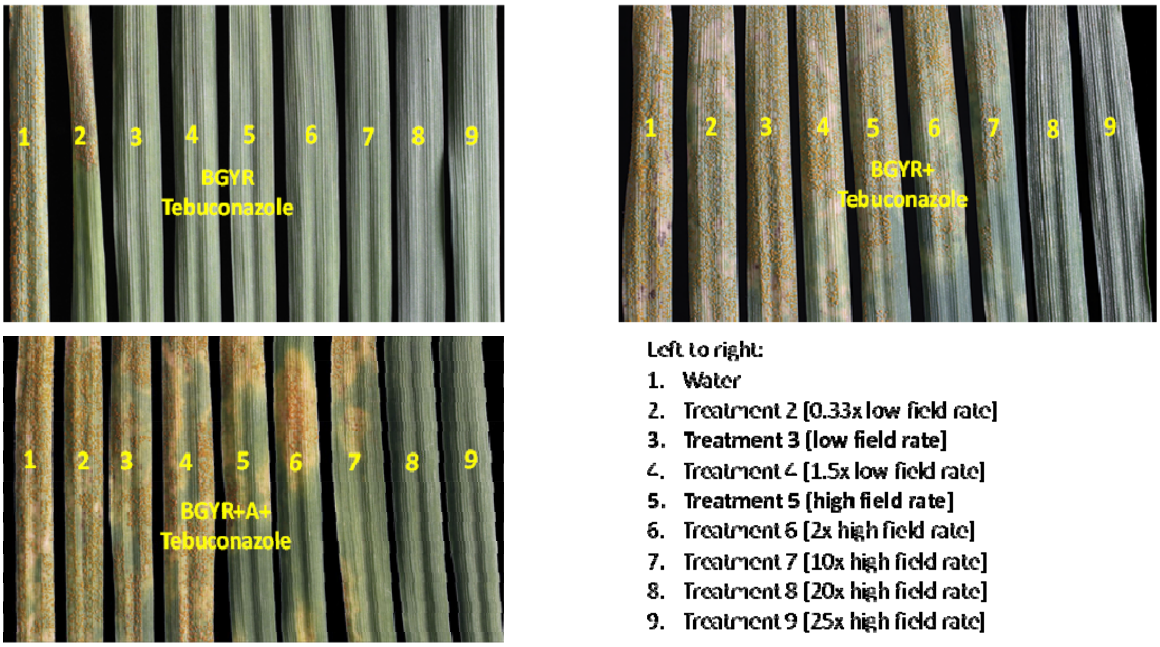
Figure 1. Frequency (%) of the five different pathotype groups of the wheat stripe rust pathogen in eastern Australia, 2016 through 2023

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 Corack, Emu Rock, and Wyalkatchem. 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

Acknowledgements

The rust surveillance program for cereals across the nation, supported by GRDC (UOS2207-002RTX) at the University of Sydney's Plant Breeding Institute, extends gratitude to all collaborators including grain growers and agronomists who submitted rust samples from wheat, barley, oat, triticale, and cereal rye. Special recognition goes out to the ongoing support from Drs Lisle Snyman, Andrew Milgate, Brad Baxter, Steven Simpfendorfer, Grant Hollaway, Hari Dadu, Tara Garrard, Manisha Shankar, and Geoff Thomas. Additionally, we want to extend our appreciation to Wes Amor and Tom McGuire at Bayer CropScience Pty Ltd for supplying the fungicides for testing.

**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.

Contact details

Robert Park
The University of Sydney, Faculty of Science
School of Life and Environmental Sciences
Plant Breeding Institute, Camden, NSW 2006
Ph: 0414 430 341
Email: Robert.park@sydney.edu.au
Twitter: @PbiCobbitty

Mumta Chhetri
The University of Sydney, Faculty of Science
School of Life and Environmental Sciences
Plant Breeding Institute, Camden, NSW 2006
Ph: 0404 392959
Email: Mumta.chhetri@sydney.edu.au
Twitter: @PbiCobbitty

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

® Registered Trademark

Septoria tritici blotch- risk and management considerations for 2024

Brad Baxter[1], Ben Ovenden[1], Steven Simpfendorfer[2], Andrew Milgate[1]

[1] NSW DPI Wagga Wagga
[2] NSW DPI Tamworth

Key words

correct diagnosis, leaf disease, STB, pycnidia, integrated disease management (IDM)

GRDC codes

DAN00213: Grains Agronomy & Pathology Partnership (GAPP) - A strategic partnership between GRDC and NSW DPI. Projects BLG208 and BLG207 (completed)
DPI2207-002RTX: Disease surveillance and related diagnostics for the Australian grains industry (NSW)
DAN1907: NVT Services Agreement 2019-2023

Take home message

- Favourable climatic conditions early in the growing season of 2023 resulted in the widespread and increased prevalence of Septoria tritici blotch (STB) in southern NSW (sNSW)
- With resultant high stubble loads from the 2021 – 2023 seasons, STB risk levels are likely to be elevated again in 2024
- STB infection and epidemic development is highly dependent on climatic conditions throughout the season. Climatic conditions in 2024 will dictate the severity of any STB epidemic.
- If optimal climatic conditions are experienced and early STB infection is evident, apply fungicide at GS31 to suppress the epidemic and enable flexibility with later fungicide applications
- Not all fungicide active ingredients are equal when it comes to controlling STB and fungicide choice is becoming increasingly important
- NSW DPI plant pathologists can assist with correct diagnosis and advice on appropriate integrated disease management (IDM) options.

Introduction

Septoria tritici blotch (STB) is a necrotrophic disease of bread wheat, durum wheat and triticale, caused by the pathogen *Zymoseptoria tritici* (*Z. tritici*). STB is considered the third most significant wheat disease globally, threatening large areas of wheat production. Studies at the Wagga Wagga Agricultural Institute (2020 to 2021) revealed that in regions with moderate to high rainfall, the disease could lead to a considerable reduction in crop yield, ranging from 19% to 49%.

STB has a fungal structure produced on wheat stubble (pseudothecia), which releases airborne spores (ascospores) under ideal environmental conditions. The ascospores produced can spread over long distances (kilometres) on the wind to infect susceptible crops. Following an infection event, lesions appear up to 28 days later and produce pycnidia (small black structures inside tan leaf lesions that give a speckled appearance). The pycnidia produce a different type of spore called conidia, which are then splash-dispersed by rainfall within the wheat canopy, causing new infections and further driving the STB epidemic.

Under the NSW DPI project DPI2207-002RTX with co-investment from GRDC, diagnostic and management advice services are offered at no cost to growers and advisors. STB, for the third year in a row, was the fourth most queried disease during 2023 (data not shown), further emphasising the importance of this disease in southern and central NSW.

Septoria epidemic during the 2022 and 2023 growing seasons

The start of the 2023 growing season for much of southern New South Wales (sNSW) was characterised by widespread STB infection in the lower canopy of susceptible wheat varieties. However, unlike 2022 this early infection did not generally progress to the upper canopy during grain filling nor result in significant yield loss. Several climatic and management differences during 2023, as opposed to 2022 can help explain this.

STB development is highly driven by climatic conditions and requires extended periods of leaf wetness (>24 hours) and optimal cycling temperatures for infection of 15-20°C. There was below-mean rainfall during winter and spring at Wagga Wagga in 2023 (Figure 1). The long-term cumulative historical mean annual rainfall for August, September and October at Wagga Wagga is 129.9 mm. During 2022, the rainfall received during that period was 335.2 mm compared with only 61.8 mm in 2023. These three months are crucial for the development of STB epidemics, as this is when STB moves from the lower to mid-canopy onto the upper leaves (Flag, Flag-1, Flag -2). This is important because the upper leaves contribute the most to yield accumulation. The 2023 spring rainfall during those critical months was less conducive to STB cycling than in 2022, resulting in reduced STB infection levels in the mid and upper canopy of wheat crops.

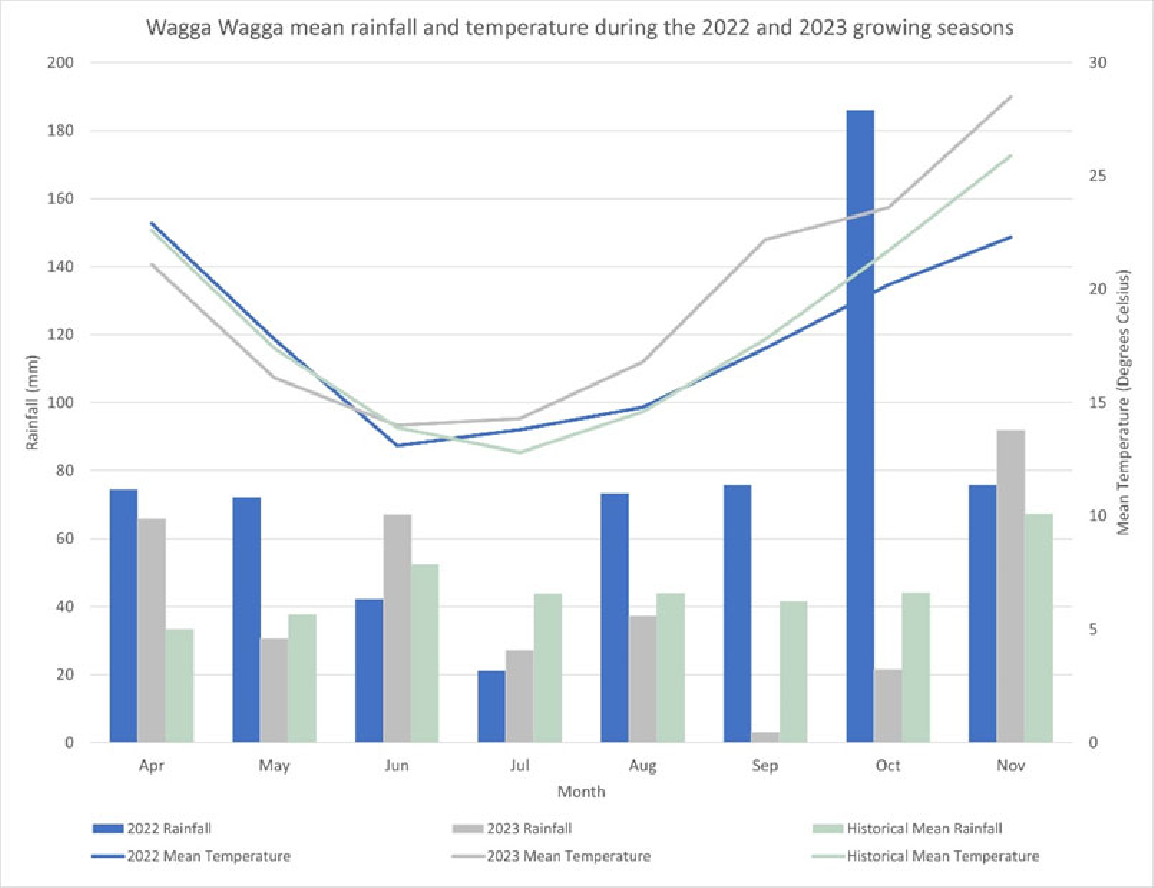


Figure 1. The growing season (April to November) rainfall and temperature during 2022 and 2023 as compared with the long-term mean monthly rainfall and temperature. The halt in STB infection levels during the second half of the 2023 growing season can be explained by the below mean rainfall and above mean temperatures during winter and spring months, particularly September and October (BOM, 2023).

The mean temperature during the spring months of 2023 was much higher than 2022 (Figure 1). The deviation from historical mean temperature for August, September and October during the 2022 and 2023 growing seasons are outlined in Table 1. In 2022, temperatures were much cooler, facilitating STB infection and cycling, whereas 2023 temperatures were outside the ideal cycling temperatures for STB development much earlier in the season and resulted in shortened leaf wetness duration. These factors reduced the number of cycles STB could undertake in 2023, helping to curb the levels of infection despite the extreme inoculum loads that had built up during the previous 2–3 years.

Table 1. Deviation from historical mean temperatures for August, September, and October 2022 and 2023

Month	Historical mean temperature (°C)	2022 deviation from historical mean temperature (°C)	2023 deviation from historical mean temperature (°C)
August	14.6	+0.2	+2.2
September	17.8	-0.4	+4.4
October	21.7	-1.5	+1.9

Temperature and rainfall are key factors that drive disease epidemics. However, for STB infection, leaf wetness and importantly the duration of leaf wetness also play a crucial role. The number of rainfall days and the consecutive number of rainfall days (greater than 2 days) during the growing seasons of 2022 and 2023 are outlined in Figure 2. A rainfall day is categorised as a fall of >5 mm in a 24-hour period and/or >5 mm falling during a single event over consecutive days (>2 days)

During the crucial three months for disease development – August, September and October – there is significantly less rain days along with less consecutive rainfall days in 2023 compared with 2022. For example, September 2022 had four rainfall events that lasted greater than two days, compared to zero during September 2023. October 2022 had four, and October 2023 had one rainfall day. This limitation in leaf wetness duration meant that the moisture requirement for STB to cycle was only partially met or not met at all, resulting in a net reduction in infection levels in 2023.

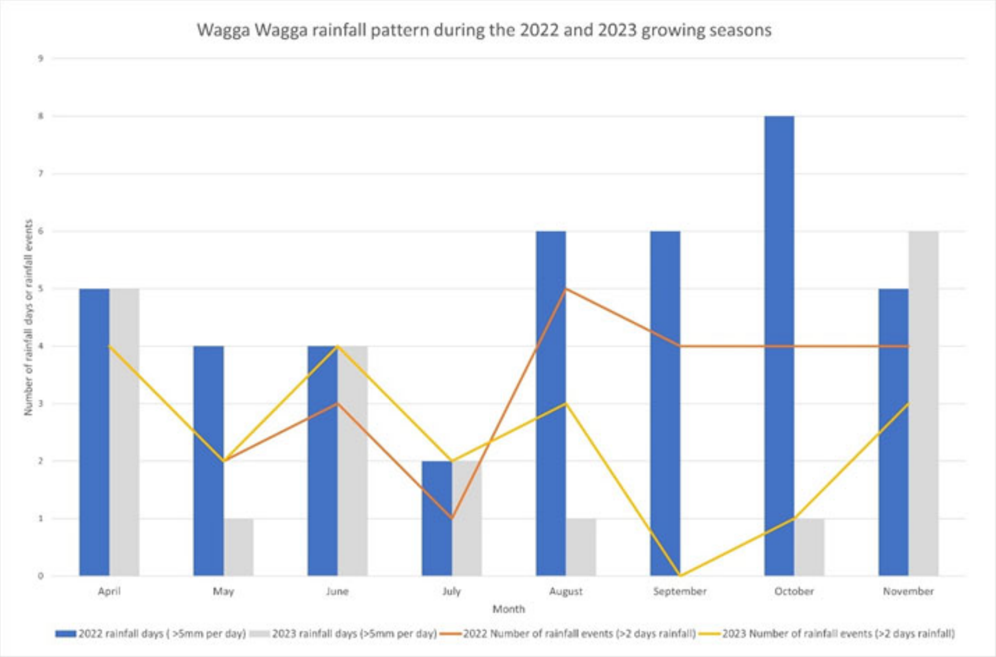


Figure 2. The growing season (April to November) number of rainfall days and number of consecutive rainfall days (>2 days) in 2022 and 2023 at Wagga.

Generally, the lack of rainfall, decrease in leaf wetness duration, higher-than-average temperatures and proactive fungicide use all contributed to STB staying in the lower to mid canopy of wheat crops in sNSW during the 2023 season. This was not the case for the entire cropping area of sNSW, particularly in the higher rainfall slopes regions, where STB continued to be a problem throughout the entirety of the 2023 season.

Septoria tritici blotch (STB) management considerations for 2024

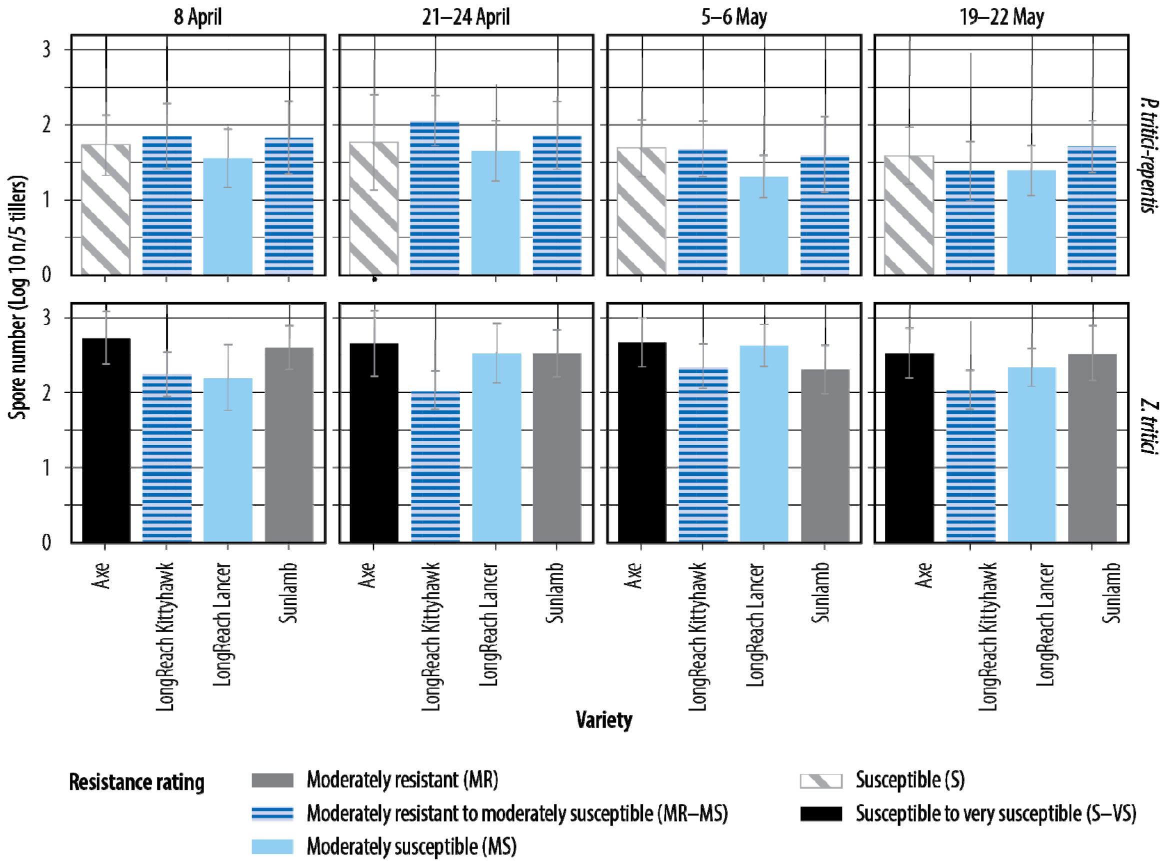
Even though STB did not pose a major threat in many regions in the latter half of 2023, the inherent risk moving forward is still elevated. An integrated disease management (IDM) system, comprised of the factors outlined below, should be implemented to reduce the risk of economic losses.

Stubble colonisation and associated management considerations

Stubble spore release experiments assessing plant resistance rating and time of sowing on ascospore release of pathogens *Z. tritici* (STB) and *Pyrenophora tritici-repentis* (Yellow leaf spot, YLS) were conducted at Wagga Wagga Agricultural Institute during 2020 and 2021 (Figure 3). Results have shown that the resistance rating of the wheat variety grown has little influence on the ability of these pathogens to colonise senescent stubble and inoculum levels produced off retained stubble, i.e., the number of spores released, in the following season.

There was no significant difference ($P = 0.05$) between the four sowing dates, or within a sowing date between varieties, in the number of *Z. tritici* and *P. tritici-repentis* ascospores released from stubble (Figure 3). In the case of STB, this means that a moderately resistant (MR) rated variety is statistically releasing the same number of ascospores in the following season as varieties rated moderately-resistant to moderately-susceptible (MR–MS), moderately susceptible (MS), susceptible (S) or susceptible to very-susceptible (S–VS). Essentially, the resistant rating of the plant does not carry over to ascospore release in the following season from the retained stubble. It is not known if the numerical differences in ascospore release numbers between variety resistance ratings, although not significant, have an influence on epidemic severity.

Therefore, any infected stubble from 2021–2023 must be considered a risk for the following wheat crop or crops nearby.

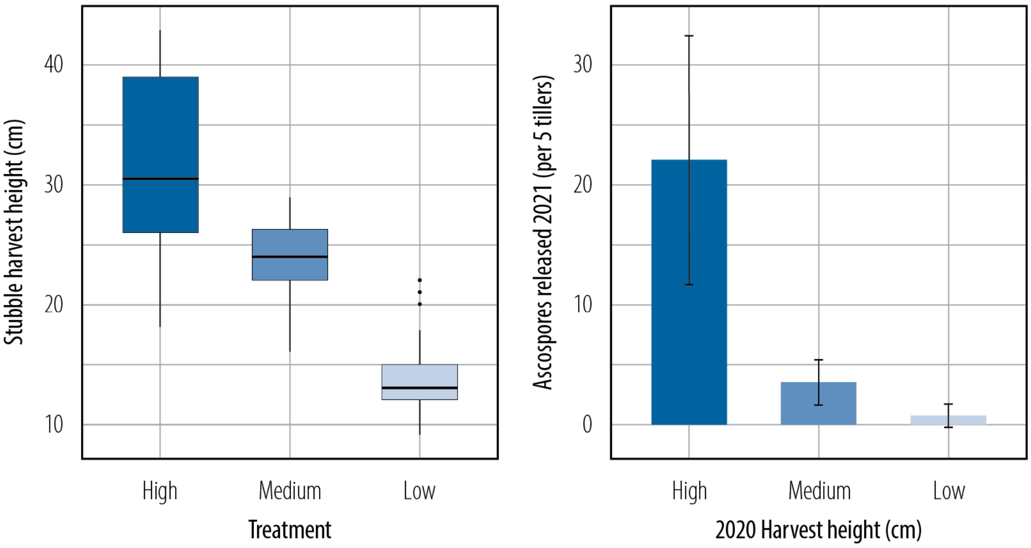


Note: The Log10 average combines all data from 2 years of spore release repetitions conducted in the laboratory.
There is no significant difference in the number of ascospores released between resistance ratings for both STB and YLS.
Log1 = 10 spores, Log 2 = 100 spores and Log 3 = 1000 spores.
Vertical bars represent 95% confidence intervals ($P = 0.05$).

Figure 3. The average number of *Zymoseptoria tritici* and *Pyrenophora tritici-repentis* ascospores (Log10) released from wheat stubble of four varieties with different resistance ratings to the diseases Septoria tritici blotch (STB) and yellow leaf spot (YLS). Varieties mentioned in the graphs above are protected under the Plant Breeders Rights Act 1994.

Furthermore, findings from other experiments (data not shown) indicated that stubble infected with the STB-causing pathogen *Z. tritici* can generate enough ascospores to initiate an epidemic two years after the wheat crop was grown, irrespective of the varietal resistance rating. This has important implications for crop sequences and stubble management. In sNSW, the cropping sequence is dominated by cereal–canola–cereal rotations. As infected stubble can produce ascospores at an epidemic-inducing level for up to 2 years, it suggests that a single break crop such as canola, might not be enough to reduce the risk of STB or YLS infection. If possible, avoid sowing wheat-on-wheat. If you are forced into a situation where this must happen, plan an IDM program to reduce the risk of yield loss.

Stubble management experiments have demonstrated that a net reduction in inoculum levels can be achieved by manipulating harvest cut height to reduce the standing stubble available for the STB pathogen to colonise (Figure 4). These experiments included three cut height treatments: 32 cm (high), 24 cm (medium), and 14 cm (low). Cut heights were selected to reduce stubble length by one node on the main stem. Using the 32 cm cut height as a baseline, lowering the cut height to 24 cm reduced the number of ascospores produced by 84%. When comparing the 32 cm cut height to the 14 cm cut height, there was a 97% reduction in the number of ascospores released from the stubble.



Vertical bars represent 95% confidence intervals ($P = 0.05$).

Note: average harvest cut heights for treatments: High – 32 cm, Medium – 24 cm and Low – 14 cm.

Figure 4. Left: Box plot showing the harvest cut height in centimetres (cm) of the high, medium, and low treatments for the 2020 STB stubble management experiment. Right: The number of *Zymoseptoria tritici* ascospore released from five tillers from the three stubble cut height treatments. This figure displays the reduction in ascospore numbers as the harvest cut height decreases.

The excess material must be removed from the paddock to result in a net reduction. Otherwise, the inoculum from the standing stubble is only relocated to the ground, which maintains the same inoculum levels within the paddock. Removal can be through baling or burning the stubble. However, the cost benefit risks of each method and other system impacts must be weighed before being undertaken.

Finally, the distinction needs to be made between managing disease in the current wheat crop to minimise yield loss and inoculum risk from the stubble in subsequent seasons. Even though the number of ascospores released from the senescent stubble does not significantly change with varietal resistance rating, variety choice remains critical to minimising losses from STB and other diseases within the growing season.

Variety selection

Research undertaken at Wagga Wagga Agricultural Institute confirms that a more resistant variety develops less disease compared with a more susceptible variety. In the absence of fungicide use, the difference in infection levels between a moderately susceptible (MS) variety and a susceptible to very susceptible (S-VS) variety with an early May sowing time can be as much as 30% less in the MS variety, resulting in a reduction of 10 – 15% in yield loss compared to the SVS variety (data not shown).

Choosing a wheat variety with a higher resistance level will protect yield in the presence of STB, while also reducing the number of fungicide applications required. This in turn decreases machinery, labour, and input costs. Minimising fungicide use also lowers the risk of fungicide resistance developing within both target and off-target fungal pathogen populations.

It is important to stay up to date with the latest variety resistance ratings as they can change from year to year. These ratings are developed through the National Variety Trial (NVT) pathology screening project and are released annually on the GRDC website (https://nvt.grdc.com.au/) and in state-based sowing guides such as the NSW DPI winter crop variety sowing guide (https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/nsw-winter-crop-variety-sowing-guide-2023).

Fungicide application

Not all fungicide active ingredients are equal when it comes to controlling STB, and fungicide choice is becoming increasingly important. The geographical spread of samples sent to Curtin University's Centre for Crop and Disease Management (CCDM) for fungicide resistance screening in 2022 is displayed in Figure 5. A further 22 samples were sent from NSW in 2023 which at the time of writing results were not available. Primarily, the 2022 results reveal that the G143A mutation, which confers resistance to Group 11 (QoI, strobilurin) fungicides such as azoxystrobin, was not detected in any of the samples submitted from NSW.

However, the G143A mutation was detected in an STB sample from Tasmania in 2022 (not shown), marking the first detection outside of South Australia. It is unclear if this is the result of gene flow (wind dispersion) or an independent mutation event. This detection should act as a warning for NSW growers to use fungicide resistance management strategies to prolong the effectiveness of Group 11 (QoI, strobilurin) chemistry against STB.

Unsurprisingly, mutations that confer reduced sensitivity to Group 3 fungicides (DMI, triazoles) were found in all the samples except one from NSW. Specifically, the mutation called Cyp51 G1 (formerly identified as Cyp51 Isoform 11) was present in most leaf samples. This mutation is particularly significant because it leads to elevated levels of reduced sensitivity to some Group 3 fungicides such as tebuconazole, flutriafol and propiconazole. It is not unexpected since Cyp51 G1 was the predominant mutation in the STB population from a previous NSW study conducted in 2016.

These results support our recommendation that Group 11 (QoI, strobilurin) fungicides are effective in preventing STB infection in NSW. We continue to advise that if your goal is to specifically target STB curatively with fungicides, it is best to avoid using cheaper Group 3 triazole actives like tebuconazole and propiconazole. Instead, opt for stronger Group 3 fungicides such as prothioconazole or epoxiconazole.

Decision support matrix and suggested fungicide regime for STB management if the 2024 season is conducive to infection and disease development is outlined in Table 2. The table also outlines the efficacy status of any fungicide application on stripe rust, as many fungicides registered for use on STB will also have efficacy on stripe rust. There is very little data showing a yield benefit from using fungicides prior to the commencement of stem elongation. That said, any sprays applied before the commencement of stem elongation will at best only have a suppressive effect on inoculum load, as none of the leaves that contribute significantly to grain yield emerge until after this growth stage. Therefore, crops which include a fungicide with the herbicide application during tillering (GS25) still require a dedicated fungicide spray at GS31-32 to protect the Flag-2 leaf. All applications may not be needed depending on seasonal conditions, growth stage, infection levels and economic considerations. Particularly if fungicide treatments are applied to seed and/or flutriafol is applied to the fertiliser to protect seedlings from early STB or stripe rust infection.

Table 2. Decision support matrix and suggested fungicide regime for STB management if the 2024 season is conducive to infection and disease development. The table also outlines the efficacy status of fungicide applications on stripe rust

Growth stage (GS)	STB present	Fungicide application required	Fungicide activity on stripe rust?
GS 25	Yes	No	Flutriafol activity if used
GS 31	Yes	Yes*	Yes
GS39	Yes	Yes/No*	Yes
GS50-59	Yes	Yes/No*	Yes

*All applications may not be needed pending seasonal conditions, growth stage, infection levels and economic considerations.

If the 2024 season is not conducive to STB development, and stripe rust is the primary foliar fungicide application target, consider products containing active ingredients such as tebuconazole or propiconazole to alleviate the selection pressure on prothioconazole and epoxiconazole after repeated use patterns during the 2021–2023 growing seasons. In dry conditions, fungicide applications may not be needed at all.

The 2022 results reiterate the need to protect fungicide modes of action when targeting all pathogens, but particularly those prone to developing resistance to diseases such as STB and wheat powdery mildew. To help prolong the life of fungicides, avoid susceptible varieties, implement crop rotation, consider non-chemical means of controlling inoculum sources, get a correct diagnosis if in doubt before applying a fungicide, rotate fungicide active ingredients and groups, adhere to label rates and use patterns. Further resistance management advice can be found at https://afren.com.au/.

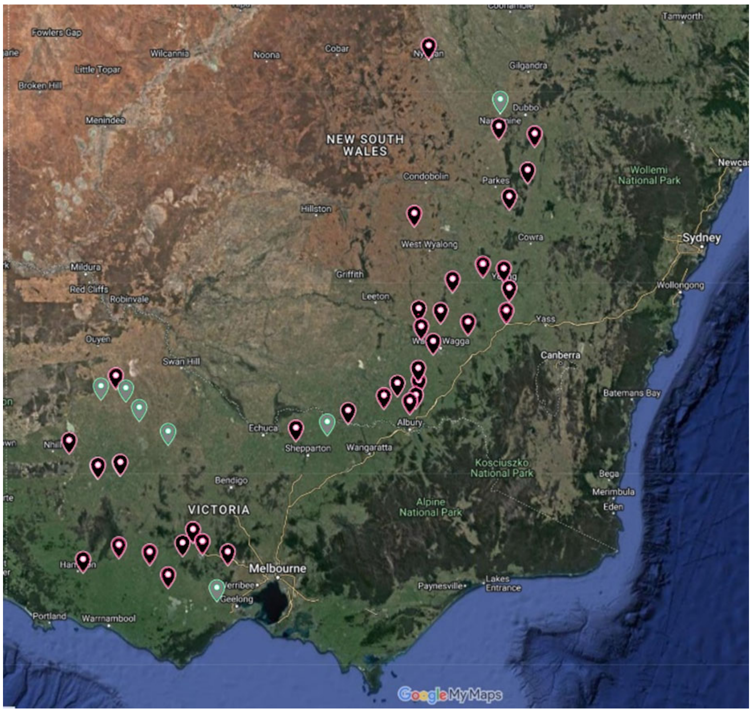


Figure 5. STB fungicide resistance screening results across NSW and Victoria in 2022. Note: Not all samples submitted appear on map, as some leaf samples did not recover DNA of high enough quality to be used for screening. Grey indicates the absence of Cyp51 G1 (Isoform 11). Black indicates the presence of Cyp51 G1 (Isoform 11) Group 3 (triazole) resistance. Courtesy of CCDM

Conclusions

With high wheat stubble loads from high yielding years from 2021 through to 2023, the STB inoculum risk for next season is elevated. However, incidence of STB is highly dependent on climatic conditions and 2024 growing season conditions will dictate the severity of any epidemic. To help counter these factors, components of the research outlined above can be implemented into an IDM plan to suppress and control STB. Acknowledging the risk and duration of the risk (i.e., >2 years) that any STB infected stubble can have on subsequent cereal crops can guide crop rotation decisions. If growing wheat on wheat, a plan can be implemented to appropriately manage the risk of STB, but it is best avoided. Cultural practices, such as variety selection, stubble cut height and stubble removal should be used in the first instance to reduce the resistance pressure on fungicides and prolong their effective lifespan.

NSW DPI is here to support growers with correct diagnosis and discussions of management options prior to sowing and as required throughout the season.

Acknowledgements

The research undertaken as part of these projects is made possible by the joint investment of NSW DPI and GRDC, and the significant contributions of growers and their advisers through both sample submission and engagement. The authors would like to thank them for their continued support. The authors would also like to express gratitude to cereal pathology staff members located at Wagga Wagga and Tamworth for their valued contributions to project work. Additionally, the authors acknowledge the ongoing support for cereal pathology capacity by NSW DPI.

References

BOM,2023. *Historical climate data*. http://www.bom.gov.au/climate/data/ Accessed 11/12/23.

Useful links

NSW DPI research result booklets: https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides

NSW DPI Sowing Guide: https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/nsw-winter-crop-variety-sowing-guide-2023

NVT Online: https://nvt.grdc.com.au/nvt-disease-ratings

Australian Cereal Rust Survey: https://www.sydney.edu.au/science/our-research/research-areas/life-and-environmental-sciences/cereal-rust-research/rust-reports.html

AFREN website: https://afren.com.au/

Contact details

Brad Baxter
NSW DPI, Pine Gully Rd, Wagga Wagga, NSW 2650
Ph: 0428 294 121
Email: brad.baxter@dpi.nsw.gov.au
Twitter: @BradBaxter1985 or @NSWDPI_AGRONOMY

Steven Simpfendorfer
NSW DPI, 4 Marsden Park Rd, Tamworth, NSW 2340
Ph: 0439 581 672
Email: steven.simpfendorfer@dpi.nsw.gov.au
Twitter: @s_simpfendorfer or @NSWDPI_AGRONOMY

Andrew Milgate
NSW DPI, Pine Gully Rd, Wagga Wagga, NSW 2650
Ph: 02 6938 1990
Email: andrew.milgate@dpi.nsw.gov.au

Podcasts

NSW DPI podcasts: are now on popular streaming platforms, such as Apple and Spotify. Just search for NSW DPI Agronomy. Alternatively, you can subscribe and receive NSW DPI podcasts on Soundcloud Stream NSW DPI Agronomy | Listen to podcast episodes online for free on SoundCloud.

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

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

Steven Simpfendorfer, NSW DPI, Tamworth

Key words

barley, fungicide seed treatments, wheat, yield loss

GRDC codes

DAN00213, DAN00175

Take home message

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

Introduction

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

What we did

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

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

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

What did we find

Averaged across all cereal entries

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

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

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

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

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

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

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

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

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

[G] All treatments not included at these sites.

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

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

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

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

What about durum

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

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

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

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

[B] Nil = no seed treatment.

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

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

Conclusions

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

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

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

Integrated management of FCR

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

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

If medium to high FCR risk, then:

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

If still considering sowing a winter cereal:

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

  - ***Stubble burning*** depending on the completeness of the burn, above ground inoculum is destroyed. Burning has no effect on the survival of the FCR fungus below ground in crown tissue, even with a hotter summer burn. Hence, the pathogen will be concentrated below ground in the previous rows, with survival between seasons dependent on the extent of summer rainfall. Burning of cereal stubble can considerably reduce fallow soil moisture storage, so a 'late-Autumn' burn is preferable to an 'early-Summer' burn. Stubble burning in combination with inter-row sowing is more likely to reduce FCR risk.
  - ***Reducing cereal stubble height*** limits the length of stubble which the FCR fungus can vertically grow up during wet fallow periods, restricting the overall inoculum load within a paddock. When relative humidity is >92.5%, the FCR fungus can colonise vertically up retained standing cereal stubble in a process termed 'saprotrophic growth'. At 100% relative humidity, this saprotrophic growth can occur at a maximum rate of 1 cm per day (Petronaitis et al. 2020). The FCR fungus can therefore saprotrophically grow to the cut height of the cereal stubble under prolonged or accumulated periods of rainfall. Consequently, harvesting and leaving retained cereal stubble longer (for example, stripper fronts) leaves a greater length of stubble for subsequent potential saprotrophic growth of the FCR fungus. This is not a major issue in terms of FCR risk if the retained infected cereal stubble is left standing and kept intact. However, if the infected stubble is disturbed and redistributed across a paddock through grazing, mulching, cultivation or the subsequent sowing process, then this can increase the incidence of FCR infection. Recent research in NSW has also demonstrated that increased cereal harvest height allowed saprotrophic growth of the FCR fungus above the harvest height of a following chickpea crop. This resulted in FCR infected cereal stubble being spread out the back of the header during the chickpea harvest process, increasing FCR risk for the next cereal crop (Petronaitis et al. 2022). Consider matching cereal stubble height at or after harvest in paddocks planned for a following shorter status break crop, such as chickpea or lentils, to prevent redistribution of retained FCR infected cereal stubble during the break crop harvest process.
- Select a cereal type and variety that has more tolerance to FCR ***and*** that is best suited to your region. Yield loss from FCR is generally durum>bread wheat>barley>oats. Recent research has shown that cereal type and varietal resistance has no impact on saprotrophic growth of the FCR fungus after harvest. Hence, cereal crop and variety choice does not have subsequent benefits for FCR risk within a paddock.
- Consider sowing a variety earlier within its recommended sowing window for your area. This will bring the grain filling period forward slightly and can reduce water and heat stress which exacerbates FCR expression and yield loss. However, this needs to be weighed against the risk of frost damage. Research across locations and seasons in NSW has shown that sowing at the start versus the end of a three-week recommended planting window can roughly half the yield loss from FCR.
- If previous cereal rows are intact, consider inter-row sowing to increase the distance between the new and old plants, as most inoculum is in the stem bases of the previous cereal crop. Physical contact between an infected piece of stubble and the coleoptile, crown or sub-crown internode of the new cereal plants is required to initiate FCR infection. Research across locations and seasons in NSW (30–35cm row spacings in stubble retained systems) has shown that inter-row sowing can roughly halve the number of wheat plants that become infected with FCR. Precision row placement can also provide greater benefits for FCR management when used in combination with rotation to non-host crops.

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

Acknowledgements

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

Useful resources

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

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

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

Contact details

Steven Simpfendorfer
NSW DPI
4 Marsden Park Rd, Tamworth, NSW 2340
0439 581 672
steven.simpfendorfer@dpi.nsw.gov.au
@s_simpfendorfer or @NSWDPI_AGRONOMY

® Registered trademark
TM Trademark
⦶ Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.

Implications of sowing Fusarium infected wheat seed in 2023

Steven Simpfendorfer, NSW DPI Tamworth

Key words

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 message

- 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.

References

Simpfendorfer S and Baxter B (2023) Fusarium head blight and white grain issues in 2022 wheat and durum crops, GRDC Update paper

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers and their advisers through their support of the GRDC. The author would also like to acknowledge the ongoing support for northern pathology capacity by NSW DPI. This research would also not have been possible without the support of growers and advisors through submission of grain samples for testing. The efforts of Peter Matthews & team (NSW DPI) in running NSW sites and Kaylx in running the Qld site (Westmar) is also gratefully acknowledged.

Contact details

Steven Simpfendorfer
NSW DPI, 4 Marsden Park Rd, Tamworth, NSW 2340
Ph: 0439 581 672, Email: steven.simpfendorfer@dpi.nsw.gov.au
Twitter: @s_simpfendorfer or @NSWDPI_AGRONOMY

® Registered trademark
ⓓ Varieties displaying this symbol are protected under the Plant Breeders Rights Act 1994.

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

Toni Petronaitis[1,2], Clayton Forknall[3], Steven Simpfendorfer[2], Richard Flavel[1,] David Backhouse[1]

[1] University of New England, Armidale, NSW
[2] NSW Department of Primary Industries, Tamworth, NSW
[3] Department of Agriculture and Fisheries, Leslie Research Facility, Toowoomba, QLD

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).

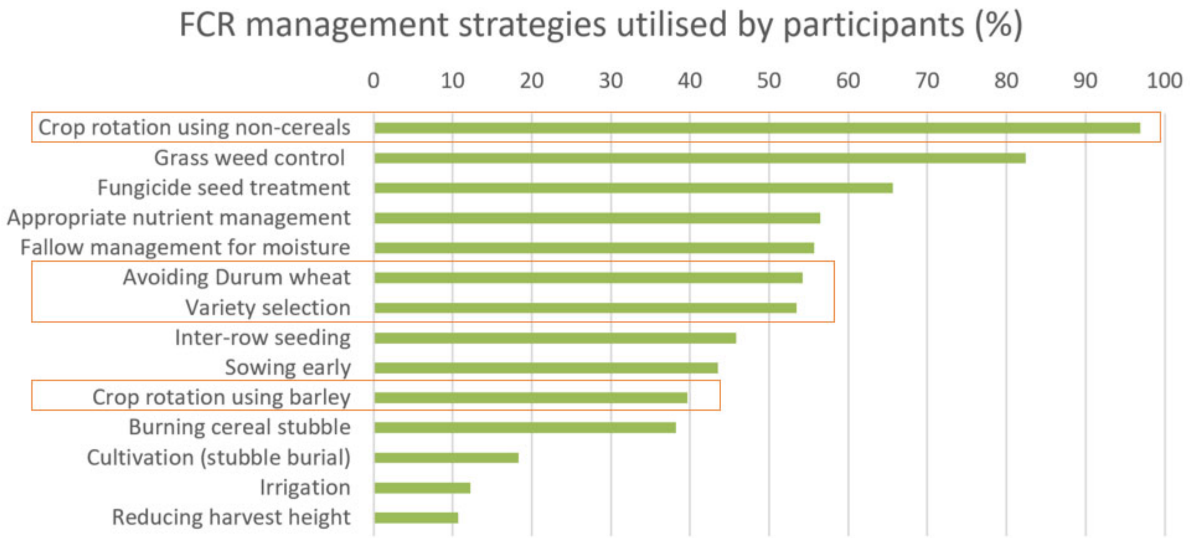


Figure 1. Strategies used in the last 2 years to manage FCR by 130 participants who completed the Fusarium crown rot survey: a grower and agronomist questionnaire conducted in August 2023 under the GRDC and DPI co-investment (DPI2207-004RTX). Strategies that involve crop and variety selection are circled. 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 Hellfireⓓ	Bread wheat (APH)	MS–S
LRPB Lancerⓓ	Bread wheat (APH)	MS–S
LRPB Stealthⓓ	Bread wheat (APH)	S
LRPB Kittyhawkⓓ	Dual purpose wheat (APH)[2]	S–VS
DBA Lillaroiⓓ	Durum wheat	S–VS
Oxfordⓓ	Barley	MS–S
Commanderⓓ	Barley	S
Spartacusⓓ	Barley	S
Eurabbie	Oat	NA

[1] Germplasm and FCR rating kindly supplied by Cassy Percy, University of Southern Queensland, 2021.

[2] For simplification, Kittyhawkⓓ 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.

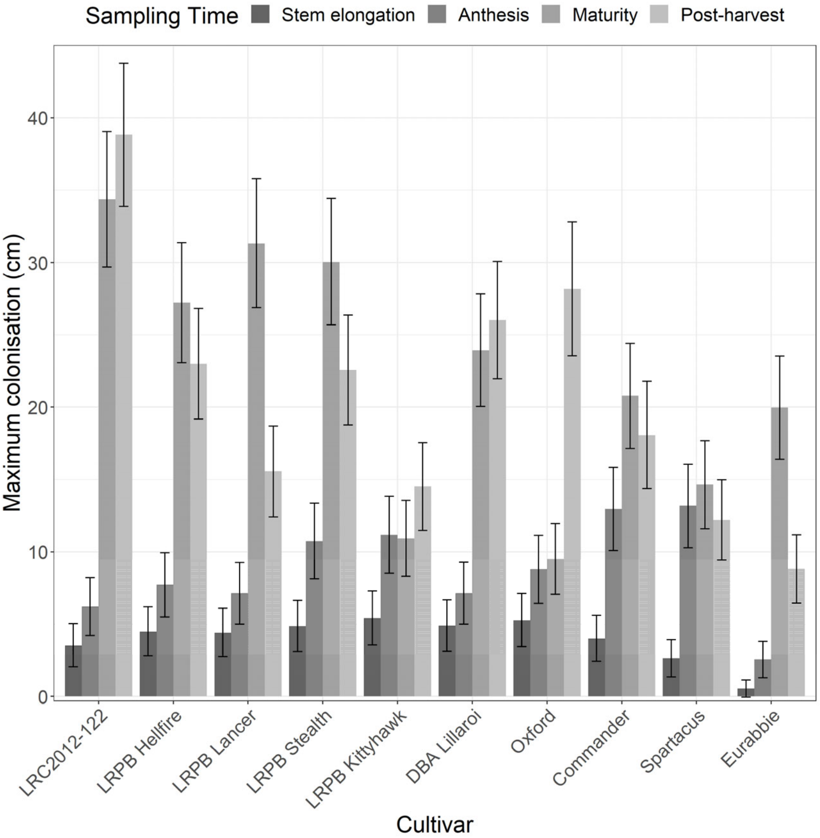


Figure 2. Maximum vertical colonisation (cm) of the main stem of different cereal cultivars by *Fp* at four different time points: stem elongation, anthesis, maturity, and post-harvest. Error bars represent the approximate back-transformed standard error of the mean.

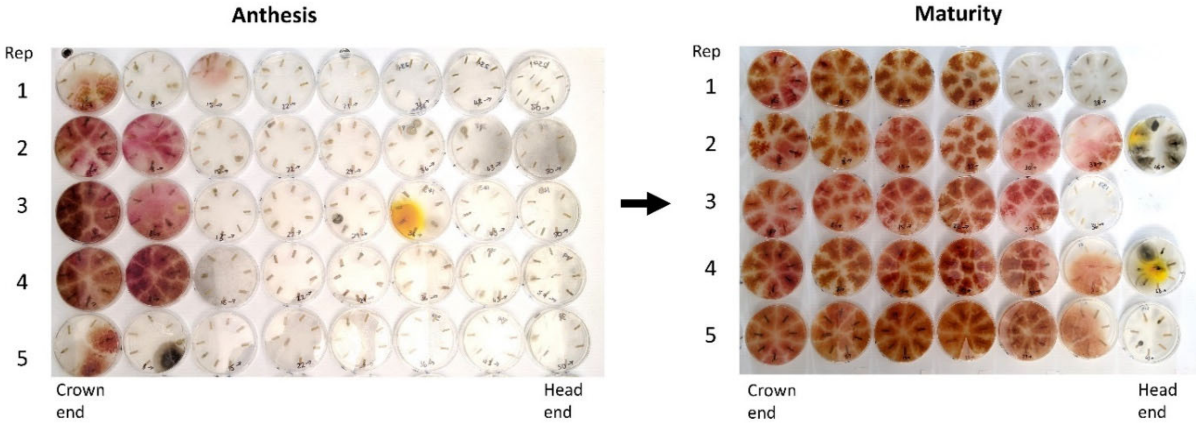


Figure 3. Example of the large increase in *Fp* colonisation observed between anthesis and maturity in the partially FCR-resistant wheat germplasm LRC2012-122. The *Fp* colonies appear as dark patches surrounding the stubble pieces (colonies are red when printed in colour). This shows extensive colonisation 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. Commanderɸ and S–VS wheat cv. LRPB Kittyhawkɸ) 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).

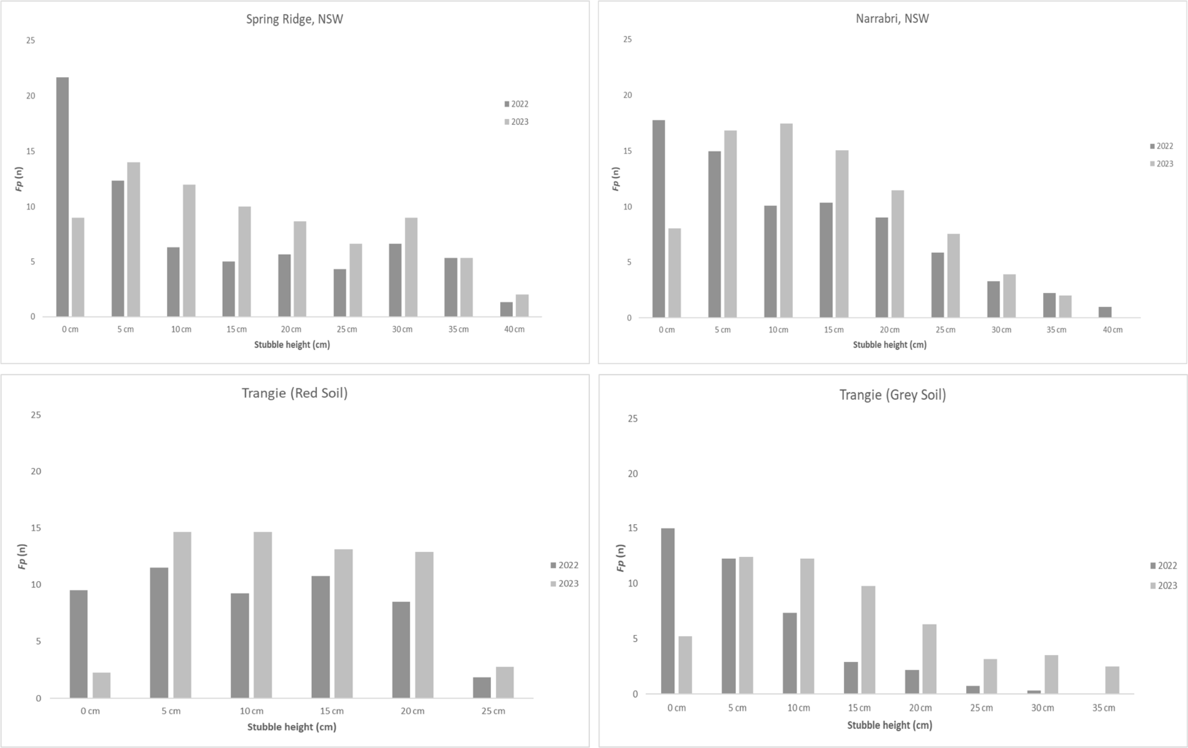


Figure 4. Preliminary data of the incidence of *Fp* recovery (*Fp* (n) being number of tillers producing *Fp* colonies) at 5 cm increments along the stubble length (stubble height, cm) at four different Northern Farming Systems experimental sites in northern NSW.

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.

References

Knight NL, Sutherland MW (2017) Assessment of *Fusarium pseudograminearum* and *F. culmorum* biomass in seedlings of potential host cereal species. Plant Disease 101:2116-2122.

Nelson KE, Burgess LW (1995) Effect of rotation with barley and oats on crown rot of wheat in the northern wheat belt of New South Wales. Australian Journal of Experimental Agriculture 35:765-770

Petronaitis T, Forknall C, Simpfendorfer S, Backhouse D and Flavel R (2022) Harvest height implications for Fusarium crown rot management. GRDC Update, online, 2 March 2022 https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/02/harvest-height-implications-for-fusarium-crown-rot-management

Petronaitis T, Forknall C, Simpfendorfer S, Backhouse D (2020) Stubble Olympics: the cereal pathogen 10cm sprint. GRDC Update, Goondiwindi, March 2020 https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2020/08/stubble-olympics-the-cereal-pathogen-10cm-sprint

Summerell BA and Burgess LW (1988) Stubble management practices and the survival of *Fusarium graminearum* Group 1 in wheat stubble residues. Australasian Plant Pathology, 17:88-93

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. Thanks also to the Grains Agronomy and Pathology Partnership (GRDC and NSW DPI) which co-funded part of this research through Dr Petronaitis' GAPP PhD scholarship.

Thanks also to Dr Cassy Percy for providing germplasm for the glasshouse experiment, and Branko Duric for providing stubble from the Northern Farming Systems project. Additional technical support provided by Nicole Dunn, Barbara Jones, Alana Roe, and Caroline Stewart is gratefully acknowledged.

Contact details

Toni Petronaitis
University of New England
Armidale, NSW 2351
Ph. 0424 209 816
Email: tonipetronaitis@gmail.com
Twitter: @ToniPetronaitis

ⓟ Varieties displaying this symbol are protected under the Plant Breeders Rights Act 1994.

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

Maurie Street[1], *Ben O'Brien*[1], *Rohan Brill*[2], *Steven Simpfendorfer*[3]

[1] Grain Orana Alliance
[2] Brill Ag
[3] NSW DPI, Tamworth

Key words

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

GRDC codes

GOA2006-001RTX
DPI2207-004RTX

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.
- BeckomΦ and LRPB FlankerΦ outyielded LRPB RaiderΦ and LRPB LancerΦ, but suffered greater yield loss from FCR. Despite this, under higher FCR pressure both BeckomΦ and LRPB FlankerΦ out yielded LRPB LancerΦ and LRPB RaiderΦ.
- 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.

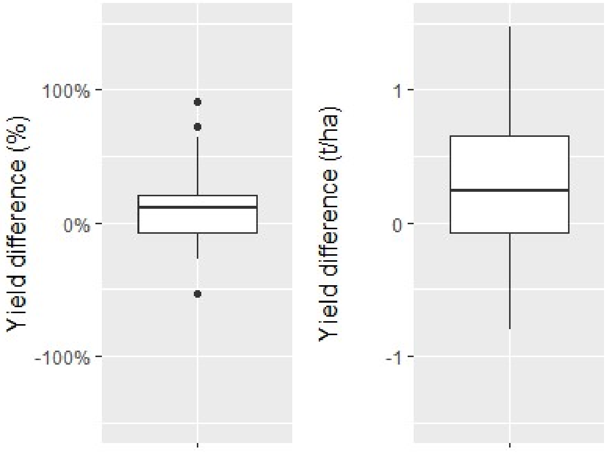


Figure 1. Yield difference % (left) and t/ha (right) moving from the lowest to the highest wheat population averaged across 5 trial years, 10 sites and 15 varieties.

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.

Beckomⓓ yielded the highest or equal highest across all sites. LRPB Flankerⓓ was the lowest yielding at Ganmain and Coonamble, LRPB Lancerⓓ and LRPB Raiderⓓ 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 Lancerⓓ) in at least three N and population scenarios. LRPB Flankerⓓ was the most affected by +FCR, with up to 0.94 t/ha yield loss in similar plant population and N nutrition scenarios. Beckomⓓ and LRPB Raiderⓓ were less affected with up to 0.56 t/ha yield loss. LRPB Lancerⓓ 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 Flankerⓓ and Beckomⓓ 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
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
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
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		
Beckom	+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
Flanker	+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
Lancer	+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
Raider	+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): Beckomⓓ -N, LRPB Flankerⓓ -N, and LRPB Raiderⓓ +N. LRPB Flankerⓓ +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). Beckomⓓ and LRPB Flankerⓓ were affected more than LRPB Lancerⓓ and LRPB Raiderⓓ by +FCR. Screenings in LRPB Flankerⓓ 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
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
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
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		
Beckom	+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
Flanker	+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
Lancer	+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
Raider	+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 Lancerⓟ, however LRPB Raiderⓟ and LRPB Flankerⓟ yield was lower at moderate populations when FCR pressure was increased, but there was no impact at higher populations regardless of N. Beckomⓟ yield was reduced under +N and high population. Screenings increased with +FCR for all but 2 comparisons: LRPB Lancerⓟ -N at both moderate and high plant population.

Table 8. Impact of FCR pressure on yield and screenings of various combinations of wheat varietiy (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		
Beckom	+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
Flanker	+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
Lancer	+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
Raider	+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 Flankerⓓ responded in all 4 population comparisons, +/- N and +/- FCR. Beckomⓓ responded in two comparisons, both +N and +/- FCR, as did LRPB Lancerⓓ for the -N treatment. LRPB Raiderⓓ 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 Beckomⓓ 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)				Δ Yield (t/ha)	Screenings (%)				Δ SCN (%)
			Moderate population		High population			Moderate population		High population		
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
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
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
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.

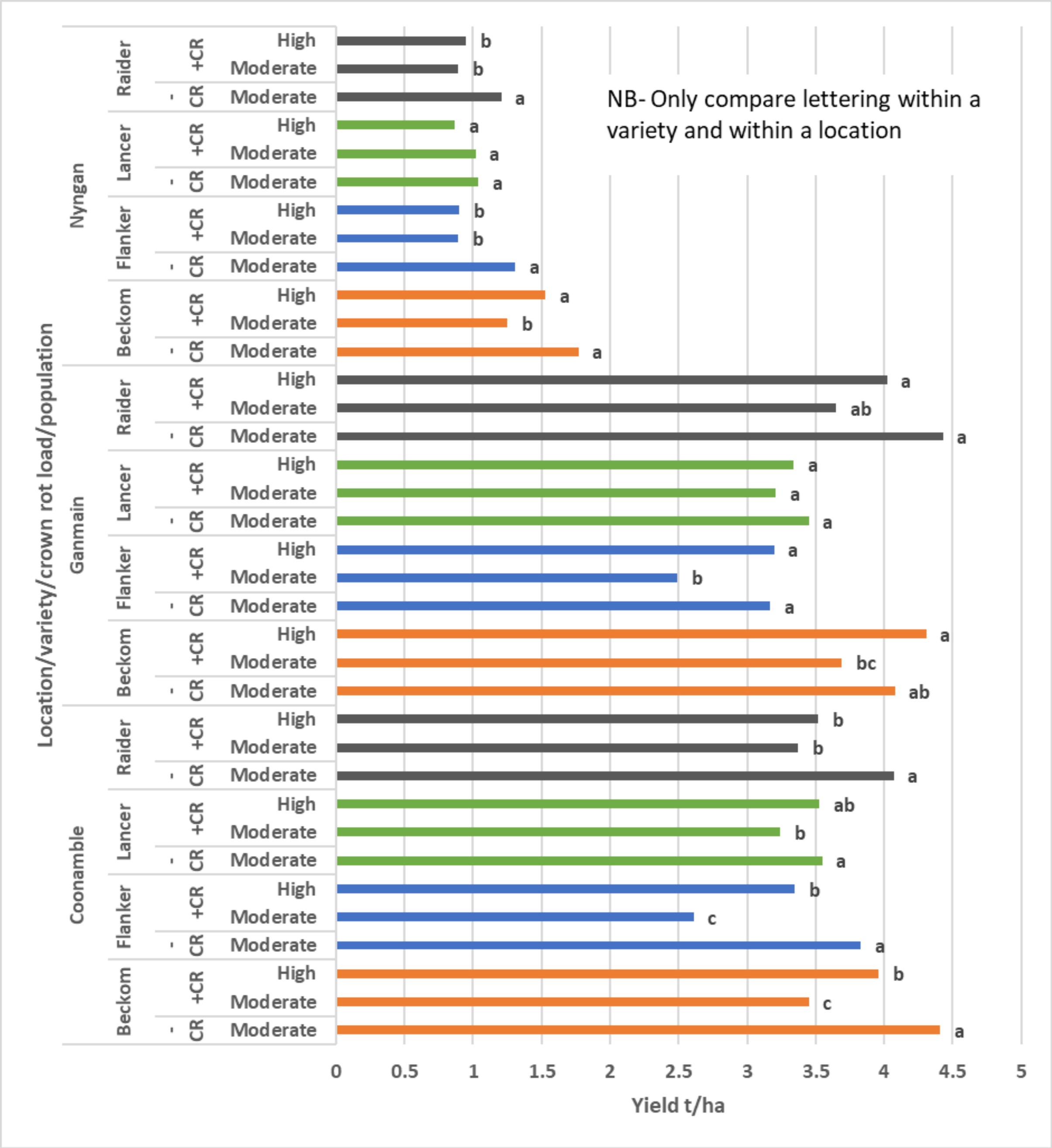


Figure 2. Impact of increased plant population at high and low FCR pressure, and high nitrogen on yield of various varieties at Nyngan, Coonamble and Ganmain, 2023.

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. Beckomɸ and LRPB Flankerɸ had the greatest yield reductions from FCR compared to LRPB Lancerɸ and LRPB Raiderɸ, however in many cases Beckomɸ and LRPB Flankerɸ, 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.

Acknowledgements

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

Contact details

Maurie Street
Grain Orana Alliance
PO Box Dubbo NSW 2830
Ph: 0400 066 201
Email: Maurie.street@grainorana.com.au

Ben O’Brien
Grain Orana Alliance
Ph:0409 697 860
Email: Ben Obrien@grainorana.com.au

Rohan Brill
Brill Ag
Ph:0488 250 489
Email: rohan@brillag.com.au

Steven Simpfendorfer
NSW DPI- Tamworth
Ph:0439 581 672
Email: steven.simpfendorfer@dpi.nsw.gov.au

® Registered trademark
ɸ Varieties displaying this symbol are protected under the Plant Breeders Rights Act 1994.

The long and the short of it: How longer hypocotyls could improve canola establishment

Matthew Nelson[1]*, Jane Brownlee*[1]*, Mark Cmiel*[2]*, Andrew Fletcher*[1]*, Natalie Fletcher*[1]*, Trijntje Hughes*[2]*, John Kirkegaard*[2]*, Kenton Porker*[3]*, Karen Treble*[1]*, Kelley Whisson*[1]*, and Greg Rebetzke*[2]

[1]CSIRO Agriculture and Food, Floreat, Perth
[2]CSIRO Agriculture and Food, Black Mountain, Canberra
[3]CSIRO Agriculture and Food, Waite Campus, Adelaide

Key words

canola establishment, long hypocotyls, deep sowing, genetic improvement, Brassica napus

GRDC codes

CSP1907-001RTX, CSP2307-002RTX

Take home message

- The hypocotyl is the elongating stem between the root and cotyledons of canola seedlings
- Long hypocotyls are associated with better emergence of canola from deep sowing (50 mm)
- All Australian varieties have short-to-medium length hypocotyls, while several overseas varieties have been identified with long hypocotyls
- Long hypocotyl genes from overseas varieties are being incorporated into Australian canola varieties to improve establishment in deeper sown crops.

Aims

7. To incorporate long hypocotyl genes from overseas varieties into locally adapted germplasm
8. To confirm these genes improve establishment of Australian canola
9. To provide improved germplasm and molecular markers to canola breeders.

Introduction

Canola (*Brassica napus* L.) production provided on average $4.1 billion per annum to the Australian economy over the last five years, making it Australia's second most valuable crop (ABARES, 2023). Canola underpins the production of other important crops through its function as an important break crop in cereal-based rotations by breaking disease cycles and enabling the control of weeds.

One of the major challenges with canola is unreliable establishment (50% of germinable seeds establish on average; McMaster *et al.*, 2019), which increases seed cost, and can reduce yield potential, increase weed-management requirements, and in extreme cases requires costly resowing. The direct and indirect costs of poor establishment to Australian growers can be conservatively estimated at between $100M–$200M annually. This problem is expected to worsen under a changing climate and with sowing into more marginal (hotter, drier) conditions.

Between 2019 and 2023, CSIRO and GRDC co-invested in a four-year research project (CSP1907-001RTX) to improve the genetics of canola establishment. After consultation with industry and reviewing the international scientific literature (Nelson *et al.*, 2022a,b), long hypocotyls and early vigour (that is, fast and strong growth from germination through to around the four-leaf stage) were identified as critical targets for genetic improvement of canola establishment (Figure 1). Multiple lab- and field-based experiments were used to search for genetic diversity for these traits and to test their impact on canola establishment (Nelson *et al.*, 2023). Among a diverse set of 255 open-pollinated canola varieties (comprising 101 historic Australian varieties and 154 overseas varieties) and 28 current Australian (mainly hybrid) varieties, it was discovered that current and historic Australian varieties all have short- to medium-length hypocotyls when screened using efficient and repeatable lab-based assays. The longest hypocotyl varieties all came from the major canola growing regions overseas (Nelson *et al.,* 2023).

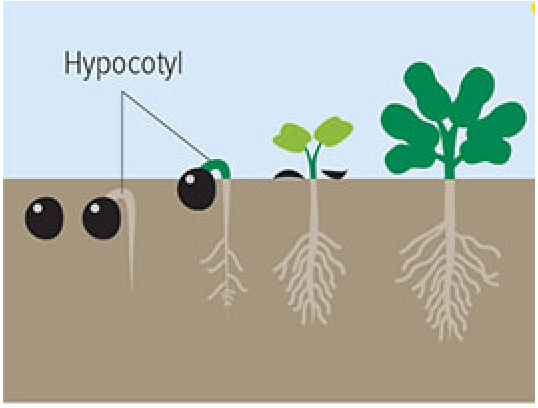


Figure 1. Schematic of early growth stages of canola seed with hypocotyl indicated. Image adapted from GRDC GroundCover (https://groundcover.grdc.com.au/crops/oilseeds/canola-establishment-under-the-scope)

A subset of 20 contrasting varieties plus five current Australian varieties were then evaluated for field emergence and establishment from conventional (20 mm) and deep (50 mm) sowing in eight field experiments in NSW and WA in 2021 and 2022. Results showed the long hypocotyls identified in the lab were associated with improved emergence when canola was sown deep (Figure 2). It was also determined that hypocotyl length is controlled by several genes in contrast to the long coleoptile trait in wheat, which is controlled chiefly by one gene (Rebetzke *et al.,* 2007).

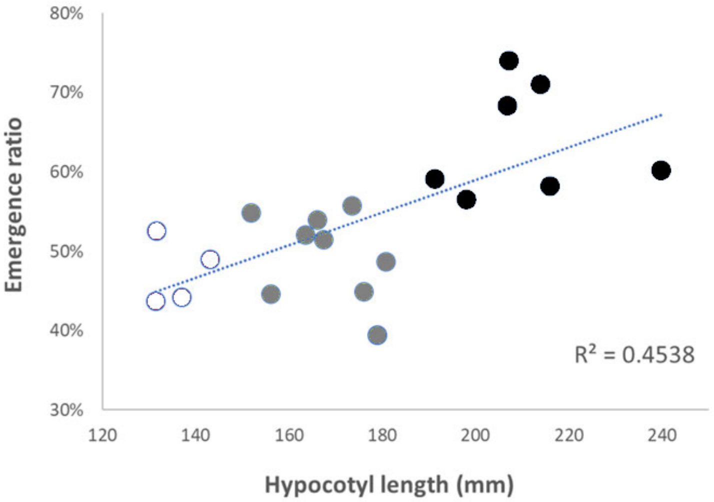


Figure 2. The close relationship between hypocotyl length measured in controlled lab conditions and effective field emergence from deep (50 mm) relative to conventional (20 mm) sowing depths for 20 international varieties averaged across seven field experiments in NSW and WA in 2021 and 2022. White circles denote historic Australian varieties with short hypocotyls, grey circles denote overseas varieties with intermediate hypocotyl lengths, and black circles denote long hypocotyl overseas varieties.

Based on these positive results, in 2023 CSIRO and GRDC co-invested in a second phase of research through a five-year project (CSP2307-002RTX) that aims to transfer the long hypocotyl trait from overseas varieties into Australian varieties using rapid generation breeding, and to confirm the value of long hypocotyls for improving canola establishment. The project will provide long hypocotyl germplasm along with efficient selection tools to commercial breeding programs to develop the next generation of canola varieties with improved establishment. Below is an overview of the strategy to introduce the long hypocotyl trait into Australian canola.

Experimental approach

Selecting parents for crossing

From the previous lab-based screening of 255 open-pollinated varieties the longest hypocotyl varieties (between 206.4 – 240.0 mm in length) were from Canada, Czechia, France, Germany, Portugal, Japan, and the UK. Genetic analysis revealed that these 12 varieties represented four distinct genetic groupings so one variety from each of the four genetic groupings was selected to maximise the diversity of, and increase the likelihood of success in selecting, long hypocotyl genes (Figure 3). For the Australian canola crossing parents, two varieties were selected with short hypocotyls (to provide a contrast to the long hypocotyl donors) with high levels of early vigour. It had previously been discovered that the long hypocotyl trait was most effective in enabling emergence from deep sowing when combined with early vigour (Nelson *et al.,* 2023).

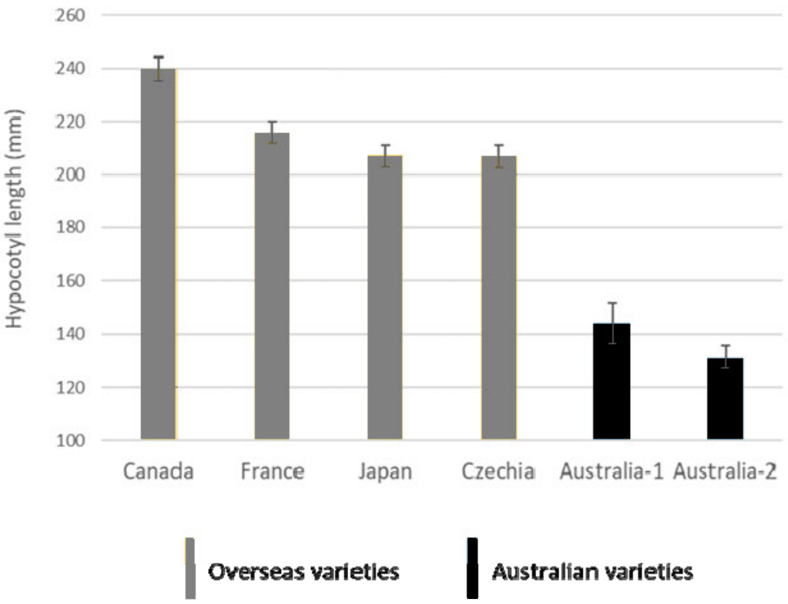


Figure 3. Hypocotyl length of four overseas canola varieties (grey bars) selected as long hypocotyl trait donors to two vigorous Australian varieties (black bars). Error bars denote standard error of each variety mean.

Crossing strategy

Due to the poor adaptation of overseas varieties to Australian growing environments, two phases of population development were designed with the aim of producing breeding lines containing the long hypocotyl trait together with local Australian adaptation and quality:

1. Introgression of long hypocotyl genes into Australian varieties through a backcrossing approach (2023 – 2026). This will involve crossing each of the four long hypocotyl donors to an Australian variety three times (while selecting for the long hypocotyl trait) followed by single seed descent for four further generations to produce 200 BC2S4 individuals per population. Rapid generation cycling methods will enable these populations to be produced within three years. The

populations will be used for genetic mapping and molecular marker development for the long hypocotyl trait.

2. Using the best individuals and the markers developed from Phase-1 population development, long hypocotyl alleles will be pyramided from the four donor sources into Australian varieties to create long hypocotyl ‘super-donors’. These will be provided to breeding companies to incorporate into their breeding programs. This process will take a further two years (2026 – 2028).

Field validation of long hypocotyl lines

The crossing activities described above will produce Australian-adapted lines incorporating long hypocotyl genes from overseas varieties. We will then confirm the effectiveness of the long hypocotyl trait for improving emergence, establishment, and final grain yield. This will involve two distinct experimental approaches during the 2026/27 and 2027/28 growing seasons:

3. Single row-based evaluation of contrasting population ‘tails’ (that is, genetically related material with contrasting long versus short hypocotyls). These carefully managed, hand-sown experiments will be undertaken at six sites across NSW, SA, and WA with the primary aim of confirming the effectiveness of the long hypocotyl trait for improved emergence and establishment from conventional (20 mm) and deep (50 mm) sowing depths. Figure 4 gives an impression of the precise, manually-intensive nature of this approach using images taken during similar experiments in the previous project.

4. Plot-based evaluation of the same contrasting population tails in cooperation with canola breeding companies targeting a minimum of eight sites per year. Some experiments will be located at NVT sites to facilitate their dual use as grower demonstration plots. The plots will be assessed for emergence, establishment, and vigour, and will be the first opportunity to measure the effect of the long hypocotyl trait on grain yield.

Figure 4. Illustrative images from single-row establishment experiments carried out at the Boorowa Agricultural Research Station in 2021 and 2022. Each seed was placed carefully in a specified position at 20mm or 50 mm depth, and then monitored closely until the fourth leaf stage. Photo: John Kirkegaard

Summing-up

In the previous project, overseas canola varieties with long hypocotyls were identified and were able to emerge better from deep sowing than any Australian variety tested. In this project, these long hypocotyl genes will be transferred into Australian varieties using rapid generation breeding, their value for improving canola establishment assessed, and then determine if the long hypocotyl trait influences final grain yield. The project will provide long hypocotyl germplasm along with efficient selection tools to commercial breeding programs thereby enabling the development of the next generation of canola varieties with improved establishment potential.

References

ABARES (2023) Agricultural Commodities report, December 2023

McMaster C, Stevenson A, Menz I (2019) Canola establishment across central NSW. Proceedings GRDC Grains Research Update, Wagga Wagga, February 2019, pp. 229-234.

Nelson MN, Nesi N, Barrero JM, Fletcher AL, Greaves IK, Hughes T, Laperche A, Snowdon R, Rebetzke GJ, Kirkegaard JA (2022a) Strategies to improve field establishment of canola: a review. Advances in Agronomy 175:133-177

Nelson M, Barrero J, Cmiel M, Fletcher A, Greaves I, Hughes T, Toovey A, Treble K, Zwart A, Kirkegaard J, Rebetzke G (2022b) Genetic improvement of canola establishment. GRDC Research Updates, https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/02/genetic-improvement-of-canola-establishment

Nelson M, Barrero J, Cmiel M, Fletcher A, Greaves I, Hughes T, Toovey A, Treble K, Zwart A, Kirkegaard J, Rebetzke G (2023) New genetics for improved canola establishment. GRDC Research Updates, https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2023/02/new-genetics-for-improved-canola-establishment

Rebetzke GJ, Richards RA, Fettell NA, Long M, Condon AG, Forrester RI, Botwright TL (2007) Genotypic increases in coleoptile length improves stand establishment, vigour and grain yield of deep-sown wheat. Field Crops Research 100:10-23

Acknowledgements

The research undertaken as part of these projects is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support. We thank CSIRO colleagues from CSIRO/GRDC canola phenology project (CSP1901-002RTX) for providing seedlots and genetic information for the panel of 255 diverse international varieties. We also thank the canola breeding companies for providing seeds of current varieties and ongoing engagement with the new project (CSP2307-002RTX). We thank Kalyx, Living Farm and the Boorowa Agricultural Research Station staff for assisting in setting up and/or monitoring field experiments in the previous project (CSP1907-001RTX).

Contact details

Dr. Matthew Nelson
CSIRO Agriculture and Food
Floreat Laboratories
147 Underwood Avenue, Floreat, Perth WA 6014
Ph: 0490 139 509
Email: matthew.nelson@csiro.au
Twitter: @Matthew67636066

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

James Maino[1], Adriana Arturi[1], Luis Mata[1], Aston Arthur[1], Xuan Cheng[1], Svetlana Micic[2], Alan Lord[2], Lizzy Lowe[1], James Ridsdill-Smith[3], Celia Pavri[3], Paul Umina[1]

[1] Cesar Australia, Melbourne, Victoria
[2] Department of Primary Industries and Regional Development, Western Australia
[3] CSIRO, Floreat, Western Australia

Key words

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

GRDC code

CES2010-001RTX

Take home message

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

Background

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

In this update, we will:

5. present data on the current resistance status of RLEM in Australia;
6. present the new seasonal risk tool for RLEM and other pests in canola;
7. demonstrate the new RLEM hatch timing tool; and
8. present research on updating the TimeRite® strategy.

The current resistance status of RLEM in Australia

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

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

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

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

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

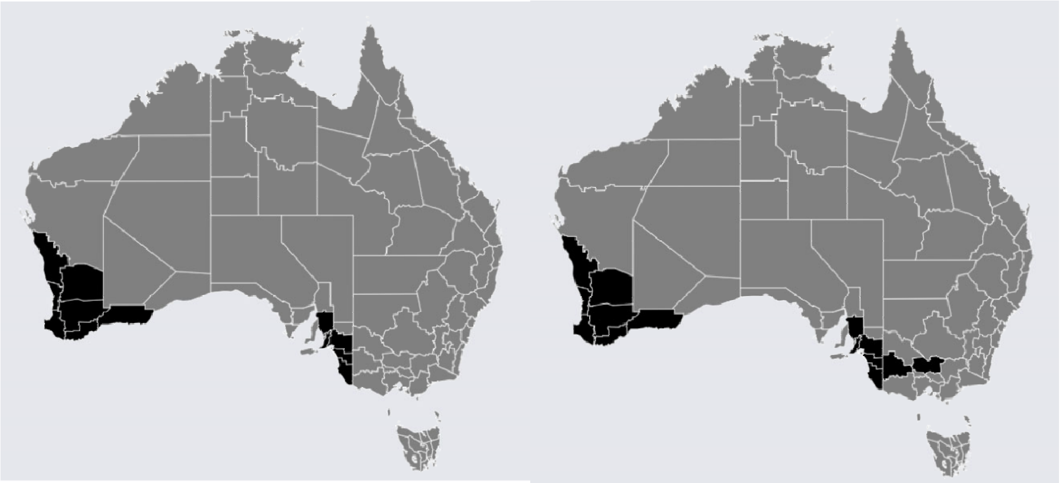


Figure 1. The current distribution of RLEM resistance to pyrethroids (left) and organophosphates (right). Regions with known resistant populations are shown in black.

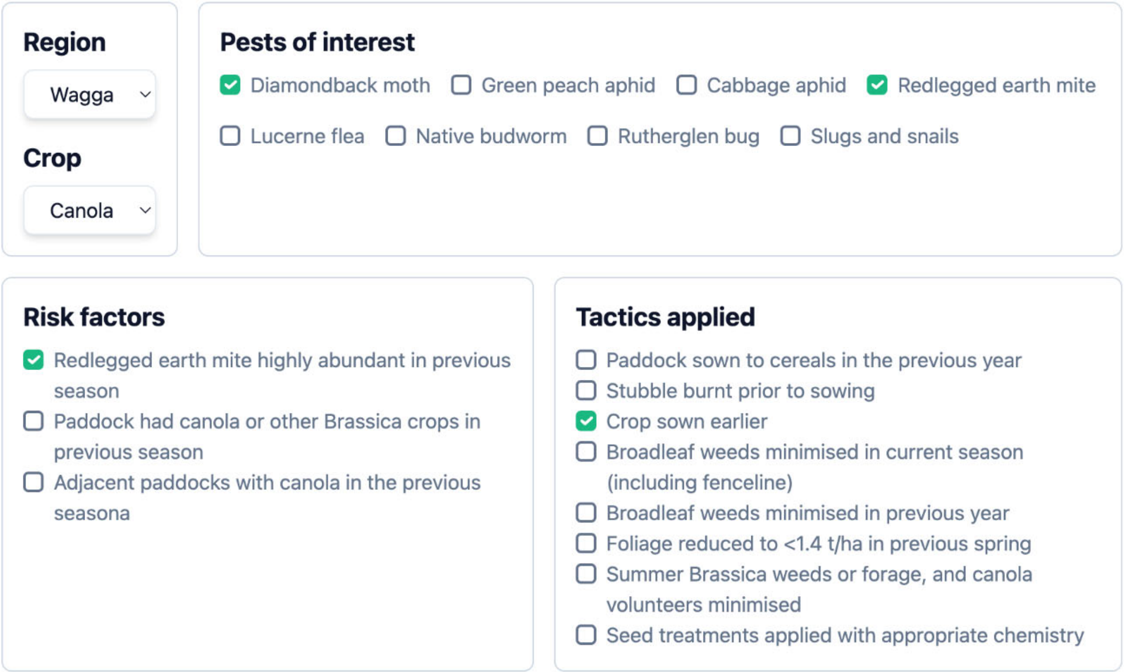
Seasonal risk tool for RLEM and other pests in canola

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

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

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

8. Known resistance issues and beneficial toxicity information are summarised for each pesticide option



Region

Wagga

Crop

Canola

Pests of interest

☑ Diamondback moth ☐ Green peach aphid ☐ Cabbage aphid ☑ Redlegged earth mite

☐ Lucerne flea ☐ Native budworm ☐ Rutherglen bug ☐ Slugs and snails

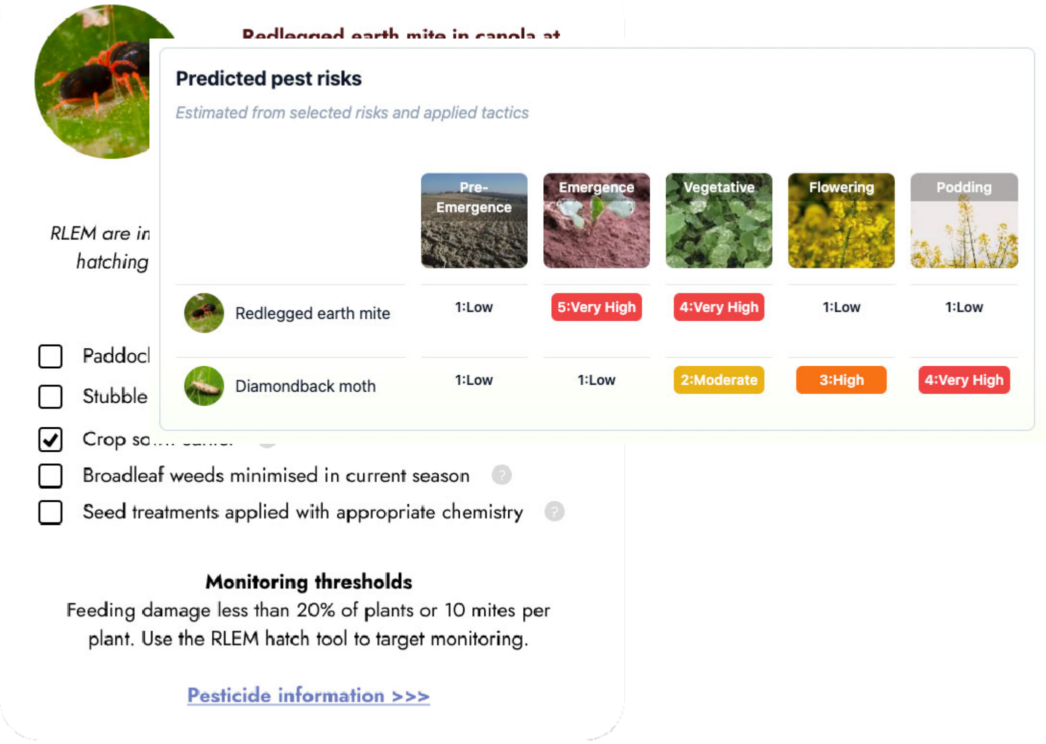
Risk factors

☑ Redlegged earth mite highly abundant in previous season
☐ Paddock had canola or other Brassica crops in previous season
☐ Adjacent paddocks with canola in the previous seasona

Tactics applied

☐ Paddock sown to cereals in the previous year
☐ Stubble burnt prior to sowing
☑ Crop sown earlier
☐ Broadleaf weeds minimised in current season (including fenceline)
☐ Broadleaf weeds minimised in previous year
☐ Foliage reduced to <1.4 t/ha in previous spring
☐ Summer Brassica weeds or forage, and canola volunteers minimised
☐ Seed treatments applied with appropriate chemistry

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



Predicted pest risks

Estimated from selected risks and applied tactics

	Pre-Emergence	Emergence	Vegetative	Flowering	Podding
Redlegged earth mite	1:Low	5:Very High	4:Very High	1:Low	1:Low
Diamondback moth	1:Low	1:Low	2:Moderate	3:High	4:Very High

RLEM are in
hatching

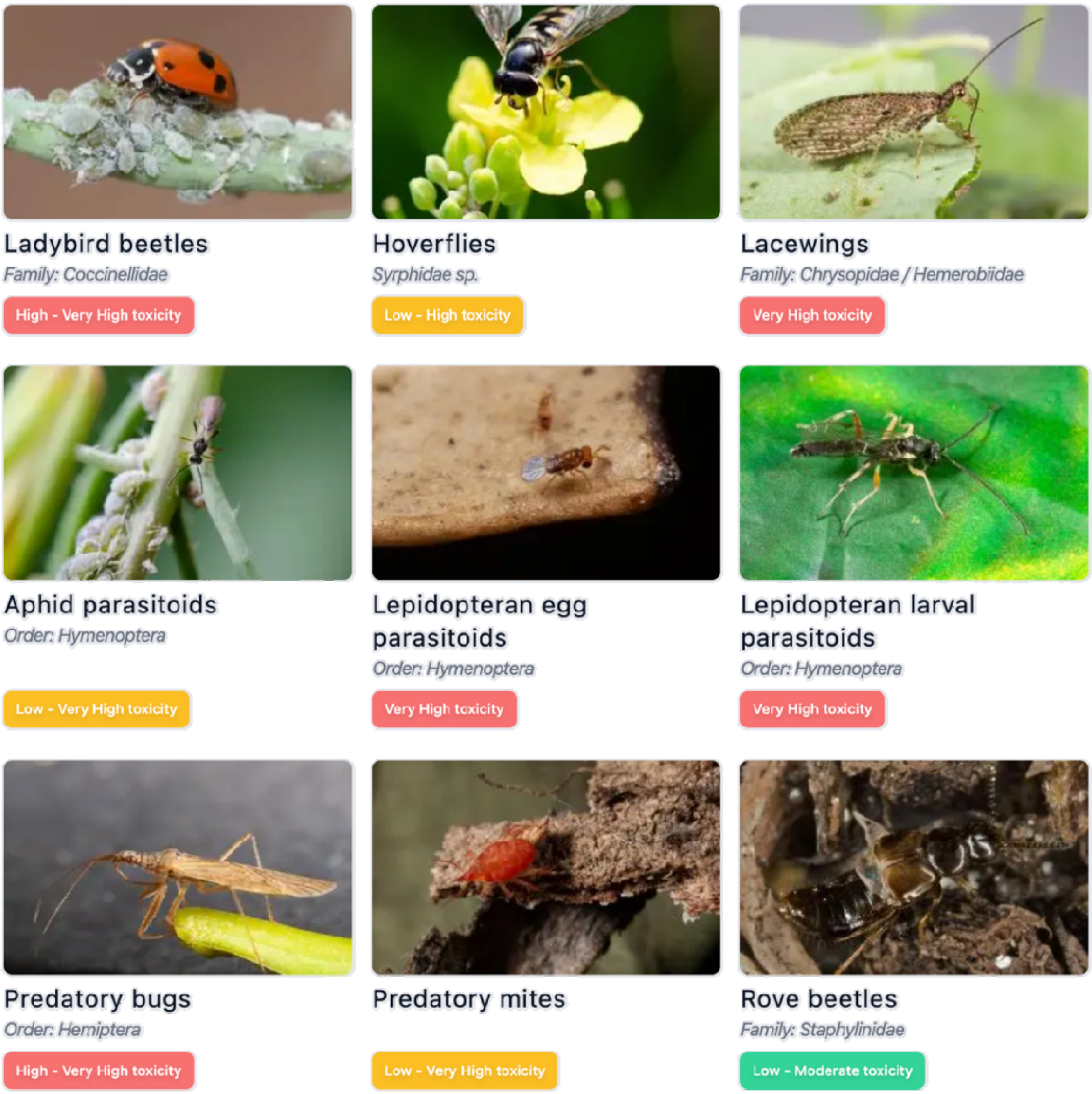
☐ Paddocl
☐ Stubble
☑ Crop so
☐ Broadleaf weeds minimised in current season
☐ Seed treatments applied with appropriate chemistry

Monitoring thresholds

Feeding damage less than 20% of plants or 10 mites per plant. Use the RLEM hatch tool to target monitoring.

Pesticide information >>>

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



Ladybird beetles
Family: Coccinellidae
High - Very High toxicity

Hoverflies
Syrphidae sp.
Low - High toxicity

Lacewings
Family: Chrysopidae / Hemerobiidae
Very High toxicity

Aphid parasitoids
Order: Hymenoptera
Low - Very High toxicity

Lepidopteran egg parasitoids
Order: Hymenoptera
Very High toxicity

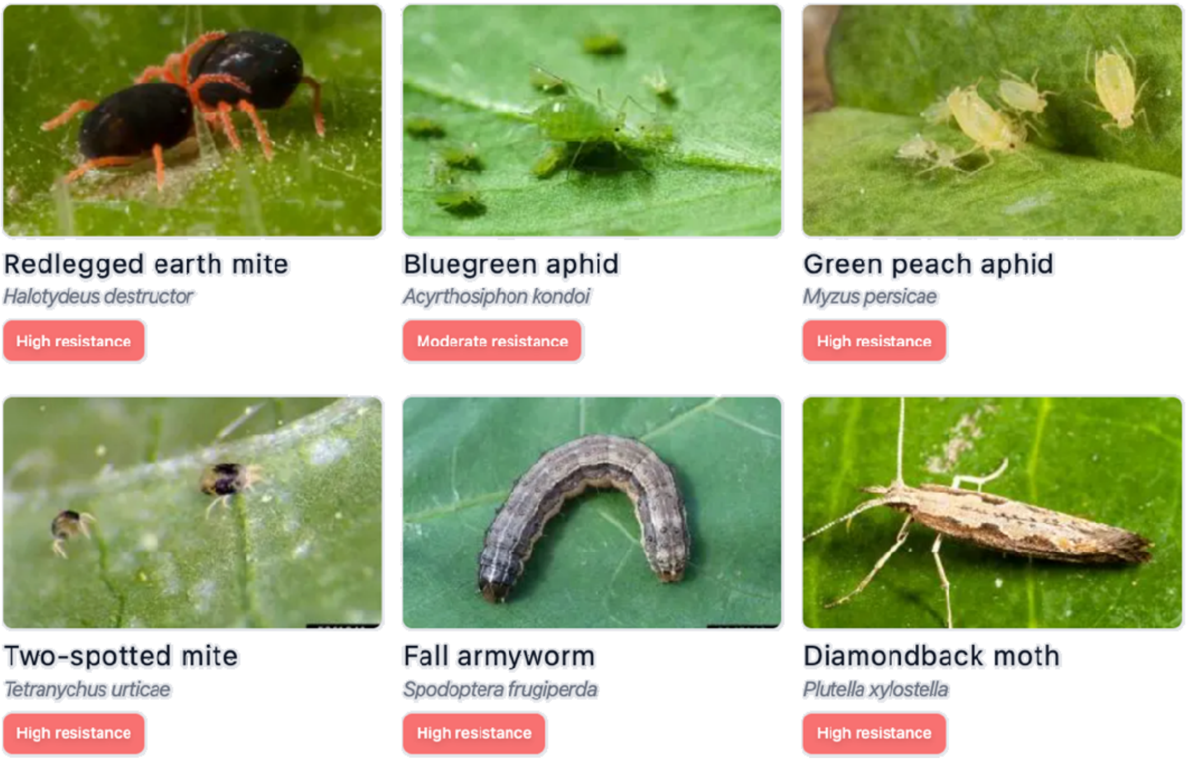
Lepidopteran larval parasitoids
Order: Hymenoptera
Very High toxicity

Predatory bugs
Order: Hemiptera
High - Very High toxicity

Predatory mites
Low - Very High toxicity

Rove beetles
Family: Staphylinidae
Low - Moderate toxicity

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


Redlegged earth mite
Halotydeus destructor
High resistance

Bluegreen aphid
Acyrthosiphon kondoi
Moderate resistance

Green peach aphid
Myzus persicae
High resistance

Two-spotted mite
Tetranychus urticae
High resistance

Fall armyworm
Spodoptera frugiperda
High resistance

Diamondback moth
Plutella xylostella
High resistance

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

RLEM hatch timing tool

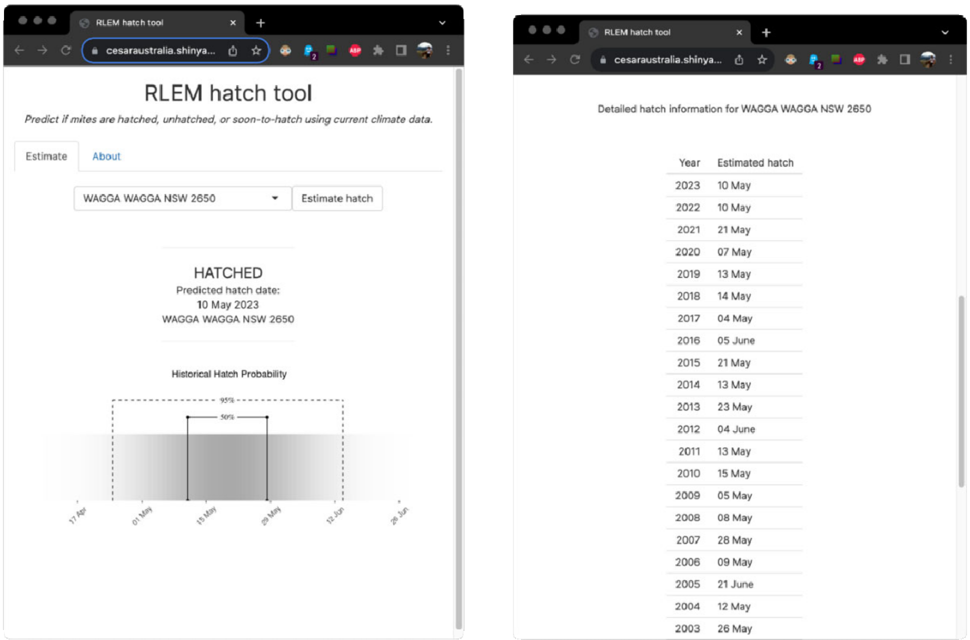
The ability to predict when RLEM eggs will hatch can help growers understand crop risk during the autumn period and optimise monitoring for RLEM pressure at crop emergence. We developed a tool that predicts the hatch status (unhatched, soon-to-hatch, and hatched) of RLEM. The tool also provides historical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

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

The model was validated against field collected mites and available data from the literature. Comparison of the observed hatch dates with predicted hatch dates revealed that the model error was no more than 15 days across all samples, with a mean error (and standard error) of -4.68 (4.03) days. The tool was successful in predicting mite activity before the most economically injurious life stage (i.e., the adult phase), which should allow sufficient time for intervention where necessary.

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

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



RLEM hatch tool

Predict if mites are hatched, unhatched, or soon-to-hatch using current climate data.

WAGGA WAGGA NSW 2650

HATCHED
Predicted hatch date:
10 May 2023
WAGGA WAGGA NSW 2650

Historical Hatch Probability

Detailed hatch information for WAGGA WAGGA NSW 2650

Year	Estimated hatch
2023	10 May
2022	10 May
2021	21 May
2020	07 May
2019	13 May
2018	14 May
2017	04 May
2016	05 June
2015	21 May
2014	13 May
2013	23 May
2012	04 June
2011	13 May
2010	15 May
2009	05 May
2008	08 May
2007	28 May
2006	09 May
2005	21 June
2004	12 May
2003	26 May

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

Updating the TimeRite® strategy

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

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

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

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

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

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

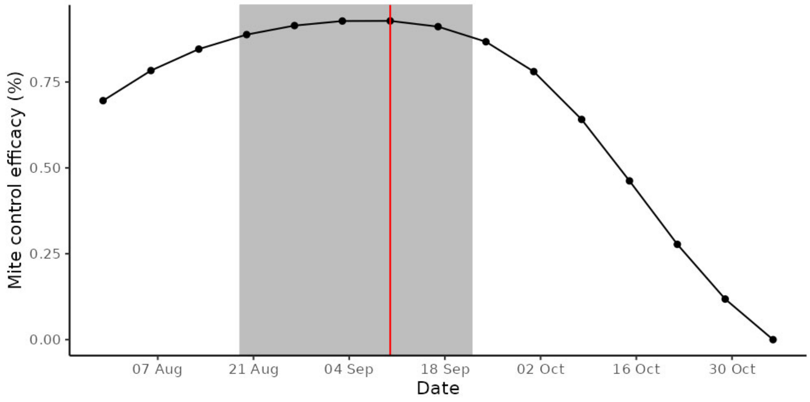


Figure 7. Updated TimeRite estimate for Wagga Wagga, NSW predicts an earlier date for optimal control timing of 7th September compared with original TimeRite date of 29th September. The vertical line denotes the optimal control date, while the grey region denotes the period where efficacy remains at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

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

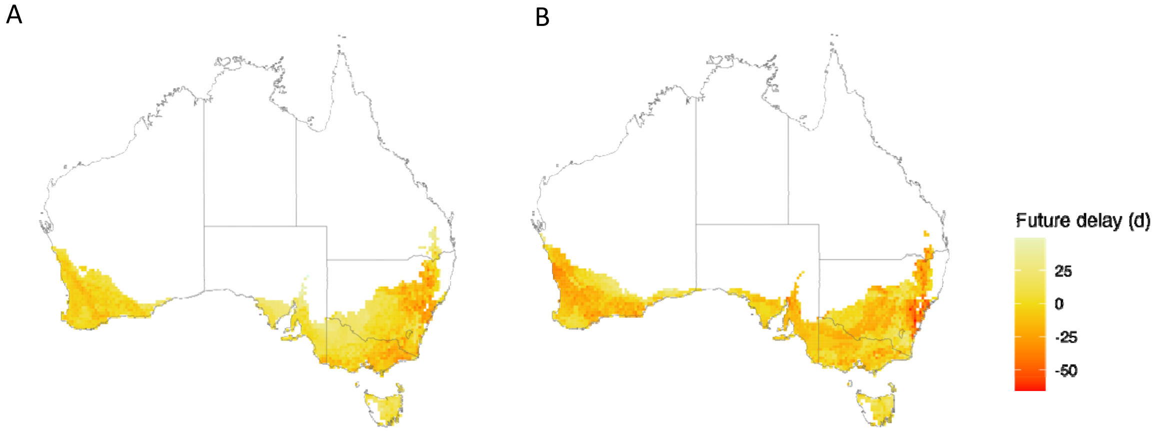


Figure 8. Predicted shifts in the point of 90% diapause by 2050 under the SSP245 warming scenario (A) and the more extreme SSP585 scenario (B). The shaded regions show the estimated delay in a population reaching 90% diapause. A positive delay represents diapause occurring later in the year relative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

Conclusion

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

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

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support. The authors would also like to acknowledge support from AWI, MLA, AgriFutures, DPIRD, and the CSIRO.

References

Arthur AL, Maino J, Hoffmann AA, et al (2021) Learnings from over a decade of increasing pesticide resistance in the redlegged earth mite, *Halotydeus destructor* Tucker. Pest Manag Sci 77:3013–3024. https://doi.org/https://doi.org/10.1002/ps.6340

McDonald G, Umina PA, Macfadyen S, et al (2015) Predicting the timing of first generation egg hatch for the pest redlegged earth mite *Halotydeus destructor* (Acari: Penthaleidae). Exp Appl Acarol 65:259–276. https://doi.org/10.1007/s10493-014-9876-x

Contact details

Dr James Maino
Senior Scientist, Cesar Australia
95 Albert St, Brunswick, VIC 3052
Ph: 03 9349 4723
Email: jmaino@cesaraustralia.com

Dr Luis Mata
Research Team Lead, Cesar Australia
95 Albert St, Brunswick, VIC 3052
Ph: 03 9349 4723
Email: lmata@cesaraustralia.com

® Registered trademark

Sensors, automation, data and Ag Tech case study: using lidar technology to reduce waterlogging

Jay Carrol, Civil Ag Design

Contact details

Jay Carrol
Civil Ag Design
Email: jay@cad.ag

Notes

Comparing the effect of weed seed impact mills on the weed seed bank

Ben White, Kondinin & John Broster, CSU

Contact details

Ben White
Kondinin Group
Email: ben@kondinin.com.au

John Broster
Charles Sturt University, Waga Wagga
Mobile: 0457 272 075
Email: jbroster@csu.edu.au

Notes

Notes

Concurrent session: Weeds

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

Michael Walsh, Gulbali Institute, Charles Sturt University, Wagga Wagga

Key words

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.

Acknowledgements

The author would like to thank the Australian-American Fulbright commission for the opportunity and support to undertake a six-month scholarship. I would also like to thank the host institutions, Kansas State University and Texas A&M for their support during the three months that I spent at each institution.

References

Dayan FE, Rimando AM, Pan Z, Baerson SR, Gimsing AL, Duke SO (2010) Sorgoleone. Phytochemistry 71, 1032-1039.

Duke SO (2015) Proving allelopathy in crop–weed interactions. Weed Science 63, 121-132.

Kong CH, Chen XH, Hu F, Zhang SZ (2011) Breeding of commercially acceptable allelopathic rice cultivars in China. Pest Management Science 67, 1100-1106.

Schreier H, Bish M, Bradley KW (2022) The impact of electrocution treatments on weed control and weed seed viability in soybean. Weed Technology 36, 481-489.

Contact details

Michael Walsh
Gulbali Institute for Agriculture, Water and Environment
Charles Sturt University
Wagga Wagga
Ph: 0448 847 272

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

Christopher Preston[1]*, Jenna Malone*[1]*, Patricia Adu-Yeboah*[1]*, Michael Widderick*[2]*,*
Navneet Aggarwal[3]

[1] University of Adelaide
[2] Queensland Government Department of Agriculture, Fisheries and Forestry
[3] South Australian Research and Development Institute

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).

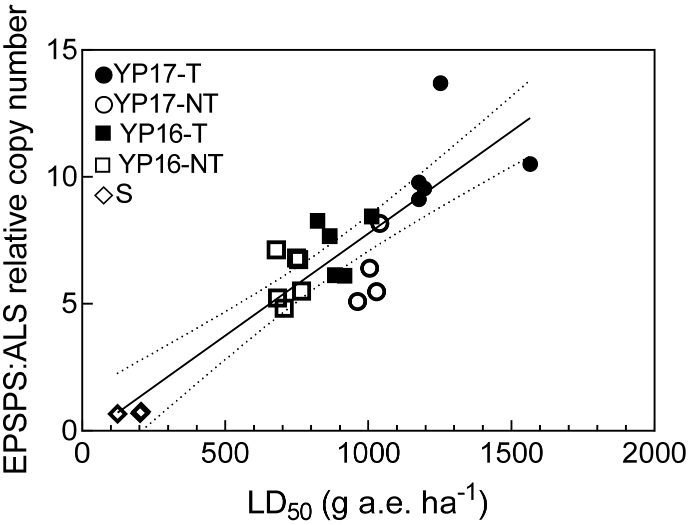


Figure 1. Increase of LD_{50} and EPSPS gene copy number in the progeny of glyphosate-resistant barley grass clones from 2 populations treated or not treated with glyphosate. Individual plants were divided into 2 clones. One clone from each individual was treated with 405 g ha^{-1} glyphosate and the 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 (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.

Acknowledgements

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

The trial at Gawler was funded by the South Australian Drought Resilience Adoption and Innovation Hub funded by the Department of Agriculture, Fisheries and Forestry through the Future Drought Fund. The trial was conducted in collaboration with Elders.

Contact details

Chris Preston
School of Agriculture, Food & Wine
University of Adelaide
Ph: 0488 404 120
Email: christopher.preston@adelaide.edu.au

® Registered trademark

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

John Broster[1], Allison Chambers[1], Michael Widderick[2]

[1] Gulbali Institute, Charles Sturt University, Wagga Wagga, NSW
[2] Queensland Department of Agriculture and Fisheries, Toowoomba, QLD

Key words

herbicide resistance, ryegrass, wild oats, sowthistle

GRDC code

UCS2008-001

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.

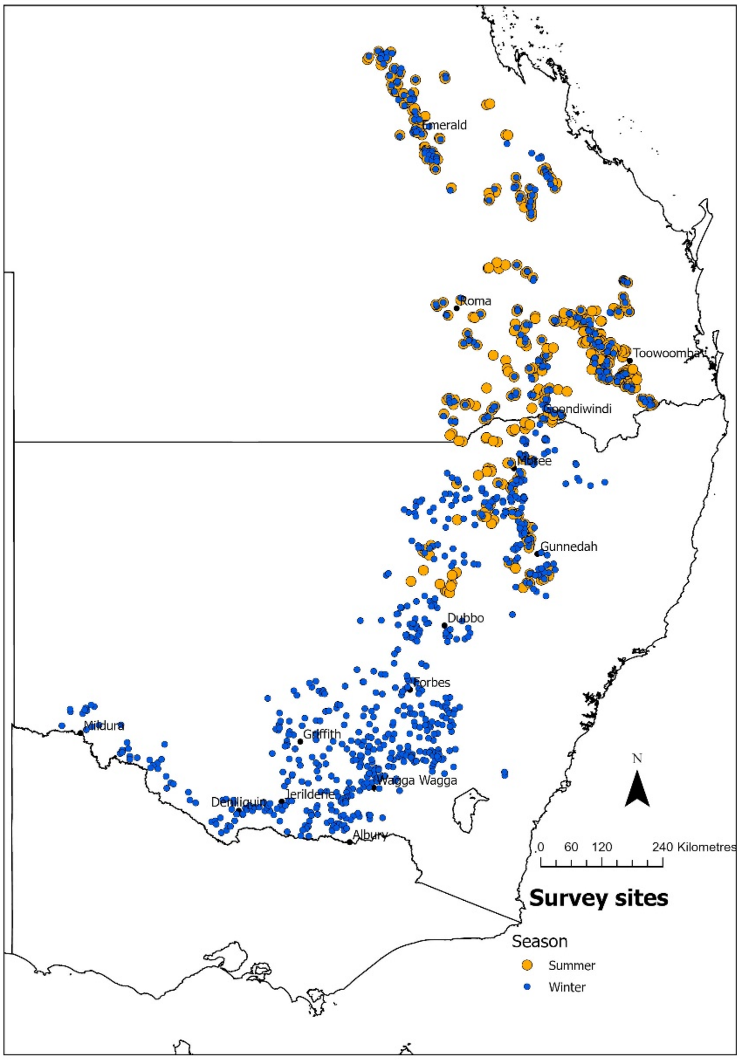


Figure 1. Winter and summer survey sites

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).

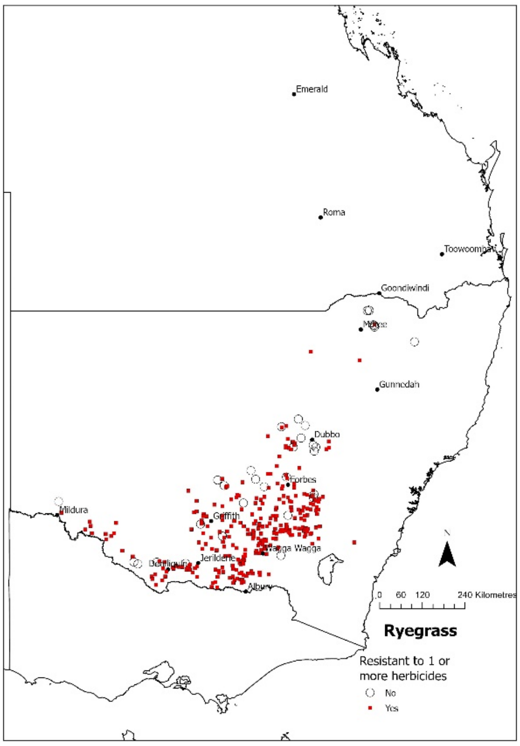


Figure 2. Ryegrass populations susceptible to all tested herbicides (open circles) or resistant to one or more herbicides (red/darker squares)

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.

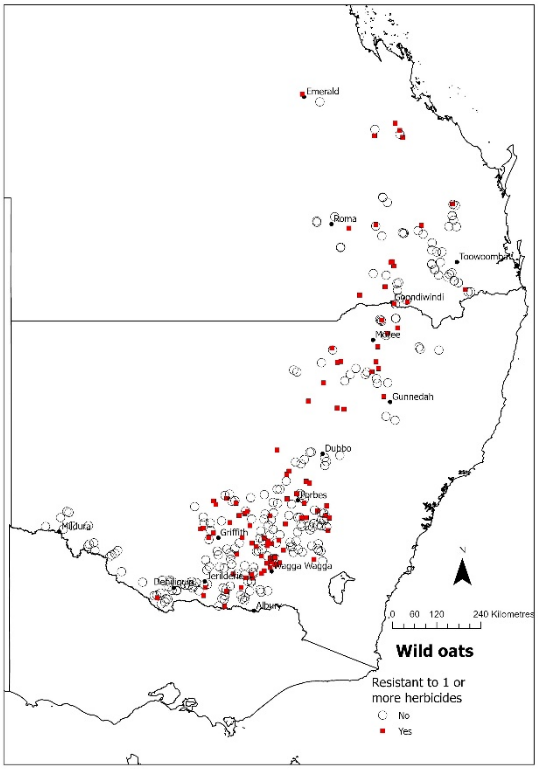


Figure 3. Wild oat populations susceptible to all tested herbicides (open circles) or resistant to one or more herbicides (red/darker squares)

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.

References

Boutsalis P, Kleemann SGL, Gill GS, Preston C (2014) A hidden threat: widespread Group B herbicide resistance in brome across south-eastern Australia. In 'Proceedings of the 19th Australasian Weeds Conference' (Ed. M Baker) pp. 202-205. (Tasmanian Weed Society: Hobart, Tasmania, Australia).

Broster JC, Chambers AJ, Jalaludin A, Widderick MJ, Walsh MJ (2018) The extent of herbicide resistance in ryegrass and wild oats in New South Wales and Queensland. In 'Proceedings of the 21st Australasian Weeds Conference' (Eds SB Johnson, LA Weston, H Wu, BA Auld) pp. 145. (Weed Society of New South Wales: Sydney, NSW)

Broster J, Jalaludin A, Widderick M, Chambers A and Walsh M (2023) Herbicide Resistance in Summer Annual Weeds of Australia’s Northern Grains Region. Agronomy 13(7):1862.

Broster JC, Koetz EA, Wu H (2011) Herbicide resistance levels in annual ryegrass (*Lolium rigidum* Gaud.) in southern New South Wales. Plant Protection Quarterly 26, 22-28.

Broster JC, Koetz EA, Wu H (2012) Herbicide resistance frequencies in ryegrass (*Lolium* spp.) and other grass species in Tasmania. Plant Protection Quarterly 27, 36-42.

Gill GS (1993) Development of herbicide resistance in annual ryegrass in the cropping belt of Western Australia. In 'Proceedings of the 10th Australian and 14th Asian-Pacific Weeds Conference' pp. 282-285.Brisbane, Qld)

Henskens F (1997) Management of herbicide resistance in ryegrass and other weed species in cropping systems in south-eastern Australia. Project Final Report (DAV-266SR) (GRDC).

Llewellyn RS, Powles SB (2001) High levels of herbicide resistance in rigid ryegrass (*Lolium rigidum*) in the wheat belt of Western Australia. Weed Technology 15, 242-248.

Nietschke BS (1997) Integrated strategies for wild oat (*Avena* spp.) management in southern Australian farming systems. PhD thesis, University of Adelaide.

Owen, MJ, Martinez, NJ, Powles, SB (2014a) Multiple herbicide-resistant Lolium rigidum (annual ryegrass) now dominates across the Western Australian grain belt. Weed Research 54, 314-324.Owen MJ, Martinez NJ, Powles SB (2015a) Herbicide resistance in *Bromus* and *Hordeum* spp. in the Western Australian grain belt. Crop and Pasture Science 66, 466-473.

Owen MJ, Martinez NJ, Powles SB (2015b) Multiple herbicide-resistant wild radish (*Raphanus raphanistrum*) populations dominate Western Australian cropping fields. Crop and Pasture Science 66, 1079-1085.

Owen MJ, Walsh MJ, Llewellyn RS, Powles SB (2007) Widespread occurrence of multiple herbicide resistance in Western Australian annual ryegrass (*Lolium rigidum*) populations. Australian Journal of Agricultural Research 58, 711-718.

Pratley JE, Broster JC, Slater PD (1996) Herbicide resistance in wild oats in southern New South Wales. Project Final Report (UCS-8) (GRDC).

Pratley JE, Leys AR, Graham RJ, Baines PR, Kent JH (1995) The extent of herbicide resistance in annual ryegrass (*Lolium rigidum*) in southern New South Wales. Project Final Report (UCS-2F) (GRDC).

Walsh MJ, Duane RD, Powles SB (2001) High frequency of chlorsulfuron-resistant wild radish (*Raphanus raphanistrum*) populations across the Western Australian wheatbelt. Weed Technology 15, 199-203.

Acknowledgements

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

Contact details

John Broster
Charles Sturt University, Waga Wagga
Ph: 0457 272 075
Email: jbroster@csu.edu.au

Panel discussion: Chemical & cultural options to manage glyphosate resistant ryegrass & sowthistle & paraquat resistant fleabane

Notes

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

David Finlay & Gordon Howard, Moisture Planting Technologies Pty Ltd trading as mpt.ag

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.

Acknowledgements

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

The research undertaken as part of this project is also made possible by significant contributions from the Department of the NSW Chief Scientist & Engineer, and the author would like to thank them for their continued support.

The author would also like to acknowledge the continued startup support from Cicada Innovations, and Sparklabs Cultiv8.

Contact details

David Finlay
mpt.ag
74 Astill Drive, Orange NSW 2800
Ph: 0417 920 803
Email: david@moistureplant.com

Using guided work instructions for on-farm maintenance, operation, and repair

Nick Walker/Liam Scanlon, Hindsite Industries

Contact details

Nick Walker
Ph: 0409 738 703
Email: nick@hindsiteind.com

Notes

Taking the lab to the field

Peter Johnston, Hone Corporation

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.

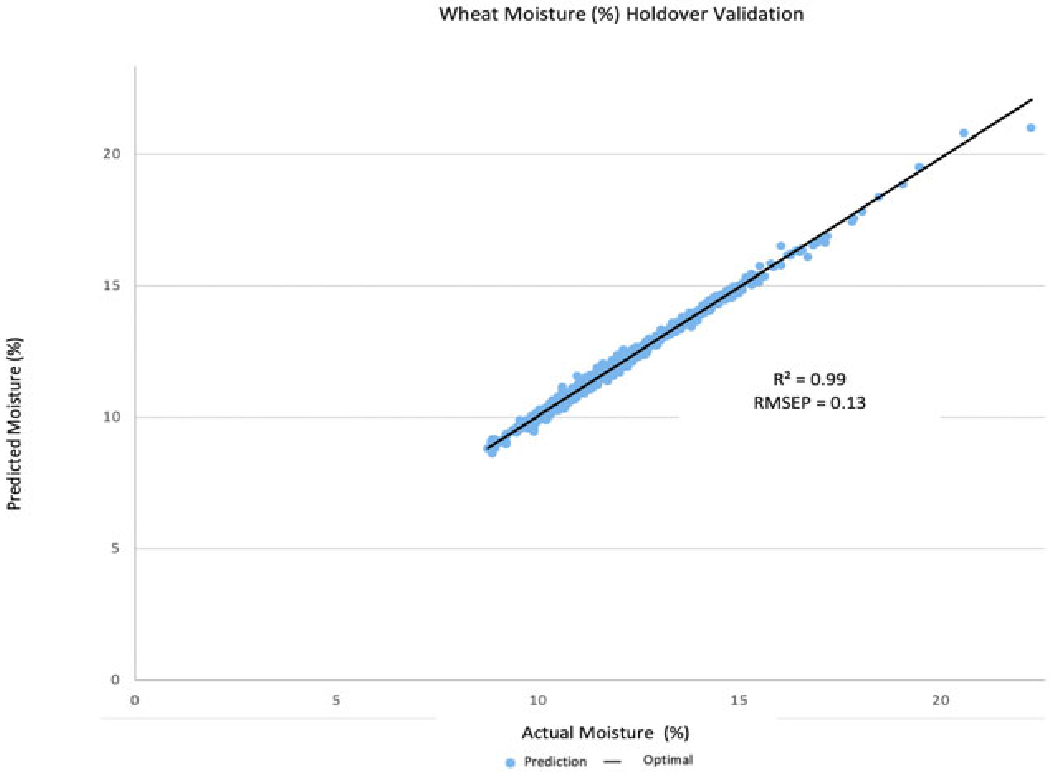


Figure 1. Wheat moisture predictive model.

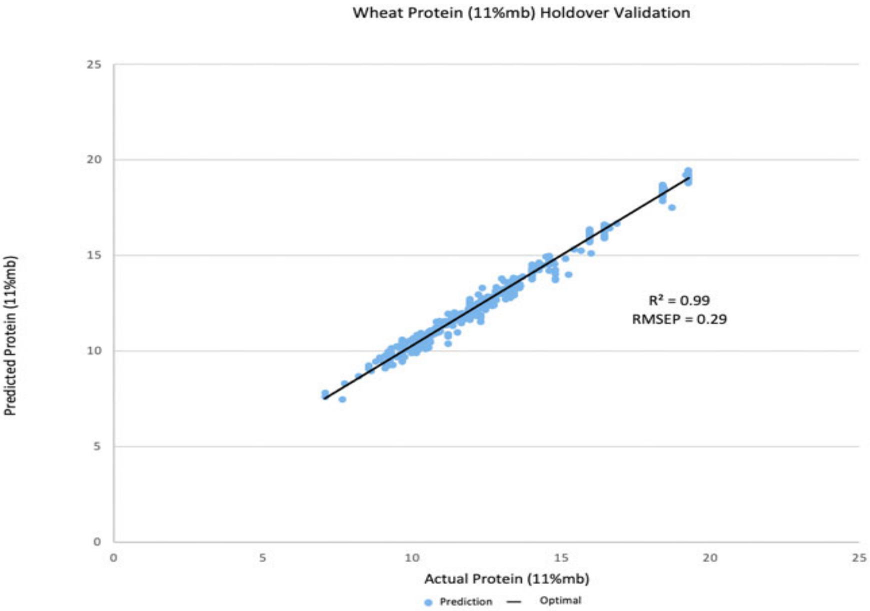


Figure 2. Wheat protein predictive model.

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.

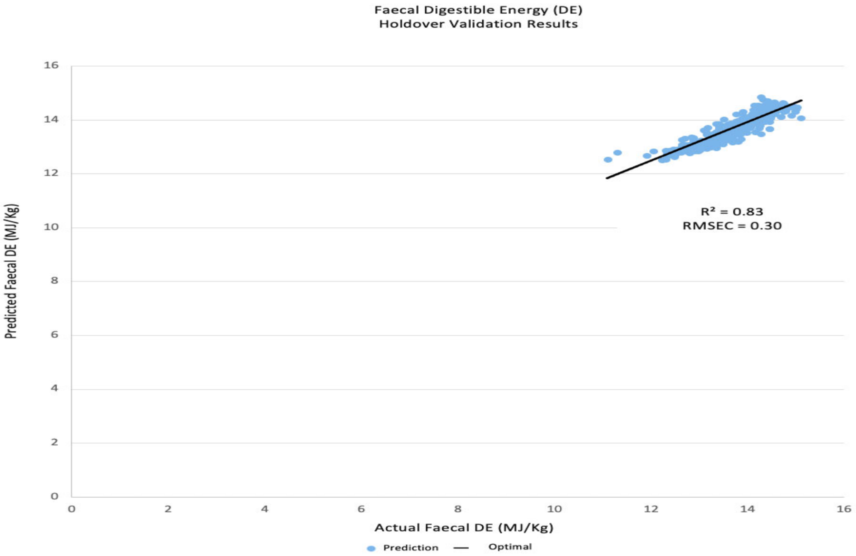


Figure 3. LHS; Faecal digestible energy (MJ/kg) cross validation results.

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**

References

Chadalavada K, Anbazhagan K, Ndour A, Choudhary S, Palmer W, Flynn JR, Mallayee S, Pothu S, Prasad KVSV, Varijakshapanikar P, Jones CS, Kholová J (2022) NIR instruments and prediction methods for rapid access to grain protein content in multiple cereals. *Sensors* **22(10)**, 3710. doi:10.3390/s22103710.

Du Z, Tian W, Tilley M, Wang D, Zhang G, Li Y (2022) Quantitative assessment of wheat quality using near-infrared spectroscopy: a comprehensive review. *Comprehensive Reviews in Food Science and Food Safety* **21(3)**, 2956-3009. doi:10.1111/1541-4337.12958.

Miskelly DM (2019) Analytical testing to support Australian wheat export quality (https://www.cerealsgrains.org/publications/cfw/2019/protectedpdfs/CFW-64-1-1210.pdf)

Walker CK, Assadzadeh S, Wallace AJ, Delahunty AJ, Clancy AB, McDonald LS, Fitzgerald GJ, Nuttall JG, Panozzo JF (2023) Technologies and data analytics to manage grain quality on-farm – a review. *Agronomy* **13(4)**, 1129. doi:10.3390/agronomy13041129.

Yan H, De Gea Neves M, Noda I, Guedes GM, Silva Ferreira AC, Pfeifer F, Chen X, Siesler HW (2023) Handheld near-infrared spectroscopy: State-of-the-art instrumentation and applications in material identification, food authentication, and environmental investigations. *Chemosensors* **11(5)**, 272. doi:10.3390/chemosensors11050272.

Contact details

Peter Johnston
Hone Corporation
Email: pj@honeag.com

Robust remote area connectivity solutions

Dan Winson, Zetifi

Contact details

Dan Winson
Email: dan.winson@zetifi.com

Notes

The regional disease surveillance network: a BioScout endeavour

Michelle N. K. Demers, Edward Gubbins and Lewis Collins, BioScout Pty Ltd

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.

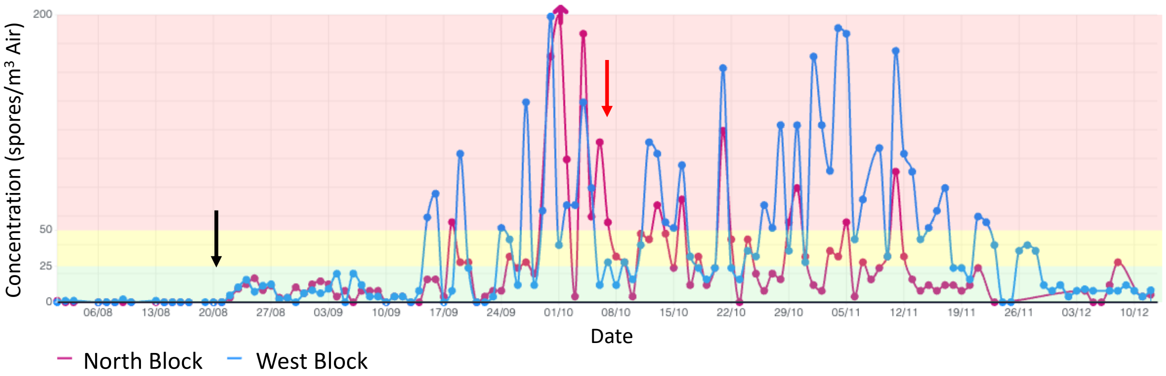


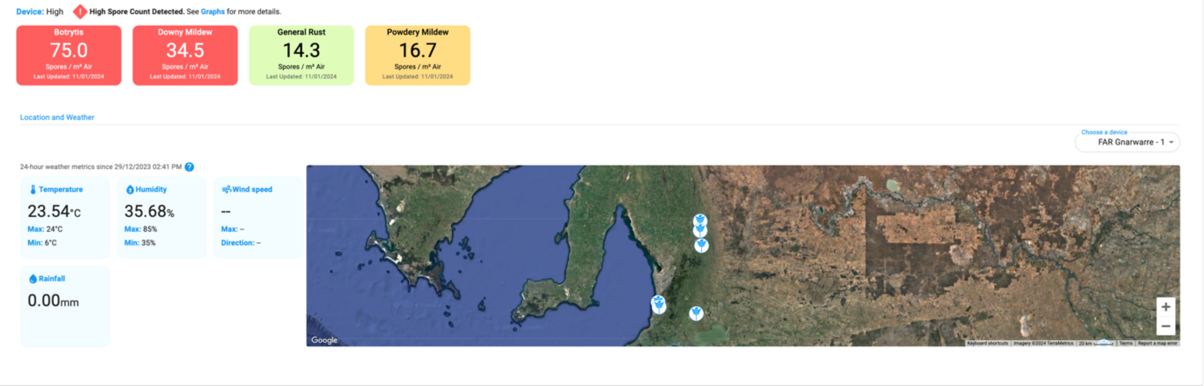
Figure 2. A graph from the BioScout dashboard displaying airborne concentrations of general rust detected through the SporeScouts during an outbreak. Two SporeScouts were placed at a site in Victoria from June to November 2023. North Block (pink line) and West Block (blue line) were located 776m and 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
75.0
Spores / m³ Air
Last Updated: 11/01/2024

Downy Mildew
34.5
Spores / m³ Air
Last Updated: 11/01/2024

General Rust
14.3
Spores / m³ Air
Last Updated: 11/01/2024

Powdery Mildew
16.7
Spores / m³ Air
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

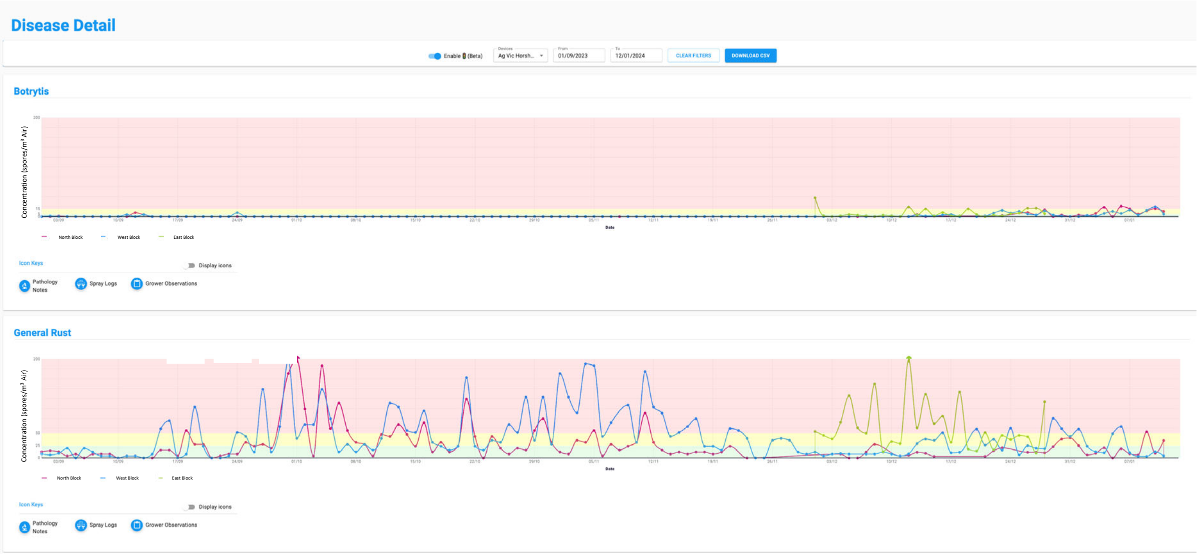
Temperature
23.54°C
Max: 24°C
Min: 6°C

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

References

FAO, 2019. New standards to curb the global spread of plant pests and diseases. Murray, G.M., Brennan, J.P., 2009. Estimating disease losses to the Australian wheat industry. Australas. Plant Pathol. 38, 558–570. https://doi.org/10.1071/AP09053

Acknowledgments

The research undertaken as part of this project (PROC-9176750 or BIS2305-001RTX) is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC. The author would like to thank them for their continued support. We would also like to express our gratitude to SARDI, DPIRD and NSW DPI for supporting this project.

Contact details

Michelle Demers
Head of Science, BioScout
Ph: 0424 611 345
Email: michelle@bioscout.com.au

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

Sam Duncan[1], Shahriar Jamshidi[1], David McClymont[2]

[1] FarmLab Pty Ltd
[2] DHM Environmental Software Engineering Pty Ltd

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.

References

Orton TG, Mallawaarachchi T, Pringle MJ, Menzies NW, Dalal RC, Kopittke PM, Searle R, Hochman Z, Dang YP (2018) Quantifying the economic impact of soil constraints on Australian agriculture: A case-study of wheat. Land Degrad Dev. 2018; 29: 3866–3875. https://doi.org/10.1002/ldr.3130

Subsoil Constraints – limiting crop profitability on alkaline soils in South Eastern Australia https://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/0d08cd6930912d1e4a2567d2002579cb/7aff9d99bf898a6fca2574c8002b3e92/%24FILE/SSC%20BROCHURE%20FINAL.pdf Accessed January 2024

Contact details

Samuel Duncan
FarmLab
4/121 Allingham St, Armidale, NSW 2350
Ph: 02 9052 4924
Email: info@getfarmlab.com

Concurrent session: Slugs, climate forecasts and weather services for cropping

Slugs – why did they appear in 2023 and are they likely to persist?

Dr Michael A Nash, La Trobe University & The University of Adelaide

Key words

canola establishment, crop protection, integrated pest management, slugs, molluscicide baits

GRDC code

DAS00127 & DAS00134, MAN2204_001SAX

Take home message

- To manage we must understand a pest's ecology
- Unlike insects, slugs do not have a set lifecycle, they breed when conditions are favorable: for example, during the recent triple La Nina event; and
- Dry spring conditions may have reduced slug breeding in 2023, however as slugs can live for two years, they are likely to still pose a risk in 2024.

Background

Research conducted supported by GRDC and industry indicates that the timing of bait applications is critical to protect emerging crops from slugs. Understanding when individual species are active, mating and breeding underpins successful management of slugs.

Slugs are hermaphrodites: both mating individuals can produce eggs that are laid in batches into moist soil. All slugs can delay breeding when conditions are dry, hence should be considered adaptive strategists. Although all slugs require moist environments to feed and breed, each have specific biology that determines when they are active, what time they breed, and when is the best time to apply baits to protect crops when they pose a threat.

The other factor to consider is that black keeled slugs can live for over five hundred days, with research indicating that they are capable of breeding in the second year of their life. The current recommendation is to be prepared to bait to protect emerging crops from slugs again next year. To support this, continuing GRDC investments aim to develop decision support tools to aid seasonal projections of likely slug risk.

Some key points from 2022 that enabled successful management of slugs in 2023

1. High soil moisture is the main predictor of high slug activity.
2. Wet winters extending into long cool springs, combined with bulky crops, provide ideal conditions for breeding.
3. Proactive management strategies gave the best results and return on investment. Long-term monitoring of slugs in spring is vital to provide information on population dynamics.
4. The use of a long-lasting slug and snail bait that is resistant to rainfall, attractive, palatable, and capable of being spread uniformly was found to be effective at protecting establishing crops.

Results and discussion

Large populations of slugs were observed up until harvest 2022. These observations highlighted the population's ability to increase numbers in wet spring conditions. Contrary to previous knowledge, black keeled slugs do breed late into spring (end of November) when conditions are favourable. Some learnings from an extremely high-pressure year (2023), as predicted from spring 2022 monitoring of slugs, snails, and spring weather conditions, are presented below.

1. Growers that did not order baits and have them on hand were often unable to source product in a timely manner, causing poor results.
2. A full moisture profile throughout summer and autumn led to slugs being active much earlier than other seasons, leading to some growers applying an early knockdown. However, due to high densities of slugs feeding, follow-up applications were required. Due to the high numbers, wet conditions and continued emergence of slugs from the soil long-lasting baits were found to be more effective than continual re-application of short-lasting baits.
3. A wave of black keeled slugs emerged in June, despite the absence of late autumn rain. Large numbers were already active from early April where there was a full moisture profile. This pattern suggests that black keeled slugs, like grey field slugs, exhibit an extended period of emergence from the soil over several months, with not all individuals in the population becoming active at the soil surface at the same time.
4. Many growers that waited to apply bait after sowing, or after the first application was consumed, had to resow some areas.
5. Monitoring bait remaining 1–2 days after the first application gave the best results.
6. Bait rate was the most crucial factor in 2023 for successful crop establishment; sufficient metaldehyde had to be applied in response to the large numbers of slugs observed actively feeding at the soil surface.
7. Baiting must be part of an integrated approach; rolling after sowing and before the first application of bait led to improved results.
8. Slugs can also damage lentils, faba beans and cereals, with an unprecedented amount of molluscicides applied to those crops in 2023.
9. Slugs were found damaging crops in regions and soil types not traditionally associated with slug damage: that is, on better quality soils away from creek lines in NSW and in new areas across the northern Wimmera of VIC.

Effective bait rate

With new molluscicide products continuing to being registered, choosing what to apply becomes increasingly challenging. Examples to add to the list (from Nash 2023):

- Sluggit Prima 30 Slug and Snail Bait (30 g/kg metaldehyde) #91239 3 kg/ha
- 4Farmers Iron Chelate Snail and Slug Bait (60 g/kg iron EDTA complex) #90221 5–16 kg/ha
- OCP™ eco-shield® Organic Snail & Slug Killer (10 g/kg iron powder) #90408 5–16 kg/ha
- MethioSHIELD™ Snail & Slug Bait (20 g/kg methiocarb) #92530 5.5 or 11-22 kg/ha

So, to revisit *What makes a good bait* (adapted from Nash 2022[c]), for baits to work, some basic principles are relied upon:

Individuals must first encounter a pellet, which requires:

- Individual activity – slugs must be actively searching for food.
- The number of baits to be distributed evenly – pellets/m^2. Pellets need to be evenly applied across the full width of application. Consistent pellet size, weight and density ensure no area is missed. Patchy control can occur when products with high variability in pellet weight are used and/or application equipment is not calibrated or able to spread the full width.
- Attractiveness of bait – individuals display non-random movement towards attractive pellets (true definition of bait). For example, grey field slugs are attracted to bran-based baits from 4 cm away, whereas modern products claim grey field slugs are attracted from 6 cm away.

Once individuals have encountered a bait, they must consume a lethal dose, which requires:

- Palatability – addition of feeding enhancers ensures individuals consume enough active ingredient to ingest a lethal dose. In the case of metaldehyde, which causes paralysis, consumption of a sub-lethal dose can be an issue with some products, because individuals cannot ingest enough to destroy their mucous cells.
- Enough bait for the target population – if product does not remain after a couple of days following application, it is usually due to large pest populations consuming it all. Re-application to those 'hot spots' will be required.
- Enough toxicant in the bait – the loading of active ingredient determines the amount consumed; hence low loadings require more total product to be applied. In wet conditions, small pellets with greater surface area to volume ratios lose more active ingredient, hence less toxicant will be consumed.

RATE & ATTRACTIVENESS ARE IMPORTANT, not just pellet points.

Some manufacturers have focused on producing small pellets in order to increase the chance of encounter, hence some of these products do not rely on attractiveness as a factor for individuals to find pellets. This theory assumes that slugs and snails randomly encounter pellets. Research (SARDI) has demonstrated Italian snails have non-random (Chi^2 test, $P < 0.01$, n = 100) movement towards bait. Hunter & Symonds (1970) calculated the probability of encounter was related to the attractiveness of a bait (x), a grey field slug's movement (y), and the pellet area or attractiveness (A):

$$P = 1 - e^{-2xy/A}$$

Where attractiveness (x) = 4 cm, movement (y) = 0.85 m/overnight and the pellet area (A) = 0.04 m^2, the commonly advised pellets/m^2 of 30 would achieve a probability of encounter of 95% (Figure 1). Thus, the probability of encounter can be calculated based on the manufacture's claims regarding attractiveness. Actual values calculated are presented in Figure 2, with a product that claims no attractiveness (e.g. Metakill®) resulting in lower probability of encounter, despite having a greater number of pellets/m^2 when applied at its label rate, compared to other products that claim to be attractive: for example, Metarex Inov® x = 6 cm, Snailex x = 4 cm.

To increase probability of encounter some manufacturers have decreased their pellet's size, hence increased the surface area to volume ratio. These smaller pellets have reduced efficacy after rainfall due to greater loss of metaldehyde (Nash 2023). That loss of active ingredient can result in an increased probability of delivering a sub-lethal dose. In 2023, it was evident that the quantity of metaldehyde applied was important. This was primarily due to the high numbers of active slugs.

Table 1 is provided to demonstrate, in theory, the effective probability of encounter and the number of slugs that could be killed by each product based on an amount of metaldehyde delivered at minimum label rates and the lethal dose required for black keeled slugs: that is, LD_{50} 190 – 210 µg/g. The more expensive wet extruded products that contain optimal levels of metaldehyde (e.g. Axcela®, Metarex Inov®) when applied at minimum label rates ensure an optimal probability of encounter when compared to cheap bran-based products (e.g. Snailex) or products that are not attractive (e.g. Metakill®) (Table 1).

Observations in 2023 support research that fewer slugs are killed by applying low rates of molluscicide. Greater slug numbers in 2023 often needed frequent reapplication of baits, especially where low rates were used. In some instances, products were applied four times to protect canola from slug damage. In cases where these products were less effective, the cumulative rate of metaldehyde applied significantly exceeded European metaldehyde stewardship guidelines. These guidelines recommend a maximum of 700 g metaldehyde/ha/calendar year, with no more than 210 g/ha/application.

Growers adhering to the International Sustainability & Carbon Certification (ISCC EU 202-2 or ISCC Plus 202-02) programs and use products containing metaldehyde, need to ensure they meet the requirements for maximum application rates, in accordance with these programs.

Table 1. Comparison of commonly used metaldehyde baits demonstrating effective baits/m^2, baits/m^2 at minimum label rate and the number of black keeled slug individuals (BKS) killed at the minimum label rate.

Product	A.I. (g/kg)	APVMA #	Label rate (kg/ha)	Bait/m^2 Pr 90%	Bait/m^2	No of BKS killed
Snailex	15	68580/139802	5–7.5	34	12	54
Axcela®	30	87576/134693	5–7	29	37	71
Delicia® Sluggoff®	30	60931/116048	3	29	28	48
Metarex Inov®	40	88160/120463	4–5	23	24	84
Imtrade Metakill®	50	64990/117488	5–8	135	29	95
IA Transcend®	50 + 1.5 fipronil	88733/130091	2–8	135	14	48

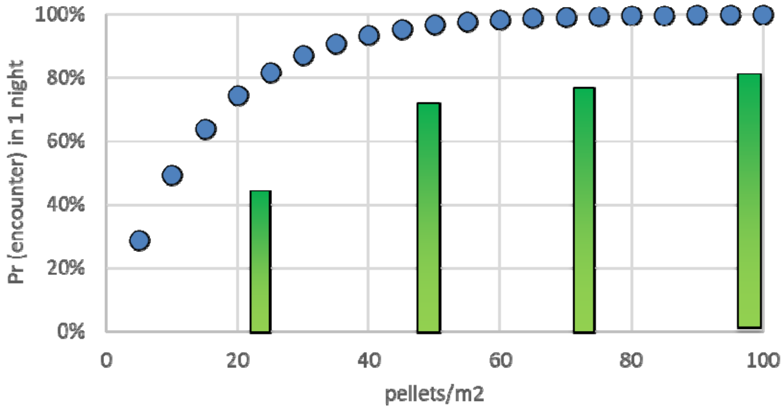


Figure 1. The probability of an individual grey field slug encountering a bran-based bait in one night as estimated by the equation $P = 1 - e^{-2xy/A}$ (dots) compared to data obtained from SARDI trials using round snails and bran-based bait (columns).

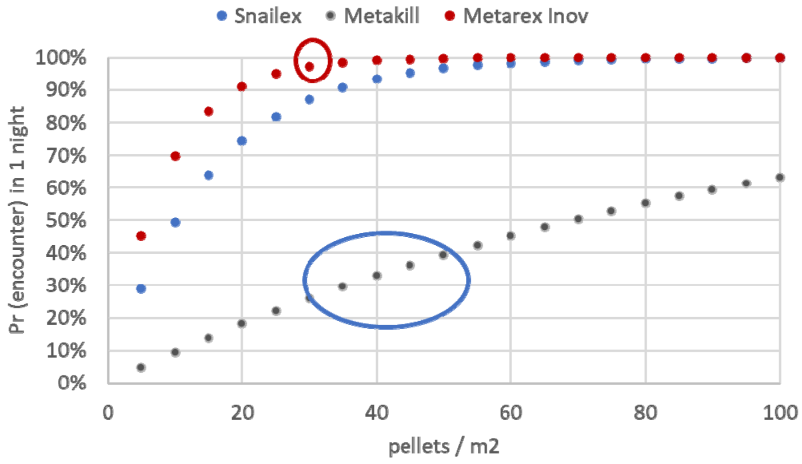


Figure 2. The theoretical probability of an individual slug encountering different products in one night as estimated by the equation $P = 1 - e^{-2xy/A}$ based on manufacturers claims regarding attractiveness. Note: despite a smaller pellet leading to greater pellets/m2 because the pellet is not attractive the chance of encounter (marked by large blue ellipse) is lower than a true bait that is attractive (marked by small red ellipse).

Conclusions

What can we predict for 2024? One would hope for lower slug numbers considering the lower-than-average late winter early spring rainfall. However, observations in southern NSW indicated that black keeled slugs were still active in September. Another observation is that high numbers of small slugs are damaging establishing fodder crops, despite the dry sowing conditions.

Understanding when individual slug species are active in your patch underpins successful management of them. Knowledge of pest population dynamics will avoid molluscicide supply shortfalls by ordering bait early, thus facilitating proactive baiting.

References

Hunter PJ and Symonds BV (1970) The distribution of bait pellets for slug control. Annals of Applied Biology 65: 1-7.

Nash M (2022[a]) Slug Control Fact Sheet - Successful crop protection from slugs. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2022/slug-control-identification-and-management

Nash M (2022[b]) Slugs In Crops: The Back Pocket Guide ISBN: 978-1-922342-31-7 https://grdc.com.au/resources-and-publications/all-publications/publications/2022/slugs-in-crops-the-back-pocket-guide

Nash M (2022[c]) Slugs – what can we learn from 2022. GRDC Update Papers 27 Jul https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/07/slugs-what-can-we-learn-from-2022

Nash M (2023) How do new molluscicide products perform in wet conditions. GRDC Update Papers 22 Feb 2023 https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2023/02/how-do-new-molluscicide-products-perform-in-wet-conditions

Acknowledgements

The author would like to thank GRDC, growers, retail agronomists and commercial clients that supported the research presented in this paper. The author would also like to thank GRDC for support of extension of this research.

Contact details

Dr Michael Nash
Email: whatbugsyou@gmail.com

® Registered trademark
™ Trademark

‘My Climate View’ – a longer-term planning tool for growers, producers, and land managers

Rebecca Darbyshire[1], Sigrid Tijs[2] and Graeme Sandral[3]

[1] CSIRO
[2] Bureau of Meteorology
[3] GRDC

Key words

Climate Services for Agriculture (CSA), climate change, farm management

GRDC code

AGI2206-002OPX

Take home message

- My Climate View is a free digital product that helps Australian farmers and land managers understand what the future climate might look like for their location and commodity
- The free climate information tool contains information that can help grain growers explore how future climate may impact their enterprise and consider how they may adapt their longer-term plans and production strategies
- Growers can access the tool at www.myclimateview.com.au

Key features

- Climate information is available for the past 60 years, for seasonal outlooks, and for future projections for the 2030s, 2050s and 2070s
- Farmers and land managers anywhere in Australia can access local climate information at a 5 km^2 resolution
- My Climate View presents climate information for 22 agricultural commodities – almond, apple, avocado, banana, barley, beef, canola, cherry, chickpea, cotton, dairy, lupin, mango, orange, pork, potato, sheep, sorghum, sugarcane, tomato, wheat and wine grape
- Users can download data and reports, and share key climate information with relevant peers, advisers or support networks.

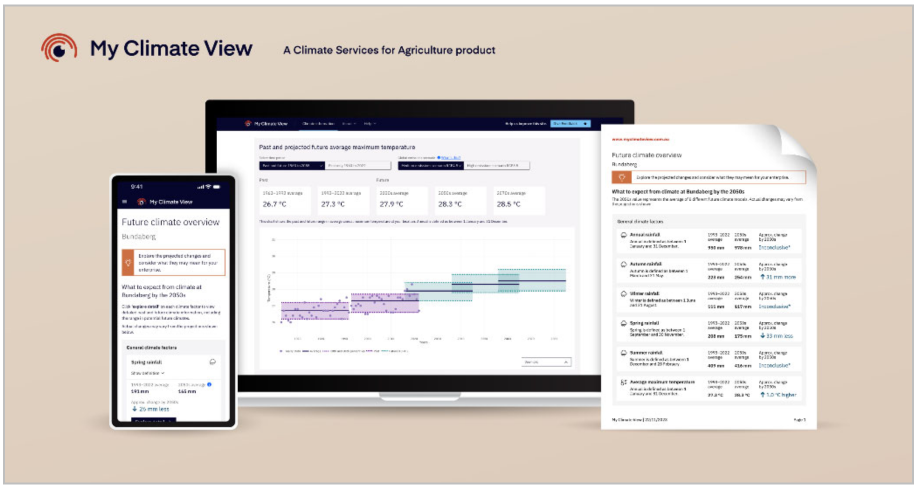


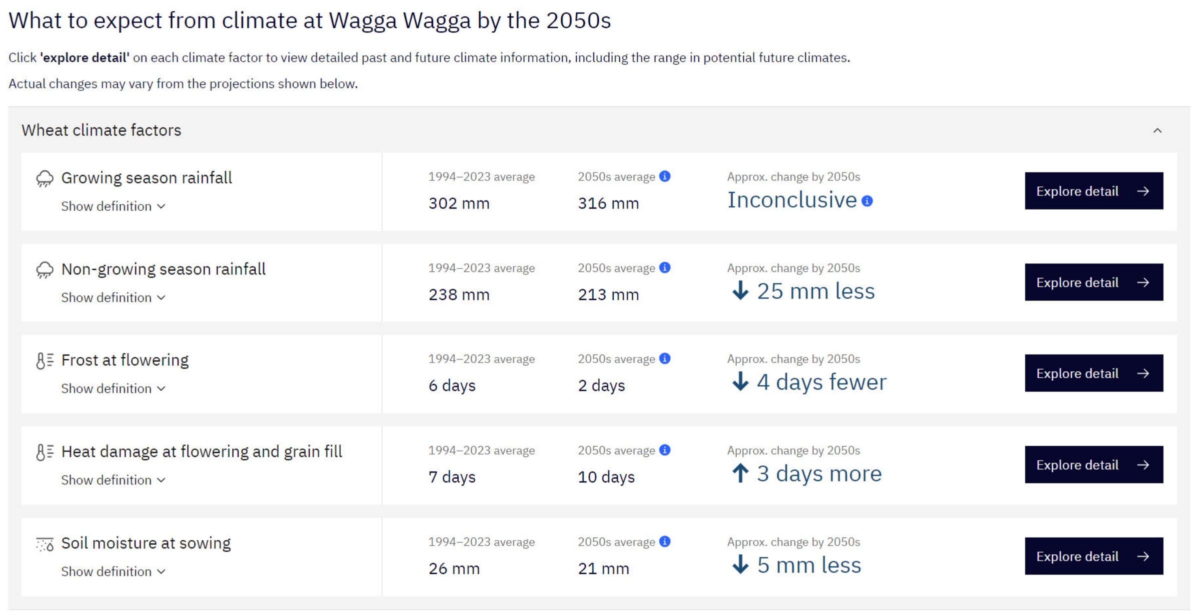
Figure 1. Website interface for My Climate View

Climate factors tailored for grain growers

Grain growers can get a tailored overview for what to expect from future climates at their location. For example, the commodity-specific climate factors for wheat, barely, canola and lupins are:

- Growing season rainfall
- Non-growing season rainfall
- Frost at flowering
- Heat damage at flowering and grain fill
- Soil moisture at sowing

Users can use the 'Overview' on My Climate View and the more detailed information to consider how potential changes to their local and commodity-specific climate factors may combine to present challenges and/or opportunities for their production in the future.



What to expect from climate at Wagga Wagga by the 2050s

Click **'explore detail'** on each climate factor to view detailed past and future climate information, including the range in potential future climates.

Actual changes may vary from the projections shown below.

Wheat climate factors

	1994–2023 average	2050s average	Approx. change by 2050s	
Growing season rainfall Show definition	302 mm	316 mm	Inconclusive	Explore detail →
Non-growing season rainfall Show definition	238 mm	213 mm	↓ 25 mm less	Explore detail →
Frost at flowering Show definition	6 days	2 days	↓ 4 days fewer	Explore detail →
Heat damage at flowering and grain fill Show definition	7 days	10 days	↑ 3 days more	Explore detail →
Soil moisture at sowing Show definition	26 mm	21 mm	↓ 5 mm less	Explore detail →

Figure 2. Example of the My Climate View 'Overview' for 2050s climate projections for wheat at Wagga Wagga

My Climate View provides detailed information about each commodity climate factor and users can modify the definition of climate factors for their specific enterprise, for example modifying the dates which define the growing season.

What is growing season rainfall?

The growing season is defined as between 1 April and 31 October.

Why does it matter?

Most barley cultivation in Australia occurs in rainfed systems. Rain received during the growing season is a major factor in determining yield.

Figure 3. Example of growing season rainfall and user ability to modify climate factor definition

How were the agricultural climate factors determined?

The agricultural climate factors on My Climate View have been tailored to provide Australian farmers and their advisers with climate information relevant to their location and their commodity.

Each agricultural commodity climate factor was created based on evidence in scientific literature, industry documentation and in consultation with subject matter experts.

How might an agricultural advisor interpret this information for on-farm decision making?

Here, the data from My Climate View has been interpreted by an experienced agricultural scientist (Graeme Sandral) with his interpretations provided below to indicate how My Climate View information can be further interpreted for individual circumstances.

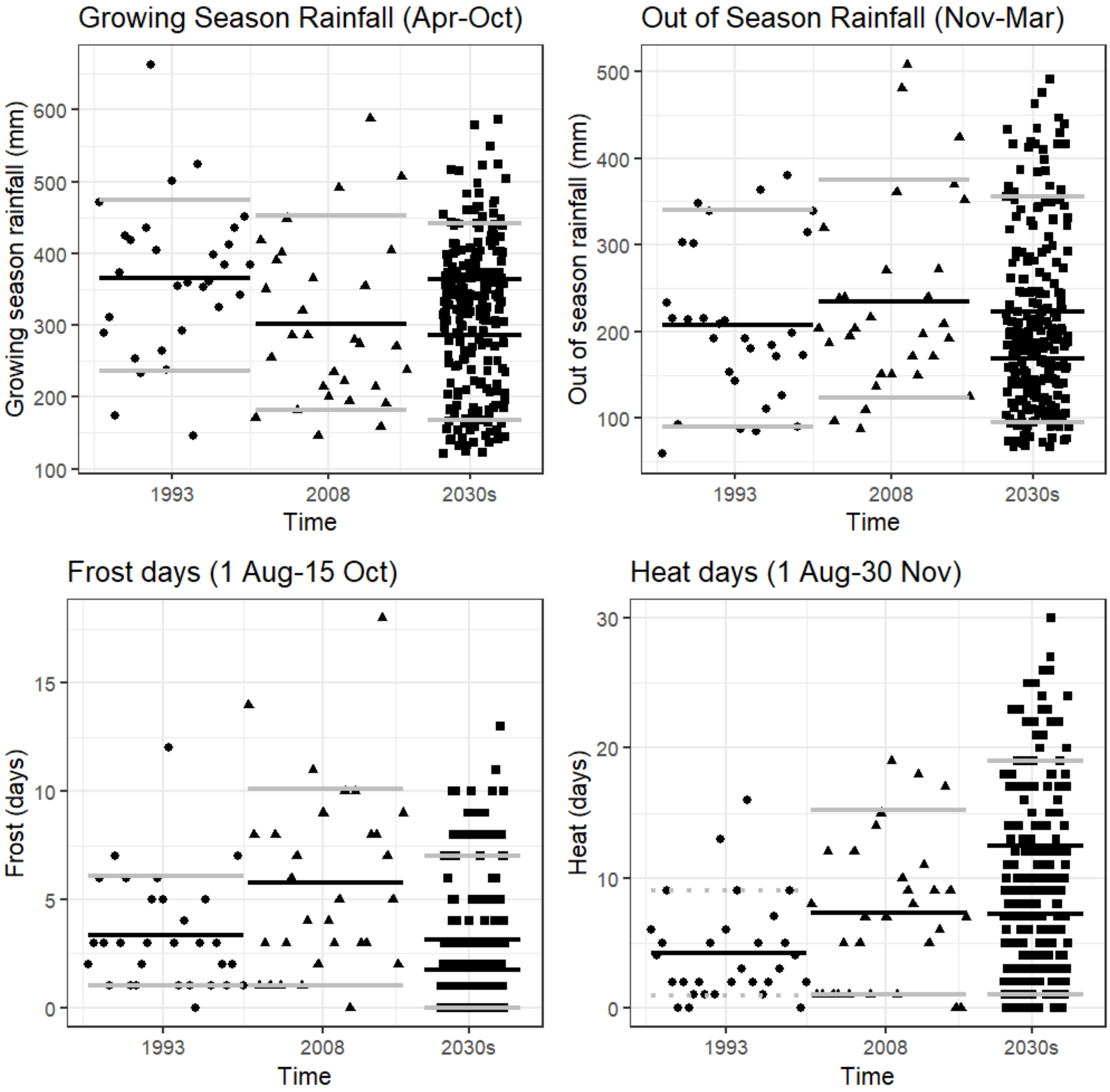


Figure 4. Data extracted from My Climate View for three 30-year time blocks, 1964-1993 (circles), 1994-2023 (triangles) and projected climate for the 2030s (squares) for growing season rainfall April 1 to October 30 (Figure 4 top left), rainfall outside the growing seasons covering 1 November to 31 March (Figure 4 top right), number of frosts equal to or below zero degrees between 1 August and 15 October (Figure 4 bottom left) and number of heat stress events between 1 August and 30 November equal to or above 32 degrees (Figure 4 bottom right). Solid black lines represent the mean and upper and lower grey lines the 90th and 10th percentiles. For the 2030s, the two solid lines indicate the mean range across 8 future climate models. The 2030s projections are based on a high emissions scenario (RCP8.5).

Comparing the period 1965-1993 (circles) against the period 1995-2023 (triangles) shows that growing season rainfall was on average lower in the more recent period (Figure 4 top left) while out of growing season rainfall increased compared with the later historical period (Figure 4 top left compared with top right). This has implications for summer fallow management and highlights its increasing importance in maintaining yield outcomes. Future scenarios (squares) for growing season rainfall suggest similar or slightly lower rainfall than historic records (Figure 4 top left) with the range in mean future rainfall shown as solid black lines. Future out of season rainfall will likely decline to levels below those records for the period 1965-1993 (Figure 4 top right).

The number of frost events (Figure 4 bottom left) show an increase when comparing 1965-1993 (circles) to 1995-2023 (triangles), however the number of frost days is predicted to decline in future climate (squares) although variability will likely be high and these data only account for changes to minimum temperatures. Hence frost risk may still continue into the future. The number of heat days experienced (Figure 4 bottom right) has increased when comparing 1965-1993 (circles) to 1995-2023 (triangles) and this is likely to continue to increase into the future. The future frost and heat conditions suggest it may be possible to consider crops that have a slightly shorter time to flowering in future climate scenarios primarily because frost events are less likely to impact yield, and this approach is likely to improve avoidance of heat stress (Figure 4 bottom right).

Using the wheat yield conversions provided by Norton et al (2023) in these proceedings, the wheat water limited potential yield (WLPY) is:

WLPY = (WU – 75)*25 / 1000 = t/ha and

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

Economic yield is WLPY * 0.8 and

Wheat nitrogen requirement is 20 kg N/t and

Nitrogen (N) use efficiency from soil is assumed at 50%, therefore soil N is 40 kg N/t of wheat.

The wheat yield estimates from the above of 6.6 t/ha (1965-1993), 5.5 t/ha (1995-2023) and a predicted range of 4.5 to 6.7 t/ha (2030s) suggests a potential continuation of yield decline is a potential outcome. The total soil N requirement for these yields is 266 kg N/ha, 220 kg N/ha and 195 to 267 kg N/ha respectively, indicating considerations of likely income and cost declines. How the future climate and corresponding yields (high emissions scenario in this case) play out is worthy of attention to ensure appropriate management strategies can be applied. Remembering it's not about the exact numbers per se but rather being aware of the existing and likely future trend so management changes can readily be brought to bear.

Balancing the above climate and yield scenarios is the other important trend, that over time grain growers have been improving input efficiency as well as water use efficiency (WUE) – producing more grain per mm of rainfall. A focus on improving input efficiency and WUE will likely be more important in future climate scenarios.

Feedback from industry

“The information [on My Climate View] would help inform on plant breeding programs, particularly in relation to factors such as frost, rainfall, and temperature tolerance.

The specific climate factors relevant to wheat [on My Climate View] would provide a great insight into what the future climate may look like over the coming decades and how best to manage it.”

NSW seed supplier at field day in Henty

Using My Climate View

- Visit the My Climate View website (www.myclimateview.com.au) and select your location and commodity.
- Explore the various climate data and projections.
- Download reports and share key climate information with relevant peers, advisers, and support networks.
- Contribute to the future of My Climate View and share how using My Climate View has helped shape your farm management practises.
- Contact the My Climate View team on CSAEnquiries@csiro.au.

Acknowledgements

My Climate View is a collaboration between Australia's national science agency CSIRO and the Bureau of Meteorology, and has been designed together with Australian farmers as part of the Climate Services for Agriculture program thanks to funding from the Australian Government's Future Drought Fund.

This program is also supported by FarmLink Research and Coutts J&R.

My Climate View was developed with extensive input from farmers across the country. Feedback has helped tailor My Climate View to enable farmers to use the projected climate information to best support longer-term agribusiness and risk mitigation planning.

Contact details

Sigrid Tijs
Bureau of Meteorology
Level 2, B Block, Parkes Place West, Parkes ACT 2600
Ph: 0427 257 287
Email: agriculture@bom.gov.au

Weather predictions, risk and decision making.
Perspectives on making better decisions on risk management from weather and seasonal forecasts.

Claire Yeo, Bureau of Meteorology

Key words

meteorology, climate, forecast, accuracy, risk

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 that connect short-term weather forecasts to long-term climate forecasts for risk management and decision making.
- 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 and decisions, 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 grain's 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

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, to support a decision support service tailored to the agriculture sector. Research conducted by the Agriculture Program has found that there is a need for weather and climate insights that provide additional perspectives when making risk management decisions.

Based on this need, the decision support service aims to provide advisers and growers a comprehensive risk assessment for weather and climate decision-making specifically. This objective is achieved through analysis and research that includes verification and case studies of weather and climate events utilising expertise within the Bureau.

The decision support service, through understanding the complex science of weather and climate, aims to provide targeted advice for high-value agriculture 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.

Case study: Storm outbreak across eastern Australia – November 2023

Agriculture Program staff attended the Cropping Solutions Seminar in Narrabri in July 2023. Through conversations with growers and advisers at the seminar and on the ground, we 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, which can limit their effectiveness in decision making.

An example of this came from canola growers near Narrabri that relied on this online source of information for a rainfall forecast more than 7 days in advance. These growers made decisions to sow 1,000ha 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 decision support service aims to make the long-term forecasts more useful for farmers. For example, it uses a range of long-term forecasts that include other international models as part of the analysis to provide a forecast beyond 7 days.

A case study has been developed to demonstrate 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. In late November 2023, several surface troughs combined with tropical moisture to produce rain and storms over eastern Australia, peaking on 24–25 November. to investigate this, an analysis of forecasts displayed on Yr.no was undertaken and captured how the forecasts changed at Dubbo and Tamworth, and then compared these to observed rainfall amounts.

Forecast on Yr.no

Figure 1 shows how the forecast for 25 November evolved for 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.

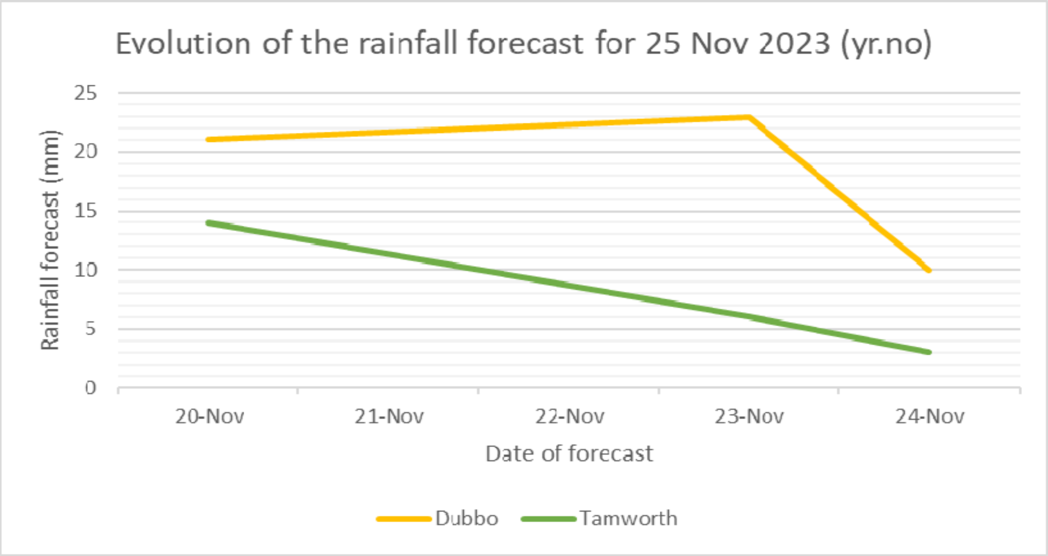
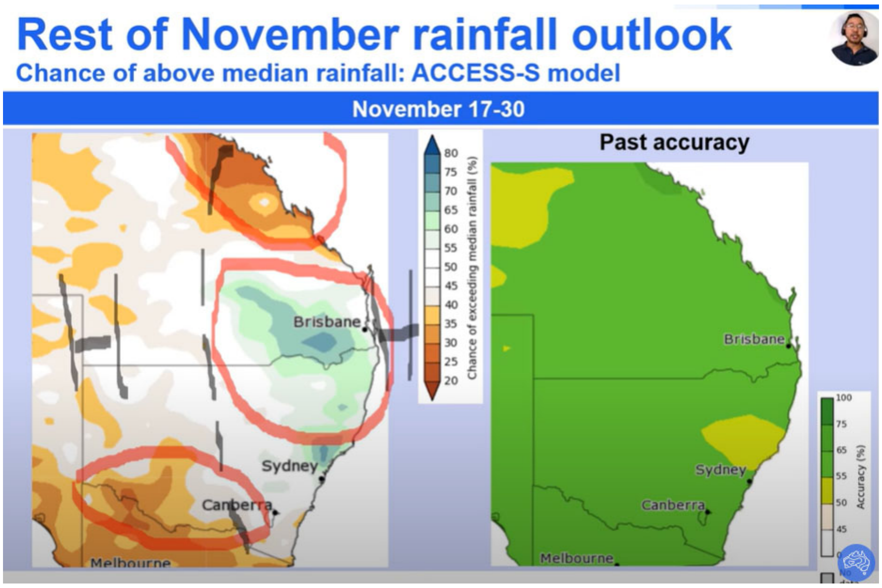


Figure 1. Evolution of the forecast at two different locations on yr.no (taken from yr.no between 20-24 November 2023)

Bureau of Meteorology forecast

The grains climate video update (November Grains Climate Outlook - NSW & Qld – YouTube), 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, we 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.



Rest of November rainfall outlook

Chance of above median rainfall: ACCESS-S model

November 17-30

Past accuracy

Figure 2. Grains video briefing screenshot from 8 November 2023 (taken from YouTube -[November Grains Climate Outlook - NSW & Qld - YouTube](#))

Rain observations

Rain observations on 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 demonstrates how some locations received high totals, for example Wellington, NSW (38 mm) while others nearby received very little, for example Dubbo (0.2 mm), which is 46 kilometres from Wellington.

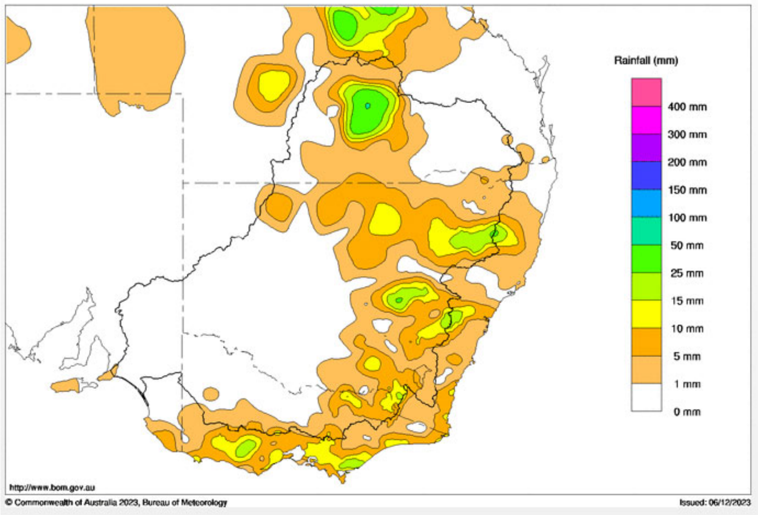


Figure 3. 24-hour rainfall totals for 25 November 2023 (observations taken from http://www.bom.gov.au)

Findings and conclusion

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 popular online resource. Some online resources can be popular as they provide the information presented in a way that is easy to understand or gives a direct solution to a complicated and evolving science, without rigorous assessment. 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.

Different computer models have their individual biases due to model resolution, grid scheme and physics all attempting to simulate the atmosphere and project forward in time. Interpolation of spatial and temporal extent varies. The atmosphere is a complex fluid, and scientists understanding of the physics is constantly evolving, helping to improve the development of models. Feedback continually collected by the Bureau from farmers assists in prioritising future service improvements. While these models will improve into the future, there will always been uncertainty in long-term forecasts due to the complexities in the atmosphere.

The Bureau therefore uses a blend of computer models to provide a rigorous analysis. In particular, the Bureau's meteorologists 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 information tailored to the agriculture sector to support on-farm high-value decisions.

The Agriculture Program will continue to engage with the agriculture industry on an ongoing basis, and identify opportunities, such as through the Agri-climate outlooks project to provide direct relevant weather and climate analysis and insights tailored to the needs of the agriculture sector. The insights captured from the agriculture sector will inform research to understand model bias, verification, and model physics in international climate models where appropriate. The team invite growers and advisors to keep up to date with the analysis of the long-term forecast, by subscribing to the Grains Climate Outlook video briefings, and by contacting the Agriculture Program via email at agriculture@bom.gov.au, or in-person at field days and seminars.

Acknowledgements

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

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

References

Bureau of Meteorology Agriculture YouTube playlist:
https://www.youtube.com/playlist?list=PLbKuJrA7Vp7mdHq2Mal0tglzznaZNbHUq

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

November Grains Climate Outlook - NSW & Qld - YouTube

Contact details

Claire Yeo
Bureau of Meteorology
700 Collins St Docklands 3008 Vic
Ph: 0477 520 760
Email: Claire.Yeo@bom.gov.au

General plenary - Day 2

Where AI adds value to agronomic and crop decision-making now, and where might this technology be in 5 years?

Liam Ryan, Jacob Humpal, Darren Plett, John Rivers, Tom Giles,
Grains Research and Development Corporation

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.

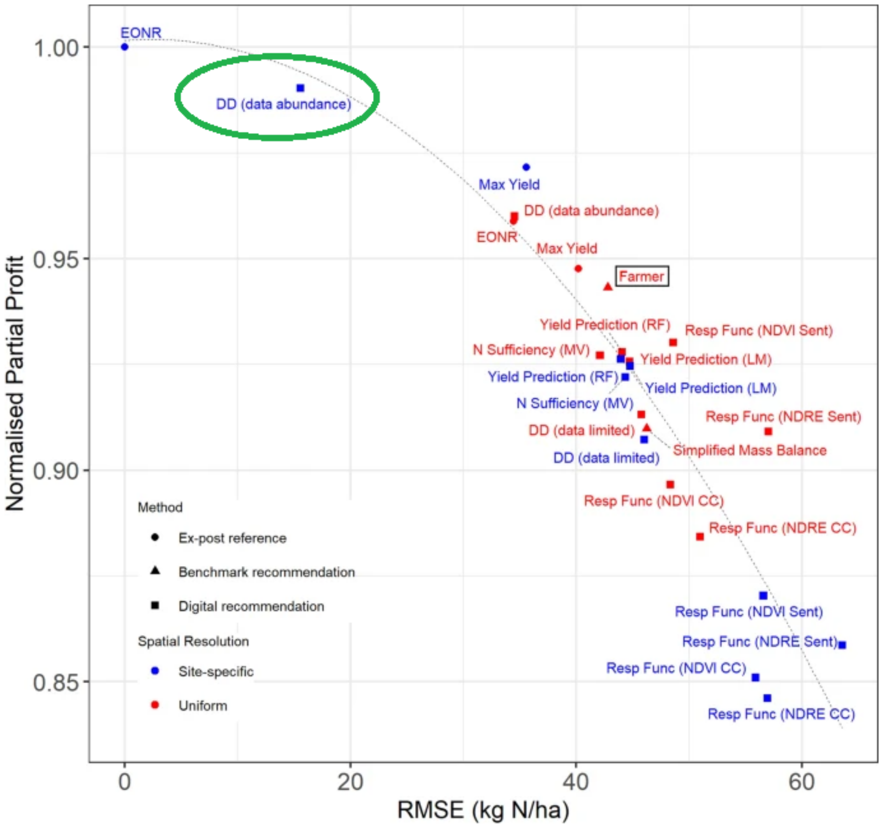


Figure 1. Error by profit biplot showing the average results of various N recommendation methods across 21 large scale on-farm trials in Australia, sourced directly from Colaço et al., (2024). The RMSE stands for root mean squared error is a measure of accuracy. The lower the RMSE the better. Normalised 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™ 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.

Acknowledgements

GRDC staff get to collaborate with many innovative growers, researchers, companies and innovators in AI and agronomy. Many of which have contributed to the development and delivery of projects listed in the paper. We're thankful for their time, efforts, and ideation over the years and into the future.

References

Colaço AF, Whelan BM, Bramley RGV *et al.,* (2024) "Digital strategies for nitrogen management in grain production systems: lessons from multi-method assessment using on-farm experimentation." *Precision Agriculture*, 230. [Online] Available at: https://doi.org/10.1007/s11119-023-10102-z

Climate Corp. (2020, February 21) "Digital modeling and tracking of agricultural fields for implementing agricultural field trials" [Patent EP3927137A1]. *Google Patents*. [Online] Available at: https://patents.google.com/patent/EP3927137A1?hl=en

Eathington S (2018) "The next evolution of digital farming technology." Retrieved from https://climate.com/blog/next-evolution-of-digital-farming/ Accessed 9/1/2024.

Kandel YR, Hunt CL, Kyveryga PM, Mueller TA, Mueller DS (2018) "Differences in Small Plot and On-Farm Trials for Yield Response to Foliar Fungicide in Soybean." *Plant Disease*, 102, 140–145. doi:10.1094/pdis-05-17-0697-re

Lacoste M, Cook S, McNee M *et al.,* (2022) "On-Farm Experimentation to transform global agriculture." *Nature Food*, 3(1), 11-18. [Online] Available at: https://doi.org/10.1038/s43016-021-00424-4

Lawes RA, Bramley RGV (2012) "A Simple Method for the Analysis of On-Farm Strip Trials." *Agronomy Journal*, 104, 371–377. doi:10.2134/agronj2011.0155

Rakshit S, Baddeley A, Stefanova K, Reeves K, Chen K, Cao Z, Evans F, Gibberd M (2020) "Novel approach to the analysis of spatially-varying treatment effects in on-farm experiments." Field *Crops Research*, 107783. doi:10.1016/j.fcr.2020.107783

Thomas S (2024) "Evolving Microsoft Azure Data Manager for Agriculture to transform data into intuitive insights." [Online] *Microsoft Azure Blog*. Available at: https://azure.microsoft.com/en-us/blog/evolving-microsoft-azure-data-manager-for-agriculture-to-transform-data-into-intuitive-insights/

Virk D, Witcombe J (2008) "Evaluating cultivars in unbalanced on-farm participatory trials." *Field Crops Research*, 106, 105–115. doi:10.1016/j.fcr.2007.10.017

Yan W, Hunt LA, Johnson P, Stewart G, Lu X (2002) "On-Farm Strip Trials vs. Replicated Performance Trials for Cultivar Evaluation." *Crop Science*, 42, 385. doi:10.2135/cropsci2002.0385

Contact details

Liam Ryan
Manager Transformational Technologies
Grains Research and Development Corporation
Level 4 East Building 4 National Circuit Barton ACT 2600 Australia
Ph: 0477 746 414
Email: liam.ryan@grdc.com.au

® Registered trademark
™ Trademark

The Cool Soil Initiative: A farmer-focused, scalable framework for emission reporting through the supply chain

Fiona McCredie, Acting Director, Cool Soil Initiative

Key words

Emissions reporting, sustainability, supply chain sustainable sourcing

Take home message

There's an increasing need for the food industry to demonstrate sustainable sourcing and to report on, and seek to reduce, all emissions created at every stage of a product's supply chain. This includes those generated on farm. For farmers, that means:

12. A need-to-know on farm emissions,
13. A need for a robust process for estimating on farm emissions that are allocated along the supply chain for individual products, and
14. Most importantly, there is a need to consider how the practices, systems and seasonal conditions are influencing farm emissions, and what can be done to improve farm performance and lower emissions.

What is the Cool Soil Initiative?

The Cool Soil Initiative provides a **scientifically** credible, pre-competitive and market-recognised **framework for delivering research, analysis and reporting, that supports farmers to improve soil health, environmental outcomes and reduce** farm (and scope 3) greenhouse gas (GHG) emissions using sustainable farming practices.

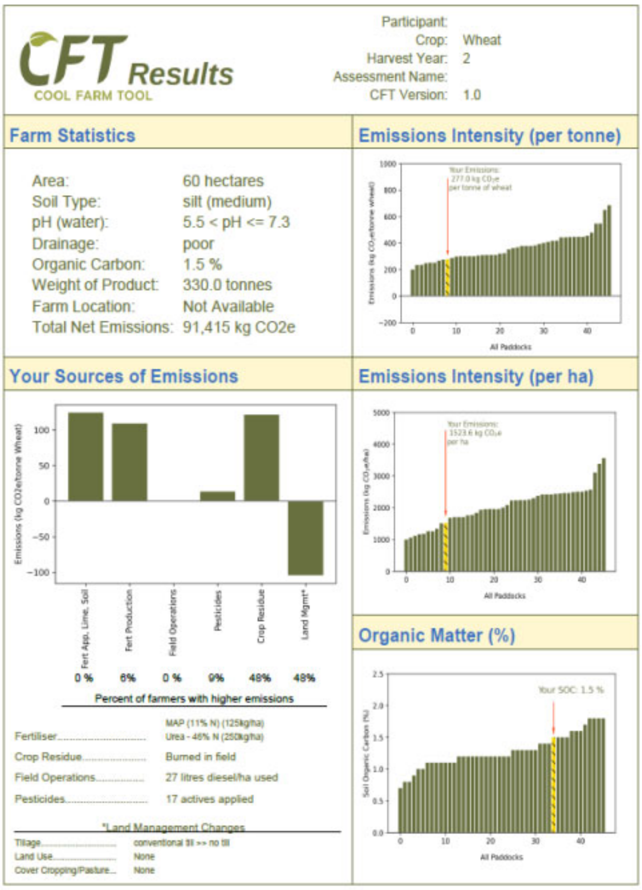
The Cool Soil Initiative (CSI) has been operational for five years, working with 200 farmers to improve soil health and environmental outcomes, as well as providing impact reporting to both farmers and the supply chain on the GHG emissions associated with growing wheat, maize and canola. The current members of CSI are Kellanova (formerly Kelloggs), Manildra, Pepsico, Mars, Allied Pinnacle and Corson Grain, and Charles Sturt University.

As CSI's partners operate in Australia and internationally, and much of Australia's grain is exported, the CSI program is designed to ensure the GHG emission numbers and impact reporting, are recognised both here at home and globally, and are accepted throughout the whole supply chain. This is why CSI uses the Cool Farm Tool and aligns its measurement, verification and reporting system with relevant global and Australian protocols

How does it work?

CSI brings together both farmers and the companies which buy and use grain, streamlines reporting AND ensures the supply chain is focused on sustainable farming practices (rather than just an emission number), recognising that greenhouse emissions are the outcomes of the farming system, rather than a driver. CSI is free for growers as it is funded by the member consortia.

CSI currently works with 4 farming systems group (FSG) in NSW and Victoria, namely FarmLink, Riverine Plains, Central West Farming Systems and Irrigation Research and Extension Committee (IREC). These FGSs work directly with 200 farmers to collect, analyse and identify opportunities to remove soil constraints and improve agronomic, economic and environmental performance. Every CSI farmer gets free soil testing, and receives an annual emissions and soil health report which is benchmarked across the region an example of which is shown in figure 1.



Participant:
Crop: Wheat
Harvest Year: 2
Assessment Name:
CFT Version: 1.0

Area:	60 hectares
Soil Type:	silt (medium)
pH (water):	5.5 < pH <= 7.3
Drainage:	poor
Organic Carbon:	1.5 %
Weight of Product:	330.0 tonnes
Farm Location:	Not Available
Total Net Emissions:	91,415 kg CO2e

Fertiliser	MAP (11% N) (125kg/ha) Urea - 46% N (250kg/ha)
Crop Residue	Burned in field
Field Operations	27 litres diesel/ha used
Pesticides	17 actives applied

*Land Management Changes

Tillage	conventional till >> no till
Land Use	None
Cover Cropping/Pasture	None

Figure 1. Example of an annual emissions and soil health report which is benchmarked across the region

The CSI's soil scientists spend time with the CSI farmers to work through the results and key drivers of GHG emissions, identify which practices could be most beneficial, and then support farmers to trial various practice changes. CSI collects crop and paddock data from each farm each year and consolidates these into regional results, which are shared with the group and tracked over time. The supply chain members receive aggregated regional emission, soil health and farm practice results and trendlines for their supply shed – noting they do not have visibility of individual farm results.

The CSI now uses an Application Programming Interface (API) version of the Cool Farm Tool specifically for Australian farms, which it commissioned to ensure modelled emissions are based on Australian climatic conditions and with alignment to the National Greenhouse Gas Inventory. CSI's technical review (Melland *et al*., 2023) has shown that the Australian version (compared with the CFT 1.0 and CFT 2.0) results in a smaller GHG footprint calculated due to better understanding of leaching potentials, better accounting for crop residue and nitrogen input emissions sources.

As part of this technical review, the emission profile analysis identified that median emission intensities calculated using CFT1.0 for wheat paddocks in 2020 in the Riverine Plains (278 kg CO2e/t) and Central West (158 kg CO2e/t) regions were similar or lower than those calculated by Sevenster et al. 2022[2] for a census of paddocks in the Australian southern (261 kg CO2e/t) and northern (295 kg CO2e/t) regions for their baseline analysis year of 2005. The median emissions intensity per hectare was similar in the Central West (565 CO2e /ha) and twice as high in the Riverine Plains (1399 CO2e /ha) in 2020 than the 2005 baseline national median (618 kg CO2e /ha). The main GHG emission sources identified in both studies were similar, with Scope 1 nitrogen and lime application dominating. Large differences in soil organic carbon stock change emission estimates would reflect differences in the year of study but moreover would reflect large differences between IPCC Tier 1 and Tier 3 methods of estimation for this emission source. Emissions or sequestration from this source can be justifiably excluded from the Cool Soil Initiative use of the Cool Farm Tool because long term changes in soil organic carbon that are reflected by these emissions are not able to be attributed to investment in practice change support by value chain corporate partners. Regional differences in the relative influence of fertiliser production and use were evident in the CFT1.0 analysis and in other Australian studies, which are a reflection of different nitrogen fertiliser use patterns.

What are the results to date?

The CSI Impact Report for 2023, based on ~350,000 ha, showed:

- A 50% increase in legume hectares over the last 3 years, noting the inclusion of legumes is the best way to maintain and build soil carbon, while building soil fertility and reducing reliance on fertiliser N
- A 35% increase in lime being incorporated – important because soil acidity is the single biggest constraint to crop production in north-east Victoria, southern NSW, which is ameliorated through lime addition with incorporation
- A reduction in emission intensity (emissions per tonne) over the period from 2017–2022, noting yield is the significant factor which impacts emissions per tonne
- CSI's innovation program had 800 innovation hectares, assessing 10 practices
- Paddocks in CSI with soil organic carbon (SOC) values of 1.5% and greater tend to have a history of pulse and/or pasture phase integration (Figure 2)
- The CSI results indicate that SOC% is strongly aligned with diversity in cropping systems
- Farmers with a longer history of multiple soil health practices are showing higher SOC, which has correlated to more resilient yield compared to their neighbours during drought years.

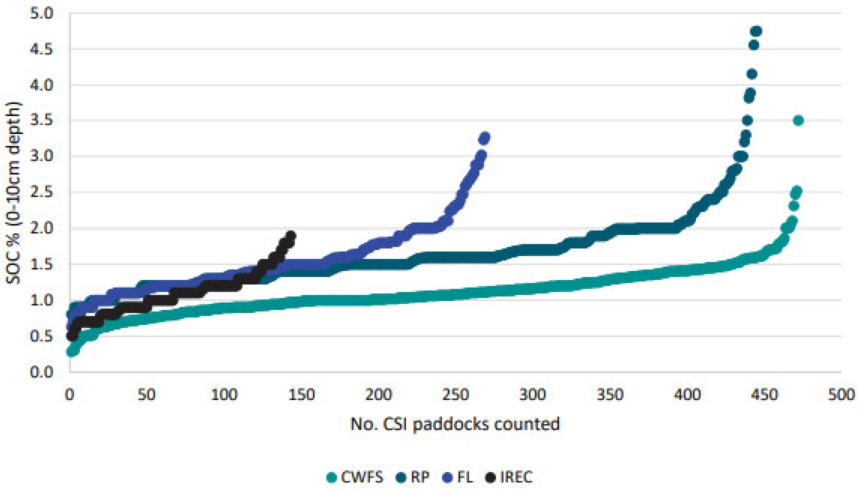


Figure 2. Soil organic carbon (SOC) (%) values (measured at 0-10 cm depth) from 1,331 paddocks across four regions, sampled from 2018 – 2022. The regions are supported by the relevant farming groups; RP – Riverine Plains, FL – FarmLink, CWFS – Central West Farming Systems, IREC – Irrigated Research and Extension Committee. Median values for each region are RP SOC = 1.55%, FL SOC = 1.45%, CWFS SOC = 1.06%, IREC SOC = 1.1%

A survey of CSI farm participants showed:

- 95% understand more about soil health and how to maintain/improve it
- 82% understand more about the type and amount of emissions on farm
- 50% have/may change practice as a result of CSI
- 68% say CSI emission baseline and reporting is useful for making decisions on farm.

From 2024, CSI is expanding into new crops, new regions, and new commodities, starting with oats in Western Australian, and livestock. There will also be new supply chain members, both pre- and post-farm gate, joining CSI, enabling greater investment on the ground.

Conclusion

It's important to recognise that we can't manage what we don't measure – the Cool Soils Initiative allows paddock, farm, and regional based metrics on GHG emissions and other eco-system services to be collected so benchmarks on points of interest can be established and tracked through time to assess progress and test new management interventions, while providing a consistent, transparent framework for supply chain Scope 3 reporting. It is anticipated that participating in the Cool Soil Initiative will provide the on-ground support needed to help grain growers and other farming business to meet product specifications, market access and GHG targets set by existing and future governments and global food supply chains.

To register with the Cool Soils Initiative, you can do so at https://www.csu.edu.au/cool-soil-initiative/join-the-initiative.

Reference

Melland, A.R., Crabbe, R. and Schefe, C. (2023) Evaluation of the Cool Farm Tool for its suitability for application to GHG emissions estimation and reporting in dryland wheat production in south-eastern Australia. Cool Soil Initiative Technical Report. (Charles Sturt University; Wagga Wagga, Australia).

Sevenster, Maartje; Bell, Lindsay; Anderson, Brook; Jamali, Hizbullah; Horan, Heidi; Simmons, Aaorn; Cowie, Annette; Hochman, Zvi. Australian Grains Baseline and Mitigation Assessment. Main Report. Canberra: CSIRO; 2022. csiroEP2022 0163.

Contact details

Cool Soil Initiative
Charles Sturt University, Wagga campus
Contact via www.csu.edu.au/cool-soil-initiative/home

Opportunities from consumer-based drivers in Asian markets

Chris Carter, AEGIC

Key words

consumer research, grain products, market trends

GRDC code

AEG2107-001RTX

Take home message

- There is optimism about Southeast Asian markets, and more generally Asian markets, regarding trends in healthy products and to a lesser extent in the sustainability of products.
- The segments of markets with high incomes are able and willing to pay for higher level product attributes. Within these segments, opportunities exist through targeting products that can use traceable systems to track provenance.
- A key driver that will affect demand for sustainably produced grain in key export markets – prior to a change in consumer's purchasing behaviour – is the shift towards ESG reporting by end users of grain (millers, brewers, food manufacturers, etc) , to meet incoming regulatory requirements and investor pressures.

Aims

The purpose of this study is to identify and analyse trends and the alignment of incentives within:

- Consumer led drivers of grain product consumption patterns
- Claims made on grain food products distributed by Indonesia's and Japan's food companies
- Consumer perceptions of issues relating to convenience, health, ethics, sustainability and safety (CHESS) attributes.

Introduction

Increasingly, the world is looking to build sustainable, ethical, and safe practices into supply chains. This is occurring in many industries including the grain industry, and food industries that utilise grain. One of the drivers in this trend is the growing consumer and investor awareness of the environmental impacts of their consumption and investment decisions, and the need to manage the emissions, resource use and pollution associated with those decisions.

Subsequently consumers are now faced with food products on retail shelves that make many various claims on their packaging regarding attributes that have been built into, or excluded from, the production of that product. However, these products face long value chains, with multiple partners working together to place the products on the shelf. To return value to all the participants in this chain there must be a shared understanding of the trends in consumption and a willingness to invest in preserving these attributes through the chain for the next link.

Food companies are critical in facilitating this process. They are at the forefront of understanding the consumer needs and responding to those needs. They are responsible for the transformation of grain into food products. They are also responsible for transmitting information on consumer trends through value chains.

This report presents findings from a set of analyses on likely movements in the Indonesian and Japanese markets in response to consumer drivers. The drivers investigated in this report include convenience, health, ethics, sustainability, and safety (CHESS). The focus is on wheat products, as wheat is the main grain exported to Indonesia and Japan from Australia.

Method

Market conversations

The key part of the Indonesian analysis was conversations with people in the market, to ground truth the findings from trend analysis and from other research pieces. To undertake this task, the project team held conversations with players in the Indonesian market in a two-week period in May-June 2023.

For the Japanese market, a survey was presented to 71 attendees of an online seminar, with the attendees representing sectors of the Japanese milling industry and relevant government agencies.

Product trends

The labelling trends were derived from data accessed within the Mintel Global New Product Database. This database provides information on new products released into the market, including information on labelling and ingredients. By filtering the data to only include products with wheat, barley, canola, oats and pulses as ingredients, the analysis was able to draw on 30,000 products released into the Indonesian market in the period, and 45,000 in the Japanese market between 2014 and 2023.

Consumer surveys

The data for these sections comes from a panel survey of 1000 consumers in the market. The survey captures data from consumers who are over the age of 18 and with access to the internet. Aside from these characteristics, the respondents are from a wide background within each market, in age, gender, income, location, living situation, employment and education.

Results

The following tables present findings from the sets of analyses in the full report. They combine the analysis from the various sets of data relating to four consumption drivers, being Convenient, Healthy, Ethical and Sustainable. For more information, please contact the author.

Table 1. Key drivers investigated for Indonesia using CHESS method (convenience, health, ethics, sustainability, and safety).

Indonesia
Convenient
Grain food manufacturers are increasing their use of convenience as a marketing hook. This marketing is attractive to the increasingly urbanised population, who are time poor and enjoy higher disposable incomes than previously. There is however a shift towards easy to prepare foods for home consumption. This is a parallel trend to the labelling, where ingredients are marketed as easy to prepare at home.
Healthy
Though there has been a slight increase in the use of healthy labelling during the COVID years, this trend has again flattened following recovery. The use of healthy claims on grain foods is running at about 24%, though this is not capturing the small and medium sized enterprise (SME) market where claims are not used as a driver of demand. The SME segment represents a significant share of the market. The centralised promotion of healthy diets is not currently effective in its health messaging, and as such intermediate processing companies (milling) are cautious when building capacity around provision of healthy grain options (e.g. wholemeal).
Ethical
There is limited utilisation of ethical claims on Indonesian grain foods. Use of claims such as ‘plant-based’ is increasing though from a very low base, and mostly in smaller product categories, such as snacks that have options to utilise animal-based ingredients, or plant-based alternatives. There is limited use of fair-trade labelling with grain foods.
Sustainable
Use of sustainability labelling is low. While consumers suggest they build personal sustainability values into their purchasing decision, the availability of products that meet these values is limited. The pull through of sustainability characteristics between producer and consumer is hampered by incomplete incentives at the primary processing stages. Government policy settings don’t appear to incentivise significant uptake of sustainability initiatives through the grain value chains, especially when extending into the SME sector.

Table 2. Key drivers investigated for Japan using CHESS method (convenience, health, ethics, sustainability, and safety).

Japan
Convenient
Grain foods using convenient claims have increased, though seemingly plateaued. The way food is consumed is stable, with Japanese consumers remaining likely to consume meals cooked from scratch. Participants in the milling industry survey are however optimistic for an increase in the demand for convenient foods. This is not yet reflected in the consumer survey data.
Healthy
Approximately 40% of consumers are selecting food that is healthy, either all the time or most of the time, while 20% of consumers indicate they eat healthily rarely or never. Though, as health food is perceived as expensive, there is somewhat of a barrier to consumption. ‘Health’ food should in this context be differentiated from healthy food which includes fresh food products. Despite enthusiasm from Japanese milling companies regarding trends in health labelling and effect on consumers’ purchasing decisions, actual product numbers utilising health labelling are low relative to the EU and Australia.
Ethical
Limited use of ethical claims in Japanese grain food products. Consumers are unlikely to choose foods based on ethical branding. There is some evidence that the effect of this labelling is decreasing, though given the low density of the labelling, the effect is somewhat unclear.
Sustainable
Use of sustainable claims on grain food products is increasing, though mostly relating to the characteristics of the packaging. There may be opportunities for Australian suppliers of packaged products. The consumer attitudes to sustainability are warm with some support from a minority of respondents, though the majority are only mildly supportive of sustainability initiatives. Processors perceive promotion of sustainability characteristics as less influential on consumers’ purchasing decisions, relative to other characteristics.

Conclusions

Indonesia

- The SME food manufacturing sector is a large, fragmented market segment. For the sector to provide products that satisfy higher-level wants and needs (sustainability, health) for consumers in this environment, there must be a clear value proposition, or compliance requirement.
- A large proportion of the Indonesian population is purchasing products that are not differentiated on product attributes (other than flavour), but compete on price within a crowded market, with consumers being mostly concerned for satiety.
- There may be demand for higher level characteristics (environmental, ethical) within large grain-food food manufacturing companies, including the multinationals. However, the capacity to meet this demand is currently hindered by limited use of mechanisms – such as traceability and country of origin systems – that work past the first point of processing.

Japan

- The Japanese market is generally conservative and risk averse, and this must be considered when developing systems that deliver grain with attached CHESS attributes.
- While consumers and manufacturers are increasingly considerate of environmental concerns, the translation into action is not rapid with grain food products. Consumer preferences and product labelling data are slowly aligning with the positive sentiment of the food manufacturers.

General

- In both markets, there is awareness of the shift in policy and investor environment towards public reporting on ESG progress.
- Regulatory and investor pressures will affect grain demand and the need for verifiable sustainability characteristics before consumer pressures become a significant driver.

Acknowledgements

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

Contact details

Dr Chris Carter
AEGIC
3 Baron-Hay Court, South Perth, WA 6151
Ph: 8 6168 9907
Email: chris.carter@aegic.org.au