TALWOOD QLD
TUESDAY 23
JULY 2024

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

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GRDC 2024 Grains Research Update Welcome

Welcome to our winter 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.

Graeme Sandral
Grower Relations Manager – North

Talwood

GRDC Grains Research Update

Tuesday 23 July 2024

Talwood Community Hall, 14 Main St, Talwood Qld 4496

Registration: 8:30 AM for a 9:00 AM start, finish 2:40 PM

	AGENDA	
Time	**Topic**	**Speaker(s)**
9:00 AM	**GRDC welcome**	*GRDC*
9:10 AM	**The science under pinning farm gate GHG footprint and what it means for a grain growing enterprise**	*Aaron Simmons (NSW DPI)*
9:40 AM	**Fall armyworm impacts & thresholds in sorghum & maize – & management options & guidance for 2024/25**	*Melina Miles (QDAF) & Joe Eyre (UQ)*
10:00 AM	**MORNING TEA**	
10:30 AM	**Farming systems – profit over time and risk. An update on local farming systems research outcomes**	*Andrew Erbacher (QDAF)*
11:00 AM	**Tracking P fertiliser recovery using P isotopes - both starter P and deep P**	*Megan Hunter (UQ)*
11:25 AM	**Optimising sorghum grain yield in western growing regions. A focus on nutrition and agronomy**	*Loretta Serafin (NSW DPI)*
11:40 AM	**Nutrition discussion – fertility decline and implications for nutritional strategies**	*Andrew Erbacher, Megan Hunter, Loretta Serafin & Stuart Thorn (MCA)*
12:00 PM	**LUNCH**	
12:50 PM	**Cereal disease management update for 2024 – rust, foliar diseases and crown rot**	*Steven Simpfendorfer (NSW DPI)*
1:25 PM	**Crown rot genetic resistance in cereals & what's in the breeding pipeline**	*Zhi Zheng (CSIRO)*
1:50 PM	**Finessing pre-em herbicides; getting the early post-em space right & resistance management strategies for glyphosate resistant weeds**	*Chris Preston (Uni of Adelaide)*
2:20 PM	**Weed management & residuals – optimising performance & avoiding pitfalls**	*Chris Preston & Stuart Thorn (MCA)*
2:40 PM	**CLOSE**	

Contents

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

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Key words

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

Take home message

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

Introduction

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

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

GHG emissions

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

Baseline emissions

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

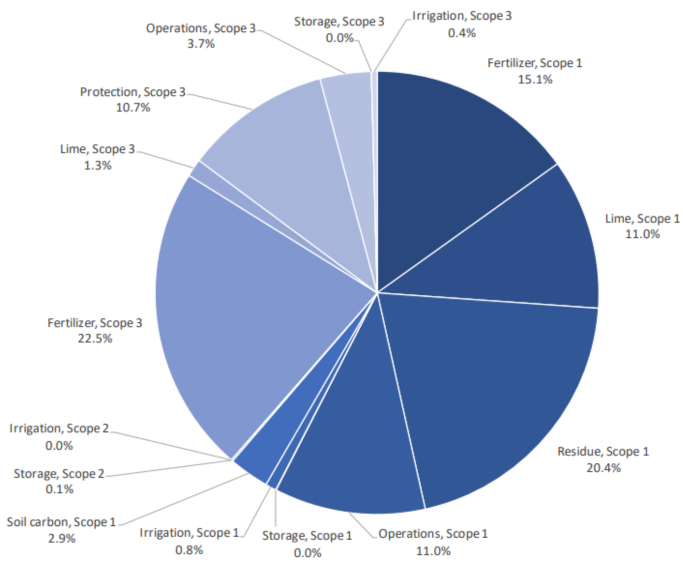

Figure 1. Contribution of emissions sources for the Australian grain sector (From Sevenster *et al.*, 2022). Scope 1 - Direct emissions from the company's operations; Scope 2 - Indirect energy emissions; and Scope 3 – Other indirect emissions.

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

Assessing changes to grain production systems to reduce GHG emissions

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

- *Check if claims for GHG emissions reductions or carbon sequestration are supported by credible scientific evidence*. Claims of unrealistic GHG emissions reductions, for example inflated estimates of soil organic carbon sequestration, are prevalent and grain producers need to ensure that any estimates of GHG emissions reductions are well proven, realistic and persist into the future. The most reliable peer-reviewed information will come from state-based agencies, reputable industry bodies or universities.
- *Prioritise avoidance of GHG emissions over C sequestration*. There is a high degree of certainty that implementing a strategy to avoid emissions (e.g. improve N use efficiency to reduce N_2O emissions) will result in a reduction of GHG emissions. Sequestration, in soil particularly, is higher risk because it must be maintained permanently and there is a high chance of reversal with a variable and changing climate.
- *Potential impacts on productivity*. Perhaps the most critical consideration is the impacts of management changes to reduce GHG emissions on the long-term productivity and profitability of the farm business. For example, reducing N inputs into the system can reduce the GHG emissions intensity of grain production yet doing so has the potential to not only reduce yields and profit but also increase reliance on N mineralised from soil organic matter that will result in a decline in fertility and a loss of soil organic carbon. Similarly, cutting back on lime applications where soil acidity limits production will also have long-term negative impacts on productivity.
- *Are carbon credits needed?* Carbon credits are not required for a GHG footprint. Further, if carbon credits are generated and sold to someone else then they cannot be used to offset emissions within the business, which may be required to maintain market access in the future.
- *Assess direct and indirect costs*. There is a direct cost associated with changing management to reduce GHG emissions however the indirect costs associated with a management change may be more critical to assess (e.g. yield reductions with lower N levels). There can also be indirect benefits, (e.g. pastures phases improving organic matter, mineral N supply and soil physical properties) associated with management changes. It is important to assess costs on a $/t CO_2-e basis (i.e. marginal abatement cost).

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

Conclusion

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

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

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

[1] Further detail on N strategies to reduce GHG emission in: *Norton R, Gourley C, Grace P, Kraak J (2024) Securing access to nitrogen for food production, a GHG perspective. GRDC Updates*.
[2] Not to be confused with green urea, which is a coated fertiliser product to reduce N_2O emissions.

Reference and further reading

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

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

Norton R, Gourley C, Grace P, Kraak J (2024) Securing access to nitrogen for food production, a GHG perspective. GRDC Updates. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2024/02/securing-access-to-nitrogen-for-food-production,-a-greenhouse-gas-perspective

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Fall armyworm impacts & thresholds in sorghum & maize - management options & guidance for 2024/25

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What's driving profitability of western farming systems?

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Key words
farming systems, intensity, diversity, legume, nitrogen, ley pasture

GRDC code
DAQ2007-002RTX

Take home message
1. Cropping intensity has had the biggest influence on system profitability
2. *Higher legume* frequency required less nitrogen fertiliser, but profitability was not improved
3. Applying nitrogen fertiliser to grass ley pastures produced more biomass in the pasture phase and returned more mineral nitrogen in the cropping phase.

Introduction
Growers are facing challenges from declining soil fertility, increasing herbicide resistance, and increasing soil-borne pathogens in their farming systems. Changes are needed to meet these challenges and to maintain the productivity and profitability of our farming systems.

In 2014 research began with local growers and agronomists to:

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

Queensland Department of Agriculture and Fisheries (DAF), CSIRO and New South Wales Department of Primary Industries (NSW DPI) then established a field-based farming systems research program, focused on developing farming systems to better use the available rainfall to increase productivity and profitability, with the question:

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

This research question is being addressed at two levels by the Northern Farming Systems initiative; to look at the systems performance across the whole grains region, and to provide rigorous data on the performance of local farming systems at key locations across the region. To do this, trials were established at Emerald, Pampas, Billa Billa, Mungindi, Narrabri, Spring Ridge and Trangie, representing a range of climates and average rainfalls.

For each of these regions typical grower practice (circa 2014) is represented in the '*Baseline*' system, then we changed the 'choices we make' to modify the farming system.

Choices we make:

- What crop to plant
    - When to plant – *Higher* and *Lower intensity*
    - What crop to choose – *Higher diversity* and *Higher legume*
- How much fertiliser to apply.
    - Quantity of fertiliser – *Higher nutrient*
    - Alternative nutrient sources – *Higher fertility* and *Pasture+/-N*

We are now into the ninth year of running these systems and in this paper we will look at some of the impacts these choices have made in our systems, focusing on the Billa Billa and Mungindi sites and drawing on others as appropriate.

Economics in this project are calculated using a 10-year average price for commodities and fertiliser, standardised cost for machinery operations (plant, harvest, spray) and actual pesticide applications using a standardised quoted price.

What crop to plant...

When to plant – crop intensity

In these experiments cropping intensity and fallow length is determined by how much plant available water (PAW) we accumulate in the soil. In our *Baseline* system this is about 60% of our PAWC (plant available water capacity); at Billa Billa this is 90mm PAW for wheat and chickpea and 120mm for sorghum. A *Higher intensity* system is planted with 40% PAWC (60mm PAW) and *Lower intensity* is 80% PAWC (150mm PAW).

We know that fallow efficiency (FE – the proportion of rainfall stored in the soil for later use) is highest on dry cracked soils and so it is not surprising to observe the highest fallow efficiencies achieved in the *Higher intensity* system. As the soil gets wetter, we have less cracks for mass flow of water into the soil slowing potential infiltration rates, and our stubble breaks-down reducing groundcover which protects our soil from evaporation (among other things), so again it is not surprising that the *Lower intensity* system has the lowest fallow efficiency.

Averaged over all seven sites and seven years, the fallow efficiency was 21% in the *Baseline*, 31% in *Higher intensity*, and 14% in *Lower intensity*. Combine this with growing more crops and we see the proportion of rainfall used by crops (that is Fallow rain x FE + In-crop rain) again favours a *Higher intensity* system. *Baseline* used 55% of rainfall, *Higher intensity* used 69% and *Lower intensity* used 42% of rainfall.

However, fallow efficiency and the proportion of rainfall used does not automatically translate to more grain yield and profit. When analysing the performance of the 163 sorghum, wheat and chickpea crops in the first six years of the project we demonstrated that crop water use efficiency (WUE – kg of grain produced per mm of water used) was maximised by having a minimum amount of PAW stored prior to planting the crop. This was about 60 mm for chickpea, 100 mm for wheat and 200 mm for sorghum. Sorghum is higher because it grows during summer with a higher evaporative demand.

If we put this all together and look at how the systems performed, we see that the *Baseline* had the best balance between storing enough PAW to improve WUE and shorter fallows to improve FE.

At Mungindi, the *Baseline* has grown six crops in the first eight years of the project (to January 2023), for a combined gross margin of $3032/ha ($378/ha/year), whereas *Lower intensity* grew four crops for a gross margin of $1128/ha ($141/ha/year).

At Billa Billa, the *Baseline* grew nine crops in the first eight years, to net $6535/ha ($817/ha/yr). Similar to Mungindi, *Lower intensity* grew less crops (six) in the same period to return $2627/ha ($328/ha/yr). *Higher intensity* grew an extra two crops (eleven in eight years) but produced less grain yield for each crop and in total; returning lower gross margins than the *Baseline* at $4426/ha ($553/ha/yr).

Across all seven sites, the average gross margin per crop is highest in the *Lower intensity* and the lowest in *Higher intensity*. With less crops grown in *Lower intensity*, only two sites (Pampas and Emerald) successfully executed high value crops to return a combined higher gross margin than the *Baseline* over the eight years. Similarly, the *Higher intensity* system only grew enough "extra crops" to return a higher combined gross margin than *Baseline* at two sites (Pampas and Narrabri).

What crop to choose – diversity

From the 1950's to the 1980's the most profitable crop across southern Queensland was wheat and the most profitable rotation was wheat followed by wheat. When zero-till farming was introduced, crops became more prone to stubble-borne diseases (crown rot), so farmers were forced to diversify their rotation to manage this disease.

As such, when we were establishing these experiments the *Higher diversity* systems predominantly set out to improve the management of crown-rot, along with root-lesion-nematodes (RLN) and herbicide resistance (particularly Group 1, formerly Group A) by forcing double break crops and allowing more modes-of-actions (MOA) with our herbicide use. In essence, the 'low-diversity' *Baseline* system had the crop options to achieve this objective with wheat, chickpea and sorghum. This poses the question, "are we adding diversity for diversity sake?" Only at Pampas has *Higher diversity* increased profitability over the *Baseline* system, but there are some useful insights that can be drawn from this system.

For Mungindi, summer crops were considered 'high risk', particularly from heat stress at flowering from spring planted crops. Without reliable summer "break crops" the system is at high risk of RLN and Group 1 herbicide resistance. A *Lower intensity* winter cropping system enabled winter fallows to use alternative herbicide MOA for black oats and phalaris control. A fallow has been shown to be as effective as a resistant crop in reducing RLN. However, as previously discussed, the *Lower intensity* system experienced a decrease in profit from forgone opportunities compared to the *Baseline*. The *Higher diversity* system has successfully reduced the RLN population at Mungindi from very damaging levels of 13/g soil to a low of 0.3/g soil in 2021 by growing resistant crops – sorghum, sunflowers and durum. *Higher diversity* has returned a lower gross margin of $2595/ha ($325/ha/yr) than the *Baseline.* However, the *Higher diversity* system was still twice as profitable as the *Lower intensity* system.

At Billa Billa, pathogens were low and have mostly remained low in all systems, so the *Higher diversity* system has had little opportunity to improve the biological outcomes of the system. Instead, all the crops grown to reduce the risk of crown rot and RLN are hosts to Charcoal rot (*Macrophomina phaseolina*), which is now present at quite high levels in *Higher diversity* at Billa Billa.

Legumes

The other 'diversity' strategy in these experiments was *Higher legume,* which was included to reduce the reliance on nitrogen fertiliser. At five of the seven sites there was a reduction in nitrogen fertiliser applied in the *Higher legume* compared to the *Baseline* (two were the same), for an average saving of 95kg N/ha over eight years (range 0-170kg N/ha). *Baseline* applied an average of 280 kg N/ha (25-520 kg N/ha) over the eight years, while *Higher legume* applied 185 kg N/ha (25-370 kg N/ha) over that period

Across all sites and seasons, the variable costs for growing a cereal crop (wheat, barley, sorghum) were $155/ha, whereas legume crops (chickpea, faba bean, mungbean) cost $220/ha; the extra costs being due to higher seed costs and more in-crop sprays (fungicides and insecticides).

Despite the reduction in fertiliser applied, the higher cost of growing legume crops meant total costs were similar for *Baseline* and *Higher legume* at five of the seven sites. Gross margin was improved by *Higher legume* at only one site, Mungindi $4360/ha ($545/ha/yr) compared to *Baseline* of $3032/ha ($378/ha/year), which was attributed to *Higher legume* growing a 2.2t/ha chickpea crop in 2021 followed by 3.5t/ha wheat crop in 2022. At the same time, the *Baseline* grew the two crops in reverse order for very different yield outcomes with 2.6t/ha wheat crop in 2021 and 0.7 t/ha chickpea crop in 2022.

Billa Billa has high chlorides and sodicity at depth, so legumes can only extract soil water from the top 50cm of the soil. This has meant that income from pulses is less than cereals (higher yielding) in most seasons and so *Higher legume* had the lowest gross margin of any site at $3916/ha ($490/ha/yr), compared to $6535/ha ($817/ha/yr) in *Baseline*.

How much fertiliser to apply…

Quantity of fertiliser – *Higher nutrient*

We have modelled the yield potentials of crops for different planting dates and starting PAWs for all locations in the project. From these we can estimate the median (50%) yield potential, then calculate a nitrogen budget and apply nitrogen fertiliser at planting as required in our *Baseline* system. The *Higher nutrient* system estimated the yield potential for a 1 in 10 year season (90% yield potential) and applied nitrogen (N) fertiliser accordingly. No N fertiliser is applied to legume crops. We also applied a higher rate of phosphorus (P) in *Higher nutrient* but this has not resulted in a yield difference in any sites, so the focus of this discussion is on the N effects.

Billa Billa, is a 'newer paddock', with 1.2% organic carbon and was previously managed as a higher nutrient farming system. The paddock had a high level of available N (~350 kg N/ha) in the soil when the experiment started and has been able to supply sufficient nitrogen for the crops, so *Higher nutrient* has only required 20kg N/ha (43 kg urea/ha) of fertiliser to date, which has had no impact on yield.

At Mungindi, we applied 134 kg N/ha (290kg urea/ha) more in *Higher nutrient* (298 kg N/ha) compared to the *Baseline* (164 kg N/ha) over four wheat crops. Each of these wheat crops has produced more biomass in *Higher nutrient*, but the extra N has delayed flowering into hotter times and so grain yields were reduced in two years. The combined results of these four crops was an extra 1.8 t/ha of biomass, but 0.4 t/ha less grain in *Higher nutrient* compared to *Baseline*. With the added cost of fertiliser, *Higher nutrient* returned $2935/ha ($367/ha/yr); $100/ha less than *Baseline*. The Higher nutrient system had on average 50 kg N/ha extra available at planting of each crop.

Alternative nutrient sources – *Higher fertility*

At Billa Billa and Emerald, 50–70 t/ha compost/manure was added to the *Higher fertility* system to mimic a 'newer' paddock with a higher organic carbon. This system was then treated with our *Higher nutrient* strategy with the aim of maintaining higher fertility.

At Billa Billa, the starting fertility of the soil has been sufficient to supply the demands of all crops in *Baseline* to date. *Higher fertility* yielded an extra 0.6 t/ha (3.6 t/ha versus 3.0 t/ha) in double cropped sorghum after chickpea in 2022 but there has not been a yield benefit overall. That system has consistently mineralised more nitrogen in the fallow, so after eight crops in this experiment, it still has adequate mineral nitrogen to supply the crops' demand whereas the *Baseline* and *Higher nutrient* systems now require nitrogen fertiliser.

Organic carbon (OC) was measured at Billa Billa at the beginning of the experiment in 2015 (before the compost was added) and again in 2019. In 2019, the *Higher fertility* system had more OC (1.4%) than *Baseline*, which maintained OC at 1.2% over that period. However, the 0.2% increase in measured OC was less than half of what was added in the compost application. OC will be measured again in 2025, to see if that downward trend has continued or stabilized.

The Emerald site had lower starting fertility (0.8% OC), so has been more responsive to both the *Higher nutrient* and *Higher fertility* systems. In nine crops grown at Emerald, *Higher nutrient* has produced 1.5 t/ha more grain than *Baseline*, while *Higher fertility* has produced an additional 5.1 t/ha.

Pasture with and without nitrogen fertiliser

At Billa Billa and Pampas, a grass ley pasture was established in 2015, with the aim of increasing the OC naturally, then returning it to cropping with a higher fertility. These grass pastures had one third of the dry matter (two thirds height) cut and removed at anthesis, and 80% of nutrients (NPKS) returned (as fertiliser) as a surrogate to grazing in the small plot cropping experiment. In addition, half the pasture plots had 50 kg N/ha (109 kg urea/ha) applied after each 'grazing event' (100 kg N/year).

In 2019, OC measurements showed that the pasture had indeed increased OC levels by 0.2% to 1.4% at Billa Billa. At this point (three years of grass), half the pasture treatments were returned to cropping and treated the same as *Baseline,* while half were retained as pasture for another three to five years.

Responses to applied N were not obvious in the pasture prior to 2019, so as expected the effect on OC was the same in these two pastures. Once returned to cropping, the *ex-fertilised pasture* had an extra 100kg/ha of available N (nitrate and ammonium nitrogen) at planting of each crop, which met the requirements of the three crops to date. Whereas, the *ex-unfertilised pasture* required 70 kg N/ha fertiliser in the third (sorghum) crop. Similar trends were observed at Pampas; while there was no fertiliser saving at Pampas, there was an extra 400 kg/ha of grain in the first three years after pasture removal (four crops).

These "ex-pasture" systems appear to have improved infiltration, meeting the planting PAW trigger to double crop twice in 2021–2022 at Billa Billa, while the long-term cropping *Baseline* was only double cropped once. Unfortunately, this increase in double cropping led to an unexpected downside to increased yield from additional N supply. The barley in 2021 yielded 200 kg/ha more in the *ex-fertilised pasture* (3.2 t/ha) than the *ex-unfertilised pasture* (3.0 t/ha), and then the double-cropped sorghum after that was 400 kg/ha lower in the *ex-fertilised pasture*. This was surprising, but we determined that the higher yielding barley crop extracted

20 mm more PAW at harvest (something commonly observed in our cover cropping research). Over a normal fallow this would typically recover and balance out, but in a double crop situation this deficit was still evident at planting of the sorghum and led to the unexpected yield penalty.

The long-term pastures at Billa Billa have had clear N responses (2019-2022), with an extra 10 t/ha (dry weight) of biomass produced from 550 kg N/ha applied since 2015. As previously described, the grazing value of the pastures has been estimated (not grazed and animals weighed). The gross margin of the *fertilised pasture* is $3058/ha ($382/ha/yr) more than that of the *unfertilised pasture* ($11816/ha or $1477/ha/yr versus $8758/ha or $1095/ha/yr).

The *longer-term pastures* experienced pasture dieback in 2022-23 summer. The decision was made to return them back into cropping, with similar trends emerging in the two crops since then (data not available yet).

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Tracking P fertiliser recovery using isotopes – both starter P and deep P

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Key words

phosphorus, deep P, ^{33}P radioisotope, placement strategy, Vertosol

GRDC code

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Take home message

- Crop phosphorus (P) responses to fertiliser placement vary widely in Vertosols
- Deep P bands (15 – 30 cm depth) are utilised by crops and can result in higher yield relative to that of starter P alone at low soil P fertility
- Crop P uptake from deep P (20 cm depth) was 1.2 – 5.0 times greater than from starter P, resulting in an additional 2.6 – 3.5 kg fertiliser P ha^{-1} accumulating in the crop
- The proportion of crop P uptake derived from the fertiliser was 29 – 49 % for deep P and 7 – 23% for starter P
- Crop recovery of fertiliser P was typically low, i.e., up to 24 % of starter P and 10 % of deep P applied was recovered by the crop in the year of application
- In general, crop uptake of fertiliser P was increased with soil N fertility.

Background

Placement strategy of phosphorus (P) fertiliser can be an important factor for improving crop growth and crop P uptake in the northern grains region (NGR) of eastern Australia. Due to continual cropping of clay soils in the NGR, soil fertility has declined which has caused an increasing reliance on mineral fertilisers. Since mineral fertilisers are often added to the topsoil layer, which undergoes frequent drying, soil fertility is often declining in the subsoil layer. This is a problem because root activity is generally higher in the subsoil where there are increased stores of subsoil moisture (Bell *et al.,* 2020). Deep placement of fertiliser P in clay soils has been an effective strategy to overcome crop P deficiency and improve crop production across the NGR.

There has been over a decade of research across southern and central Queensland (DAQ00148, UQ00063 & others) investigating crop responses to deep P, which typically involves the placement of P bands in the 10 – 30 cm soil layer. Substantial yield responses to deep P have been shown compared to the traditional strategy of applying starter P alone, with the benefit of deep P typically being additive to starter P (Bell *et al.,* 2020). However, there are situations where crop responses to deep P were negligible, which may be due to differences in crop type, soil properties, and seasonal growing conditions (detailed in Lester *et al.,* 2022). Furthermore, it is unclear whether deep P results in improved fertiliser P recovery, or more efficient utilisation of native soil P pools.

Using radioisotopes to track P fertiliser

The use of radioisotopes to label mineral fertilisers is a powerful method to track the fate of fertiliser P in the cropping system. In general, radioactive isotopes behave similarly to their stable isotope counterparts, but provide a 'fingerprint' or 'tag' which can be tracked in the system. All the P in nature exists as the stable P isotope, ^{31}P. The radioactive isotopes of P, i.e., ^{32}P and/or ^{33}P, can be incorporated into a fertiliser source. Therefore, any of the radioactive isotope (e.g., ^{33}P) detected in the crop must have come from the added radiolabelled fertiliser.

The use of radioactive isotopes is the gold standard for tracking the fate of fertiliser P in soil-plant systems. However, there are some limitations including: the half-life or decay of the radioactive isotope (^{32}P half-life = 14.3 days and ^{33}P half-life = 25.4 days), which prevents its use over multiple growing seasons, its high cost to purchase, and increased regulation. Consequently, studies in the field generally need to be carried out in microplots and need careful planning and approval.

The results outlined in this paper are from a single growing season under field conditions using ^{33}P-labelled fertiliser added to microplots at the Colonsay long-term field experiment. It forms part of a PhD project assessing the effects of P placement strategy and soil fertility on crop utilisation of P fertiliser in Vertosols of the NGR.

Method

Experimental design

In 2023, a microplot experiment under field conditions was established at 'Colonsay', a long-term N x P experiment located in the Darling Downs region of south-east Queensland. The site is located on a black Vertosol (Isbell, 2016) and has been under cultivation since 1944. In 1985, it was established as an experimental site (Lester *et al.*, 2008). Briefly, the overall experiment is 4 x 4 factorial design comprising main plots (14 x 2.5m) of four N application rates (0, 40, 80, 120 kg N ha^{-1}) and four P application rates (0, 5, 10, 20 kg P ha^{-1}). Agronomic management generally reflects regional farmer practice. This current microplot experiment utilised a subset of the overall long-term N and P treatments to which fresh, ^{33}P-labelled MAP solution was applied using contrasting placement strategies (Table 1).

Table 1. Overview of experimental treatments including past N and P application rates and fresh P placement strategy.

Factor	Description
Past N application	1. 0N – no N applied 2. 80N – 80 kg N ha^{-1} applied as urea in shallow band pre-plant
Past P application	1. 0P – no P applied 2. 10P – 10 kg P ha^{-1} applied as triple superphosphate (TSP) in seeding trench at sowing
Fresh P placement strategy	1. Starter P – ^{33}P-MAP applied equivalent to 10 kg P ha^{-1}, placed 5 cm deep 2. Deep P – ^{33}P-MAP applied equivalent to 40 kg P ha^{-1}, placed 20 cm deep

Soil analyses confirmed that the selected plots provided contrasting initial soil N and P fertility in (at least) the top 30 cm of the soil profile, particularly in the 0 – 10cm layer (Table 2).

Table 2. Soil P and N levels across past N and P application rates at 'Colonsay'. Sampled June 2022.

Depth	Colwell P (mg P kg^{-1})				Nitrate-N (mg N kg^{-1})			
	0P, 0N	80N, 0P	0N, 10P	80N, 10P	0P, 0N	80N, 0P	0N, 10P	80N, 10P
0–10cm	14.0	12.0	37.0	35.0	7.3	13	6.8	12
10–30cm	6.0	< 5	8.0	14.0	6.5	7.3	5.7	6.2

Applying ^{33}P-labelled fertiliser to the field

Barley (*Hordeum vulgare* L.) cv. AGT-Yeti⊕ was sown on 11 June 2023 at a planting rate of 100 plants/m^2 with 0.32 m row spacing. Commercial-grade MAP was labelled with ^{33}P and was applied in solution form 9 days after sowing (DAS). Briefly, a 0.2 m long microplot along a plant row was established within each pre-existing experimental plot. Microplots were placed in a central plot row where emergence was consistent, and not within 0.5 m of either end of the plot. A 5 mm diameter x 25 cm long metal tube with a removable metal insert was inserted into ground at depth, the metal insert removed, and then the ^{33}P-labelled MAP solution injected into the tube (Figure 1). All microplots were hand-harvested at late-booting (76 DAS) to determine aboveground biomass, total P uptake and uptake of the P released from the ^{33}P-labelled MAP solution.

Figure 1. Example of a microplot where the ^{33}P-fertiliser was applied at 9 DAS (left) and at harvest (right). ^{33}P-labelled MAP solution was applied as: starter P (eqv. to 10 kg P ha^{-1}, 5cm deep); or deep P (eqv. to 40 kg P ha^{-1}, 20 cm deep) to each microplot.

Results

Seasonal growing conditions and overall crop performance

The 2023 winter growing season was very dry, experiencing decile 1 rainfall for the region. There was a total of 31 mm of rainfall over the season, approximately half of which fell on July 4 (25 DAS). Consequently, grain yields in the broader N x P experiment (i.e., the main plots, which were harvested at maturity) were considerably less than in wetter years, ranging 667 – 1700 kg ha^{-1}, with the bulk of this difference attributed to N.

Biomass responses to contrasting P placement strategy

When initial soil N fertility was low, the application of deep P increased barley shoot biomass by 57 – 79 % compared to when starter P was applied to the 0P and 10P plots respectively (Figure 2). In contrast, barley shoot biomass at different P placement was similar under conditions of elevated soil N fertility. This suggests that the growth differences in the 0N treatment were largely an N response to the additional MAP applied with deep placement, consistent with the N responsiveness observed across the broader main-plot experiment. This N limitation was reduced in the 80N plots, where growth was likely limited by water, decreasing the potential for P responses in this season.

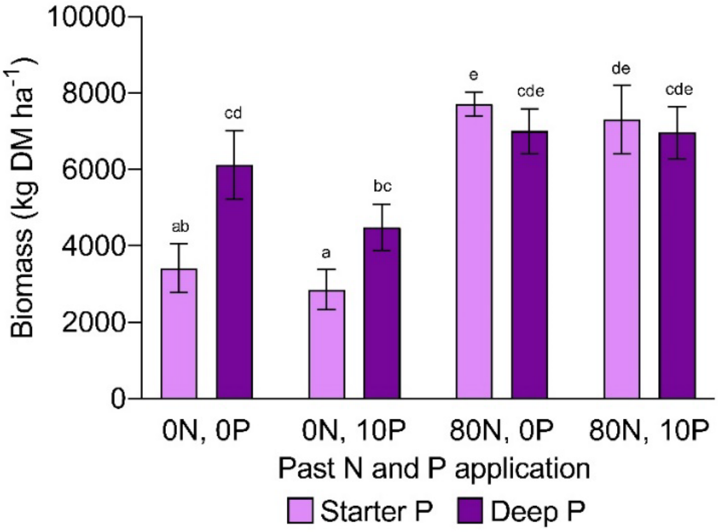

Figure 2. Barley aboveground biomass (kg DM ha^{-1}) with contrasting P placement strategy, soil N and P fertility. Error bars represent SEM (n=3), and values do not differ at the 0.05 level if accompanied by a common letter.

How much P fertiliser ended up in the crop?

Phosphorus placement strategy had a clear effect on the amount of fertiliser P taken up by the crop. Deep P supplied 1.2 – 5.0 times more crop P than starter P, resulting in an additional 2.6 – 3.5 kg fertiliser P ha^{-1} accumulating in the crop (Figure 3). This also meant that a greater proportion of total crop P was derived from deep P (29 – 49 %) than starter P (7 – 23 %). Nevertheless, the soil remained the primary source of crop P (> 50 %).

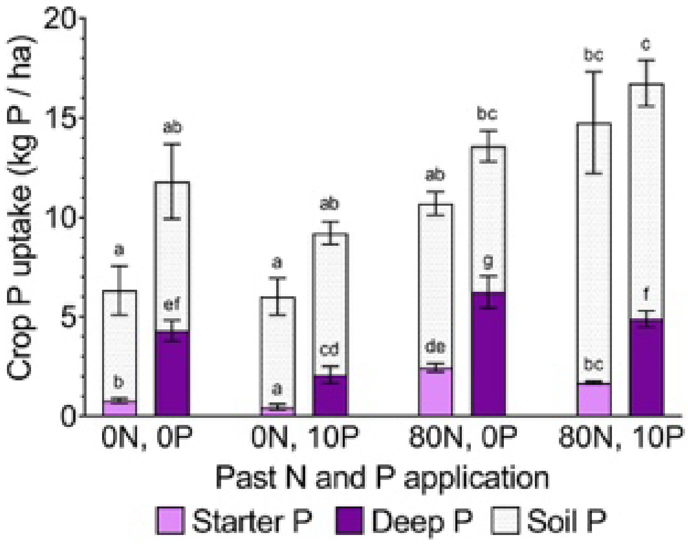

Figure 3. Crop P uptake (kg P ha^{-1}) from ^{33}P-labelled MAP and the soil with contrasting P placement strategy, soil N and P fertility. Error bars represent SEM (n=3). Total crop P uptake does not differ at the 0.05 level if letters above a column are the same. Crop uptake of ^{33}P-labelled fertiliser does not differ at the 0.05 level if letters within a column are the same.

The increase in crop P uptake from fertiliser placed at depth was accompanied by an increase in total crop P uptake. However, these differences were not statistically significant, likely influenced by dry seasonal conditions and considerable variability in crop P uptake. Nonetheless, the increase in fertiliser P uptake with deep placement demonstrates that it was a more effective strategy to get fertiliser P into the crop, providing greater potential to increase yield responses to P when seasonal conditions permit. This is consistent with previous field experiments where yield responses to (unlabelled) deep P are apparent (Lester *et al.,* 2022).

Crop P uptake of fertiliser P was affected by initial soil fertility. Elevated soil N increased crop P uptake of fertiliser P, while increased soil P fertility decreased crop P uptake of fertiliser P, which was due to more P coming from the soil instead. However, dry seasonal conditions likely limited crop uptake of these soil nutrients which are concentrated in the 0 – 10 cm layer, potentially lessening their effect on the contribution of fertiliser P to crop P uptake.

How much P fertiliser was recovered by the crop?

Crop recovery of P from the radiolabelled fertiliser ranged 3 – 24 % (Table 3). Elevated soil N fertility increased crop recovery of fertiliser P, particularly when applied as starter P. Consequently, recovery of deep P was less than starter P in the 80N treatment. However, it is important to consider the overall objectives of deep P application when comparing the recoveries of deep P and starter P. Deep P will likely provide crop P across multiple growing seasons, meaning recovery in the year of application represents only a fraction of what will eventually accumulate in successive crops. While the ability to directly quantify the residual value of deep P using ^{33}P-labelled fertiliser is limited by its short half-life, previous experiments have demonstrated yield responses to deep P at least 5 years following application (Sands *et al.,* 2020). Nonetheless, crop P recovery in the year of application was generally low for both placement strategies, highlighting the need to investigate opportunities to further improve the efficiency of P fertiliser use.

Table 3. Recovery of ^{33}P-labelled MAP (%) with contrasting placement strategy, soil N and P fertility. Values do not differ at the 0.05 level if followed by a common letter.

Past N and P application	Crop recovery of ^{33}P-MAP (%)	
	Starter P	Deep P
0N, 0P	8.0_{bc}	6.9_{abc}
0N, 10P	4.6_{ab}	3.3_{a}
80N, 0P	24.4_{e}	10.0_{cd}
80N, 10P	17.0_{de}	7.8_{abc}

Summary

This experiment has demonstrated that P placement strategy can have a profound effect on how much fertiliser P ends up in the crop. Deep P was a relatively more important source of crop P compared to starter P, even across conditions of variable soil N and P fertility. While potential growth responses to deep P (and therefore economic benefits) were limited by a lack of rainfall in this dry season, these findings provide further evidence that applying deep P is an effective P management strategy in our northern cropping systems. Furthermore, elevated soil N fertility was found to increase crop recovery of fertiliser P, highlighting the importance of ensuring N supply is adequate to optimise P fertiliser use.

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Optimising sorghum grain yield in western growing regions – a focus on agronomy and nutrition

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Key words
sorghum, nitrogen, row spacing, improving water use, yield and grain quality

GRDC code
PROC -9176856 – Increasing sorghum area in northwest NSW through understanding and adoption of early sown sorghum principles.
UOQ 1808-001RTX – Optimising sorghum production in the northern region.

Take home messages

- Ensuring starting soil water >150 mm and a low weed seed bank is essential for improving the likely success of sorghum crops in western regions of northern NSW
- August planting once soil temperatures are at 13 °C and rising provides an opportunity for early sowing, with a very low risk of frost damage after 7 leaves or floral initiation
- Establish 5–6 plants/m^2, regardless of the row configuration; this population has been the most reliable performer across sites and seasons, west of Moree
- In high yielding seasons solid plant rows (50–100 cm) will outperform single and double skip.
- In lower yielding seasons (<4 t/ha), more data is required to establish the performance of narrow (50 cm) row spacings
- Positive grain yield responses to nitrogen have been demonstrated in the last two seasons. The economics of applying nitrogen to sorghum in western regions will depend on seasonal pricing of sorghum grain and nitrogen, and the predicted grain yield.
- Across two years of testing, a soil N bank target of ~170 kg N/ha provided the best economic returns from vary contrasting starting soil N levels
- Low grain protein <9% is often a useful indicator of significant nitrogen deficiency.

Introduction
Western growing regions of Northern NSW have long been recognised for their ability to reliably produce winter crops, but they also have the potential to produce significant areas and tonnages of sorghum.

Research over the last 15 years has led to changes in our agronomy practices and identification of ways to optimise crop performance in the region. Advances in our knowledge into the future will continue to push the yield frontier further.

Maximising crop performance always starts with good rotational practices, such as maintaining clean fallows and ensuring soil water profiles are full prior to planting. In western regions research indicates profit and risk management are best considered with >150 mm of starting PAW. This paper contains an overview of the current knowledge for optimising crop yield potential for sorghum in the west.

Small steps to achieve big changes in the western regions

Over the last fifteen years, we have conducted research in northwest NSW to develop our knowledge of the best methods to optimise sorghum production in this variable environment. This research has covered row spacing, plant population, hybrid selection, time of sowing and nitrogen nutrition. The results of these trials have each provided yield gains which have led to a focus on delivering a combined package for sorghum agronomy in this environment.

How many plants do I need to maximise grain yield?

Grain yield responses to plant population has been tested across a wide range from very low (~1.5 plants/m^2) to very high (~12 plants/m^2). These populations have been tested across the main row configurations used in the region; 100 cm solid, single skip, double skip and super wide rows (150 cm solid) (Figure 1).

Plant population is a balance between establishing enough plants to achieve the maximum potential yield and to avoid any unnecessary expenditure on seed costs. Plant population is firstly about maximising grain yield but also has implications for weed competition, improving resource capture and efficiency (water, sunlight etc) and crop evenness for pest control and desiccation.

In areas west of Moree - as a rule of thumb, establish 5–6 plants/m^2, regardless of the row configuration; this population has been the most reliable performer across sites and seasons. Establishing higher populations (we have tested at 9 and 12 plants/m^2) has not provided any grain yield benefits. In contrast, establishing less than 3 plants/m^2 has limited yield potential. Very low plant populations also deliver additional challenges with gaps and uneven plant stands in a paddock.

Which row spacing to use?

Sorghum can be successfully established and grown on row spacings as close as 25 cm or as wide as a double skip on 100 cm configurations. The choice of row spacing depends on your attitude to risk in your growing environment, starting soil water, seasonal forecast, availability of machinery and system fit.

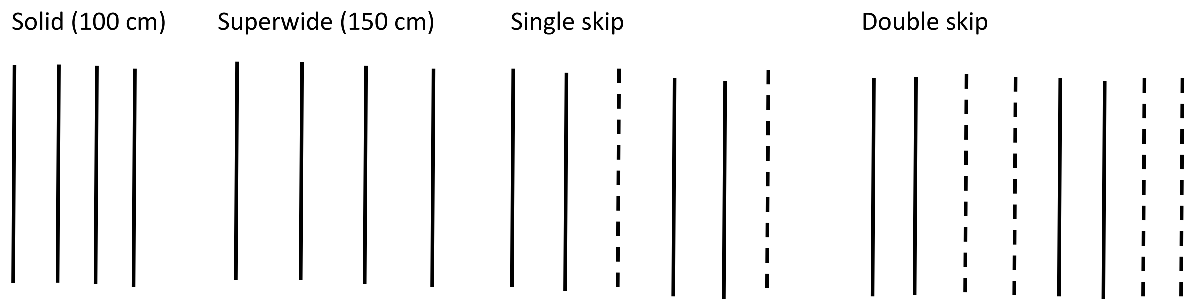

Figure 1. Row configurations used in sorghum.

The recommended row configuration where yield expectations are >3.5 t/ha has been 75–100 cm using a precision planter. The use of precision planters enables less seed to be used, more uniform seed spacing and a more even crop maturity. However, sorghum can still be established using air seeders, although the risk of poorer establishment outcomes is higher.

Sorghum has a strong compensatory mechanism through its production of tillers and will respond to competition and environmental conditions. It is recommended to match your row spacing to your expected yield and the available soil water. As a rule of thumb, >3.5 t/ha use solid plant row spacing's and for <3 t/ha use 100 cm solid or consider skip or wide row configurations.

Recently there has been increased interest in the use of narrow row sorghum in the western regions (50 cm or less). The interest in narrow row spacings relates to the ability to utilise existing winter planters for summer crop planting and hopes of increased ground cover and improved fallow infiltration and retention under closer plant rows.

Research results from the last two seasons which include narrow row sorghum are preliminary in nature, as they are from sites where yields were >4.0 t/ha. In the 2021/22 season, with a site average yield of 8.2 t/ha at Mungindi, there was no significant difference between 33, 50 and 100 cm row spacings. In the 2023/24 season at Weemelah with a site mean yield of 6.1 t/ha there was no difference between 50 and 100 cm solid row spacings, however there was a decline in yield from using single skip (Figure 2).

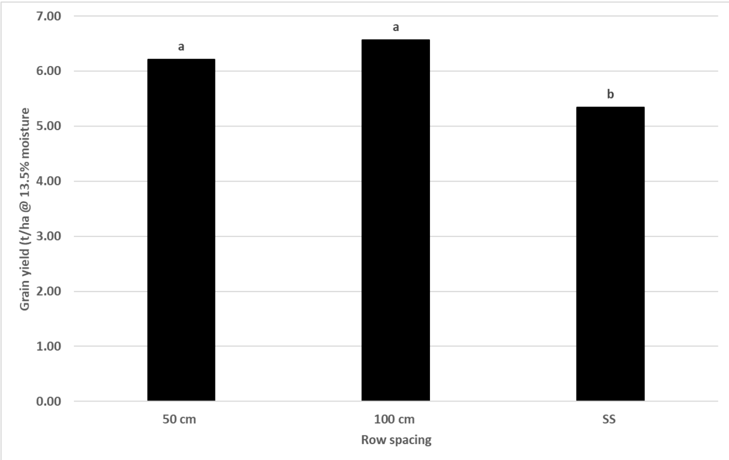

Figure 2. Grain yield at three row spacings at Weemelah, 2023/24. Data with the same letter are not significantly different (*P*<0.05).

At Millie, where average yield was 4.31 t/ha, there was an interaction between hybrid type and row spacing. At this site there was no significant difference between the yields at 50 and 100 cm row spacings for A14 and Viper IG but Halifax yielded significantly less than the other 2 hybrids at the 50 cm spacing only. Single skip yields were lower for the quick maturity hybrid Viper IG (Figure 3).

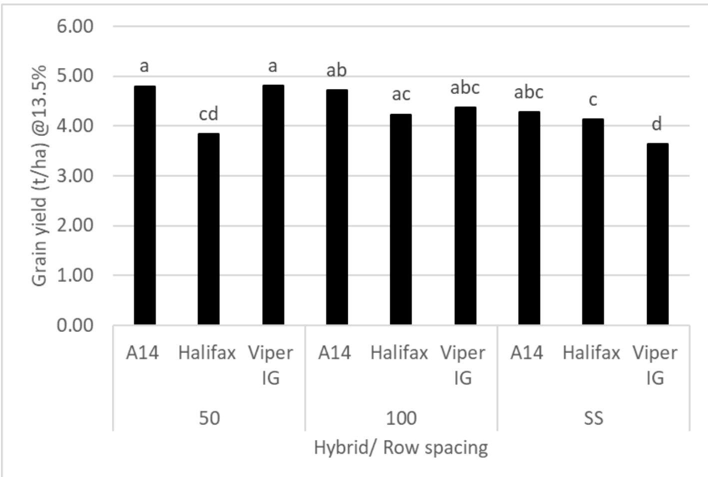

Figure 3. Grain yield at three row spacings and hybrids at Millie, 2023/24. Data with the same letter are not significantly different (*P*<0.05).

Therefore, based on the available data there has been no difference between 50 and 100 cm rows spacings, except for Halifax this season with yields greater than 4.0 t/ha. It may be premature to use these results for yields <4.0t/ha. The next season will hopefully provide data on the response of narrow versus 100 cm rows in lower yield scenarios of 2 – 4 t/ha.

The advantage of wide or skip row spacing is the ability to conserve water in skip areas for flowering and grain fill as the plant roots are generally unable to explore this area fully before flowering. Weed control is more critical in wide row configurations because of the lower interrow competition. If weeds are not controlled adequately the advantage of a wider row configuration maybe negated. These wider row spacings are very reliable but also cap yield outcomes in high yielding seasons.

When is the best time to plant?

The ideal time to plant sorghum is always a compromise. Planting is encouraged when you can meet the highest number of "ideal" parameters for successful establishment and yield. Sowing time is recommended to be either early (August) or late (December/January) in the western growing regions, depending on your attitude to risk and fit with your other farm operations. These timings ensure the critical flowering period received the likely best temperature conditions and avoids yield loss due to heat stress. Early sowings may also allow plant establishment before FAW can increase its population.

It is not recommended to plant during October and November in most situations as the crop will reach flowering and grain fill in December/January when the risk of heat stress is high. This can reduce head exertion, seed set, crop yield and increase the likelihood of crop failure.

Regardless of the planting time, the soil moisture profile should be full (>150 mm) and seedbed moisture should be sufficient to support the germination and emergence process, which can be 14 days for early sown sorghum and 7 days for late sown sorghum.

Table 1. Pro's and con's of early or late planting times

Early planting (August)		**Late planting (December/ January)**	
Pro's	**Con's**	**Pro's**	**Con's**
Crop should flower before the extreme heat period. Crop establishment in a period of low FAW pressure.	Soil temperature needs to reach a minimum of 13°C and rising. False starts can reduce establishment.	Fallow weed control can be completed to ensure weeds are controlled.	Soil temperature can be very high, reducing seed emergence and drying out the seedbed quickly.
Crop yields will be as good or better than planting in September.	Crop growth and development will be slower, so it takes more days to reach 50% flower.	Seed will rapidly emerge due to very warm soil temperature.	Later to flower, slower maturity and grain dry down. Harvest will be late so grain may need to be dried. Shorter days mean fewer harvest hours.
Earlier harvest, usually from mid-January. This starts the fallow re-fill earlier, allowing the possibility of double cropping.	Paddocks need to be clean of winter weeds, e.g., black oats, as the crop will be emerging when these species can still be germinating.	Opportunity to wait longer for a full soil moisture profile prior to planting.	Harvest can clash with winter planting.

Avoid clashes with winter crop planting & harvest.	High quality seed is needed. Hybrid cold tolerance varies so hybrid choice is important.	Crop growth and development will be quicker. Most hybrids will flower in 65–70 days.	There is no opportunity to double crop, so a long fallow is required to move back into a winter crop.

Nutrition

The attitude towards crop nutrition in the western regions is steadily changing, as agronomy practices have improved crop reliability and overall yields. Data from the Australian Bureau of Statistics on sorghum production in NSW shows that in the 10-year period between 2005-6 and 2015-16 average yields have increased by more than 1.0 t/ha, from 2.72 t/ha in to 3.80 t/ha.

As such, it seems reasonable that we should be investing in crop nutrition in line with increasing yield if it is supported by positive economic returns. It is still more common for dryland sorghum in this environment to be planted without the application of any nitrogen and in some cases without any starter fertiliser. Historically we invested in fertilising our wheat and relied on following sorghum crops to utilise the remnant nitrogen after the wheat, as well as mineralised nitrogen which became available during the long fallow.

Nitrogen

Nitrogen remains the crop nutrient required in the largest amounts for crop production. In grain sorghum we remove ~15 kg of nitrogen (N) for every tonne of grain so on average we are exporting ~60 kg/ha in every 4-tonne sorghum crop. In may crops the industry standard is to assume the N removed in grain is doubled to estimate the N required in the soil meaning ~30 kg of soil N is required for every tonne of sorghum grain or 65 kg of urea/t. Estimates of soil mineralised N are essential for sound budgeting and are subtracted from the projected crop N requirements to determine fertiliser N inputs. Potential yield is reached with grain protein levels above 10%, between 9 and 10% N is considered to be marginal and below 9 % N is deficient.

In 2022/23 and 2023/24 experiments were conducted at Millie testing nitrogen application timing and rate. Eight nitrogen treatments were applied in the form of urea, including a nil treatment and a mix of upfront, in crop (6 or 10 leaf growth stage) or split applications.

In 2022/23 the site started with 81 kg/ha nitrogen in the top 120 cm. The average site yield was 3.4 t/ha and total soil N requirement based on this yield at 50% efficiency was 102 kg/ha. Subtracting the soil N of 81 kg/ha indicates at least 21 kg of fertiliser N/ha was required or ~46 kg urea. There was a positive grain yield response of more than 1.0 t/ha to any additional urea applied (Figure 4a).

The highest yield (Upfront 210 kg/ha urea Figure 4a) advantage was 1.2 t/ha priced at $320/t is a $384/ha advantage. The cost (N cost) of achieving this yield in this experiment was $147 assuming a urea cost of $700/t. Applying a spreading cost of $15/ha and based on the price assumptions, the partial gross margin benefit was $222/ha. The lowest yielding N treatment (figure 4a) was upfront 140 kg urea with a yield advantage of 0.7 t/ha and a partial gross margin of $111/ha.

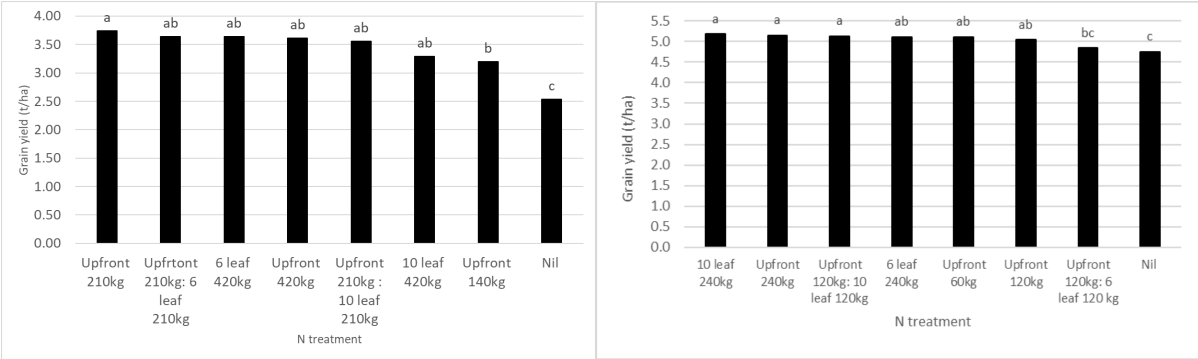

Figure 4. Grain yield of urea treatments at Millie in a) LHS: 2022/23 and b) RHS: 2023/24

In 2023/24 the site started with 137 kg/ha of nitrogen to a depth of 120 cm (Figure 4b). The average site yield was 5.04 t/ha. There was an increase in grain yield of ~0.3–0.4 t/ha from the application of any urea over the nil treatment (Figure 4b). Comparing the Upfront urea at rates 240 and 60 kg urea/ha they both achieved a yield increase of 0.4 t/ha and partial gross margins of -$58 and $68/ha respectively.

In this work the 2022/23 season where starting N was 81 kg/ha and added N upfront was ~97 kg N/ha (210 kg urea/ha) it provided a soil bank of ~178 kg N/ha while in 2023/24 the starting N was 137 kg N/ha and upfront N was ~28 kg N/ha (60 urea /ha) it provided a soil bank of ~164 kg N/ha. In these circumstances a total N bank of between 160 and 180 kg N/ha provided a partial gross margin between $111 and $222 per ha with the lower return associated with high starting soil N. While the sites varied greatly in starting N, topping the N bank up to ~170 kg N/ha was most profitable across both seasons. A positive response was also recorded in grain protein, with more than a 1% protein increase from 8.36% to 9.99% from applying 240 kg of urea (data not shown).

It is important to remember that yield responses to nitrogen application will vary between seasons and the decision to apply nitrogen should be based on measurement of the starting soil nitrogen level, the price of the nitrogen fertiliser, starting soil water, potential crop yield and likely economic return. However, results from the last two seasons support that additional nitrogen to a N bank target of ~170 kg N/ha can result in higher yield and profit in this region.

Conclusions

The research and agronomic advancements over the past fifteen years in north western NSW have significantly improved our understanding of sorghum production, leading to optimized practices tailored for this variable environment. Key areas of focus such as row spacing, plant population, hybrid selection, time of sowing, and nitrogen nutrition have collectively contributed to yield gains.

Timing of planting is crucial, with early (August) and late (December/January) sowing recommended to avoid heat stress during critical growth periods. Adequate soil moisture (>150 mm) is essential for successful and early sowings (rising temperature plain from 13°C has the additional advantage of avoiding FAW in the early establishment phase.

Establishing optimal plant populations, specifically 5-6 plants/m^2, has been shown to reliably maximize grain yield across different row configurations. Row spacing decisions should be guided by yield expectations and soil water availability, with solid plant rows recommended for yields above 4.0 t/ha and skip or wide rows for yields below this threshold.

Nitrogen removal in sorghum grain is ~15 kg N/t. Recent trials indicate that maintaining a total nitrogen bank of 160-180 kg N/ha can enhance both yield and profitability. It's essential to base nitrogen application decisions on current soil water and nitrogen levels, and economic considerations.

Continued research management strategies and genetic adaptation will further enhance the region's capability to produce high-yielding sorghum crops, contributing to the sustainability and profitability of local farming systems.

Acknowledgements

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Cereal disease update for 2024: where do we sit in the north?

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Keywords
leaf diseases, Fusarium head blight, stripe rust, yellow spot, fungicide, climatic conditions

GRDC codes
DPI2207-002RTX: Disease surveillance and related diagnostics for the Australian grains industry

Take home messages
- Favourable planting and growing conditions so far are likely to be conducive to the development of wheat leaf diseases in 2024
- Correct identification is critical in disease management, with around 15% of cereal diagnostics submitted each season not related to disease
- The predominant leaf and head diseases in wheat in the last two seasons have been stripe rust, yellow spot and Fusarium head blight (FHB)
- These diseases are likely to also be prevalent across the region again in 2024
- Growers need to be proactive in their disease management plans and adapt to seasonal conditions
- In particular, FHB risk in 2024 is potentially high given the levels of Fusarium crown rot (FCR) in recent seasons, but risk will vary between individual paddocks and is heavily reliant on specific conditions (>36 h of above 80% humidity) occurring over a narrow window at flowering
- Assessing FCR levels (basal browning) around GS39 in wheat crops and inspecting retained sorghum and maize stubble for raised black fruiting structures (perithecia) is important to determine likely FHB risk in individual paddocks
- Prosaro® 420 SC foliar fungicide is registered for FHB control and must be applied at the start of flowering. Application by ground rig with twin angled nozzles and a high-water volume (minimum 100 L/ha) is recommended
- Help is available with disease identification and stay abreast of cereal disease management communications throughout the season, as 2024 is likely to be another dynamic year.

Introduction
If we all had a crystal ball, then this cropping game would be easy. So, what do we know from previous seasons with cereal diseases and what can we pre-emptively plan for and then proactively act on as required?

The contrast between leaf and head disease issues across the north in 2023 and 2022 was obviously stark. However, our memories of 2022 are fresh enough to have us nervous of cereal diseases in 2024 with the expectation of wetter spring conditions. This is particularly challenging in the north where fungicide supply issues often occur throughout the season and the so called ‘tap’ (rainfall) can turn off suddenly. What did we learn from the past two seasons and how can we use this to optimise management in 2024?

2022 – an exceptional season
The 2022 season was wet! Records were broken and flooding was widespread in some areas. Spring rainfall (Sep–Nov) in 2022 was generally very much above average across northern NSW

and southern NSW compared with average to below average in 2023 (Figure 1). Frequent rainfall is very conducive to the development of leaf diseases such as stripe rust, as causal pathogens require periods of leaf wetness or high humidity for spore germination and initial infection. However, just as significant a contributing factor to the prevalence of cereal leaf diseases was the spring (Sep–Nov) temperatures in 2022 which remained mild, compared with 2023 (Figure 1).

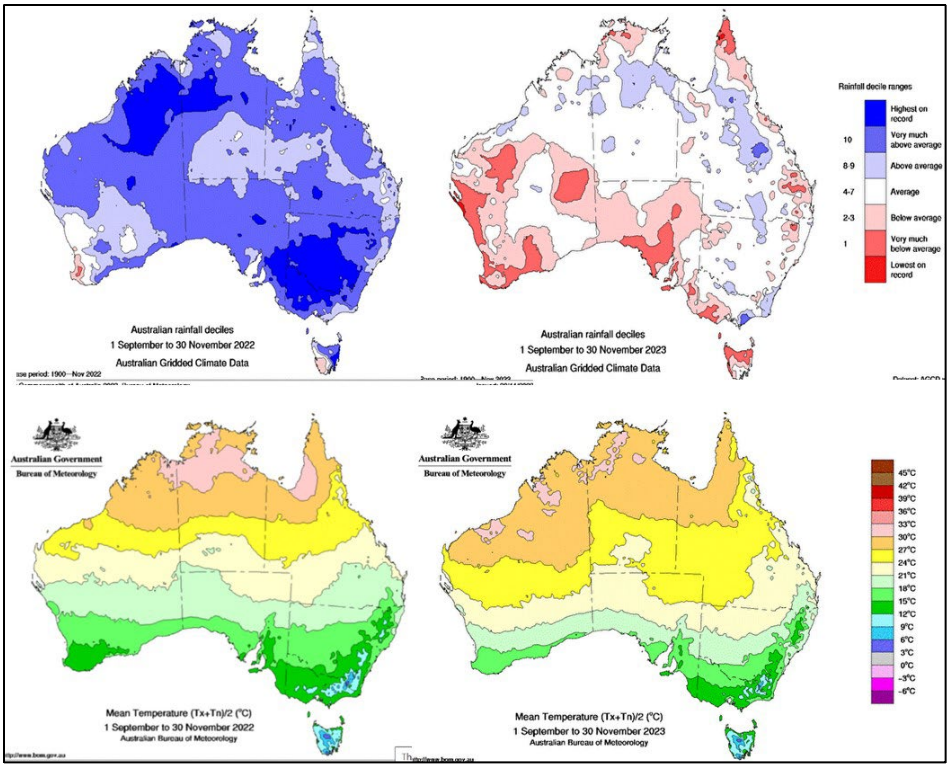

Figure 1. Rainfall decile (top) and mean daily temperature (bottom) for spring (Sep–Nov) in 2022 (left) compared with 2023 (right). Source: Bureau of Meteorology (www.bom.gov.au).

Temperature interacts with cereal diseases in two ways. Each pathogen has an optimal temperature range for infection and disease development (Table 1). Time spent within this temperature range dictates the latent period (time from spore germination to appearance of visible symptoms) of each disease, which is also often referred to as the cycle time. Disease can still develop outside the optimum temperature range of a pathogen, but this extends the latent period. Hence, prolonged mild temperatures in 2022 were favourable to extended more rapid cycling of leaf diseases such as stripe rust, Septoria tritici blotch and wheat powdery mildew compared with 2023 (Figure 1).

Table 1. Optimum temperature range and latent period of common leaf and head diseases of wheat.

Disease	Optimum temperature range (°C)	Latent period (opt. temp)
Stripe rust	12–20	10–14 days
Septoria tritici blotch	15–20	21–28 days
Wheat powdery mildew	15–22	7 days
Leaf rust	15–25	7–10 days
Yellow leaf spot	15–28	4–7 days

Fusarium head blight	20–30	4–10 days

The second effect that temperature can have on disease is more indirect, on the plants themselves. The expression of adult plant resistance (APR) genes to stripe rust can be delayed under lower temperatures. However, cooler temperatures also delay development (phenology) of wheat plants, extending the gap between critical growth stages for fungicide application in susceptible wheat varieties. The slower development under cooler spring temperatures therefore increases the time of exposure to leaf diseases in between fungicide applications, which is the case for stripe rust which is also on a rapid cycle time under these temperatures. Hence, underlying infections can be in their latent period and beyond the curative activity (~ ½ of cycle time with stripe rust) when foliar fungicides are applied. This can result in pustules appearing on leaves 5 or more days after fungicide application. The fungicide has not failed, rather the infection was already present but hidden within leaves and was too advanced at the time of application to be stopped by the limited curative activity of fungicides. At optimum temperatures, stripe rust has a 10-day cycle time in a susceptible (S) rated variety, whereas it is a 14-day cycle in a moderately resistant moderately susceptible (MRMS) variety. Disease cycles quicker in more susceptible varieties!

Reliance on fungicides for management makes susceptible (S) wheat varieties more reliant on correct timing of fungicide application. Frequent rainfall in 2022 caused plenty of logistical issues with timely foliar fungicide applications related to paddock accessibility by ground rig and/or delay in aerial applications. The associated yield penalty was significantly higher in more stripe rust susceptible varieties due to the shorter disease cycle time. There were plenty of reports of 10-day delays in fungicide applications around flag leaf emergence (GS39) due to uncontrollable logistics that saw considerable development of stripe rust, particularly in S varieties. Yield loss at harvest has been estimated at around 30–50% due to this 10-day delay. This simply does not happen in more resistant varieties, where there is more flexibility with in-crop management, because the disease is not on speed dial when climatic conditions are optimal. The recent 2022 season certainly challenged the risk vs reward of growing susceptible varieties – the management of which does not fit logistically within all growers' systems.

Main leaf diseases in 2022 and 2023

How has the contrast in spring conditions in the last two seasons impacted the prevalence and levels of key cereal diseases across the northern region?

In collaboration with a range of locally based agronomists, random surveys of cereal crops across NSW were conducted annually with a total of 283 cereal crops surveyed in 2022 and 338 in 2023. This was composed of 468 bread wheat, 102 barley and 51 durum wheat crops (Figure 2).

Dried and ground tissue samples collected from each crop were assessed for the prevalence and levels of a range of cereal pathogens using quantitative PCR (qPCR) through the South Australian Research and Development Institute (SARDI) molecular diagnostics laboratories. It is important to understand qPCR DNA assays are extremely sensitive with specificity to the target fungal pathogen of interest. Hence, we expect there to be high levels of pathogen found when infections occur. The approach used in this survey differs from traditional PREDICTA® B soil testing where calibrations have been developed to determine the relative risk of infection prior to sowing. Traditional PREDICTA® B tests quantify the amount of target pathogen DNA in the soil, old plant roots and stubble residues. This approach helps define the risk of infection developing within a season.

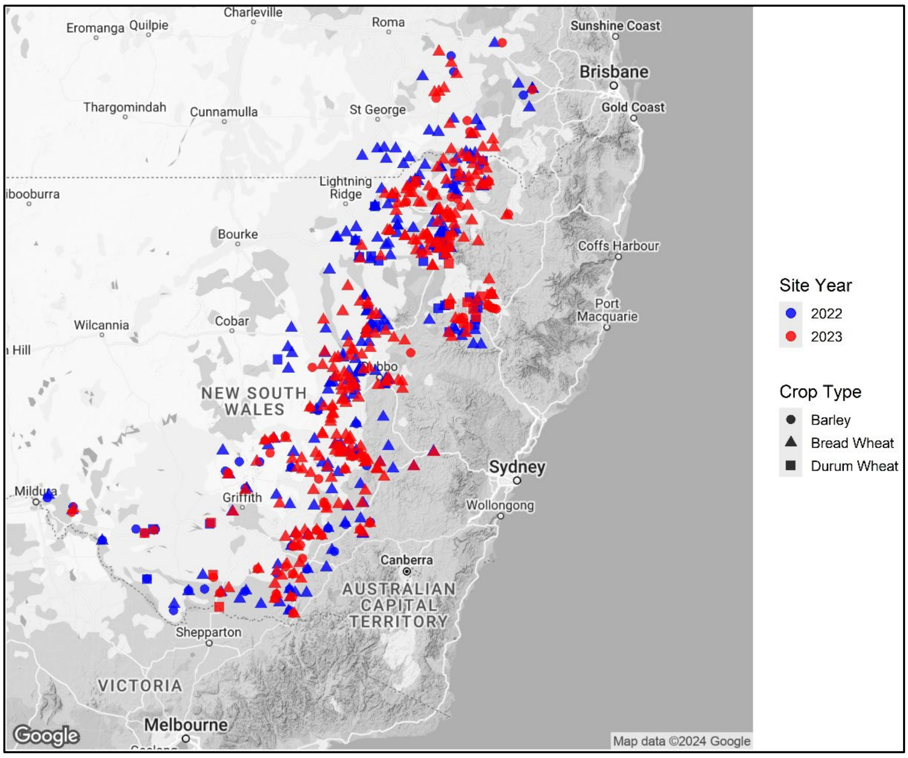

Figure 2. Location and cereal crop type surveyed across NSW in 2022 and 2023

In this survey, plant samples were collected during grain filling and washed to remove soil and old stubble residues. Hence, the DNA tests in this context, determine the level of pathogen burden within either the base or top of the plant at a specified growth stage and do not measure contamination from previous crop residues. This represents actual infection levels of various pathogens within the actual crop plants during that season.

The key point being the DNA values presented in the following maps across seasons should **not** be compared with current PREDICTA® B pre-sowing risk levels or population densities for the different pathogens. Furthermore, the DNA values within plant tops or bases are generally presented on a log scale which indicates relative differences in pathogen loads within plants. This data is for comparative purposes only as the relationship between the actual quantity of different pathogen DNA in plant tissue and yield impacts has not been fully determined. However, increasing levels of pathogen DNA did relate to increased severity of visual disease symptoms in surveyed plant samples, e.g. crops with higher incidence and severity of basal browning had elevated *Fusarium* DNA levels. All data is presented as regional maps with colouring indicating the pathogen levels detected within plant tissue.

Puccinia spp. (cereal rusts, stripe rust)

A general qPCR test exists for the detection of the three wheat cereal rusts (stripe, leaf and stem) but cannot distinguish between species, and also detects barley and oat rust species. Fortunately, these rust species are easy to distinguish on visual assessments of collected random cereal samples. Hence, the *Puccinia* spp. maps over seasons predominantly (around 95%) relate to the detection of *Puccinia striiformis* (stripe rust) in wheat crops (Figure 3). The only other cereal rusts recorded within the surveys have been a low prevalence of *Puccinia triticina* (wheat leaf rust) and *Puccinia hordei* (barley leaf rust) in 2022.

The prolonged wet and mild conditions during grain filling in 2022 was favourable for continued stripe rust development in upper canopies and even resulted in head infections in some crops despite fungicide applications. *Puccina* spp. levels were noticeably higher in 2022 (Figure 3) where continued rainfall across much of NSW often prevented access to paddocks to apply fungicides by ground rigs or delayed application. This was further exacerbated by a shortage of aerial applicators. Drier and warmer spring conditions in 2023 markedly reduced the prevalence and levels of stripe rust infection in wheat crops across northern NSW and southern Qld (Figure 3). Arguably, difficulties with stripe rust management in more susceptible wheat varieties in 2022 also saw many of these dumped and/or a significant reduction in planting area to these varieties in 2023 in the north. Hopefully, the memory was still fresh enough from 2022 for growers not to venture back into these harder to manage varieties in 2024.

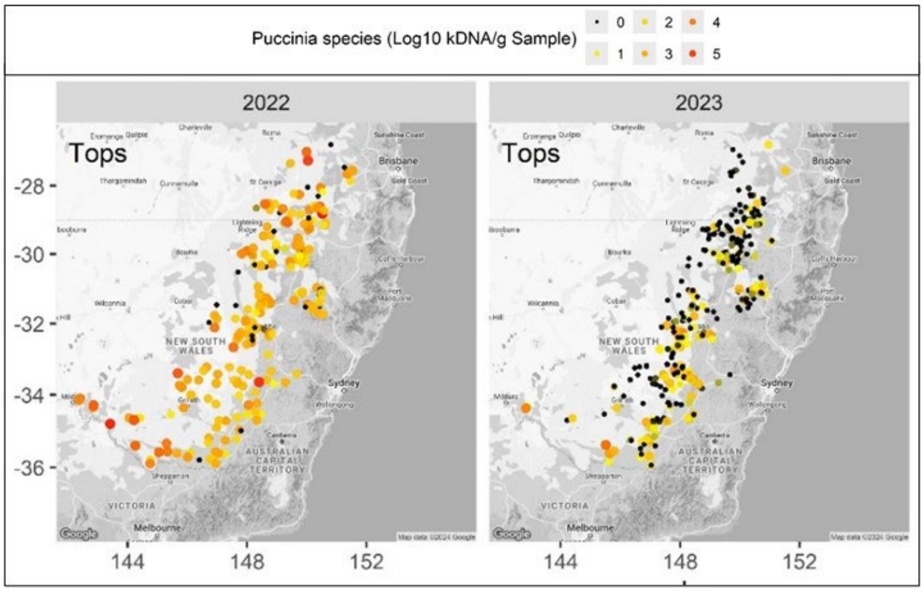

Figure 3. Quantification of *Puccinia* spp. (cereal rust) levels within plant tops of randomly surveyed cereal crops across NSW – 2022 and 2023.

Pyrenophora tritici-repentis (yellow spot)

Yellow spot is a stubble-borne disease of durum and bread wheat caused by the fungus *Pyrenophora tritici-repentis* (*Ptr*). Wet weather favours infection and production of tan lesions with a yellow margin on the leaves of susceptible wheat varieties. Repeated rainfall events during the season are required for yellow spot infection to progress up the canopy of a wheat plant. Yellow spot has been reported to cause up to 30–40% yield loss in susceptible varieties under conducive conditions. Following generally dry conditions in 2019 the prevalence and levels of *Ptr* have progressively increased across NSW, especially in central and northern areas with consecutive wetter seasons in 2020, 2021 (data not shown) and 2022 (Figure 4). *Ptr* levels declined in 2023 with a drier seasonal finish restricting the severity of infection in the upper canopy.

Yellow spot infection can appear explosive when prolonged leaf wetness in wetter seasons such as 2022 favours repeat infection events. The high prevalence of *Ptr* in wheat crops across northern NSW and southern Qld in 2022 and 2023 indicates that there is elevated risk of yellow spot in wheat crops in 2024 in paddocks sown into retained stubble from these past two seasons. The yellow spot fungus releases spores (ascospores) off infected cereal stubble throughout the season so early fungicide application (<GS31) has little effect on inoculum loads later in the season.

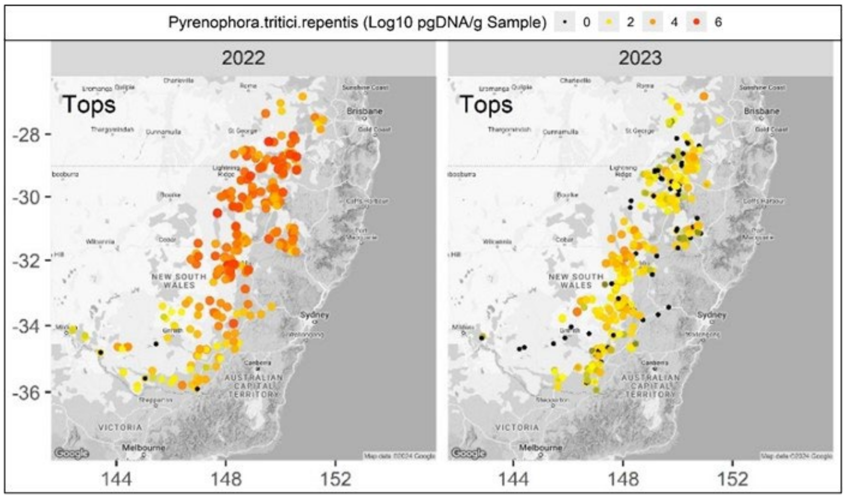

Figure 4. Quantification of *Pyrenophora tritici-repentis* (yellow leaf spot) levels within plant tops of randomly surveyed cereal crops across NSW – 2022 and 2023

Fungicide management in 2024

The 2022 season was the year for fungicides, especially in more susceptible varieties and with the mix of diseases that occurred. The prolonged mild conditions also extended the length of grain filling so there was a benefit from retaining green leaf area through this period in 2022. Remember, fungicides do NOT increase yield, they simply protect yield potential (i.e., stop disease from killing green leaf area). As highlighted above, disease is very dependent on individual seasonal conditions, so the same fungicide inputs were not required in 2023 with drier and warmer conditions being less conducive to cereal leaf diseases. What's your disease management plan if spring returns to wetter and milder conditions? Seasonal outlook must be part of disease management planning. Early leaf disease pressure is likely to occur again in 2024, given elevated inoculum levels from 2022 and 2023 along with decent levels of stored soil moisture. Manage early leaf disease pressure in 2024 if present, then adapt management to spring conditions. The most effective fungicide can often be 2 to 3 weeks of warm and dry weather in spring.

No matter what your strategy there are a few fungicide basics that do not change.

1. Fungicides do not fix environmental, herbicide, physiological or nutritional issues within crops. Correct identification is the first critical step in disease management with around 15% of cereal diagnostics submitted each season not related to disease, so fungicide application is unnecessary.
2. Fungicides only protect leaves emerged at the time of application, they do not move into or protect leaves that emerge after application
3. The top three leaves (flag, flag-1 and flag-2) are the main contributors to yield in cereal crops so fungicide strategies need to focus on maximising green leaf retention (that is minimising infection) in these structures
4. All fungicides generally have much stronger protectant than curative activity, but this can vary between fungicide actives and pathogens (e.g. generally 1–2 days at best curative activity with yellow spot compared to 5–10 days with stripe rust)

5. Length of protection depends on how quick each fungicide active moves through leaves (e.g. cyproconazole moves quickly so good rapid clean out of established stripe rust infections but more limited length of protection. Conversely, azoxystrobin much longer protectant but limited curative activity)
6. Coverage is critical with foliar applications so higher water volumes are better and ground rig generally improved efficacy over aerial applications
7. Fungicide resistance in fungal pathogens is real. Rotate and mix fungicide mode of action groups and actives within Group 3 (DMI, triazoles) between applications within a season (AFREN | Australian Fungicide Resistance Extension Networks).

Fusarium head blight risk in 2024

The prevalence of Fusarium head blight (FHB) and white grain disorder (*Eutiarosporella* spp.) across large areas of eastern Australia in 2022 was unprecedented. However, what is the likelihood of these specific conditions (>36 h of above 80% humidity during flowering) occurring at a time-critical growth stage (early flowering) again in 2024?

Fusarium crown rot (FCR) was widespread in 2022 and 2023 cereal crops and particularly elevated in more central and northern areas in 2023 (Figure 5). Testing of grower retained grain samples from the 2022 harvest showed that the dominant cause of FHB across eastern Australia in 2022 was related to tiller bases infected with FCR. That is, Fusarium infection of bread wheat, durum and barley crops in 2022 expressed as FHB due to wetter/milder conditions during flowering and grain fill (see Fusarium head blight and white grain issues in 2022 wheat and durum crops - GRDC).

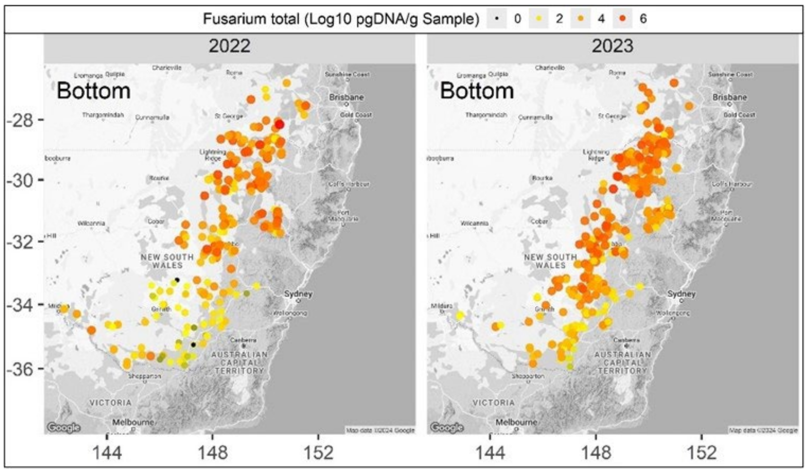

Figure 5. Levels of Fusarium crown rot within plant bases of randomly surveyed winter cereal crops across NSW – 2022 and 2023

Cause of FHB in 2022

The main cause of FHB in 2022 was *Fusarium pseudograminearum* (*Fp*; maximum log$_{10}$ of 6) with lower prevalence and levels of *F. graminearum* (*Fg;* maximum log$_{10}$ of 5) in the tops of cereal plants from qPCR testing (Figure 6). These two species have different pathways for causing FHB with *Fp* reliant on basal FCR infections resulting in spore masses (macroconidia) being formed around lower nodes and rain splashed into heads during flowering. Hence, FHB risk when caused by *Fp* is closely linked to the levels of FCR within individual paddocks. Therefore, assessment of the extent of basal browning from FCR around flag leaf emergence (GS39) or earlier provides an indication of FHB risk from this species, if prolonged high humidity (i.e. rainfall) is predicted to occur during the subsequent flowering period of that crop.

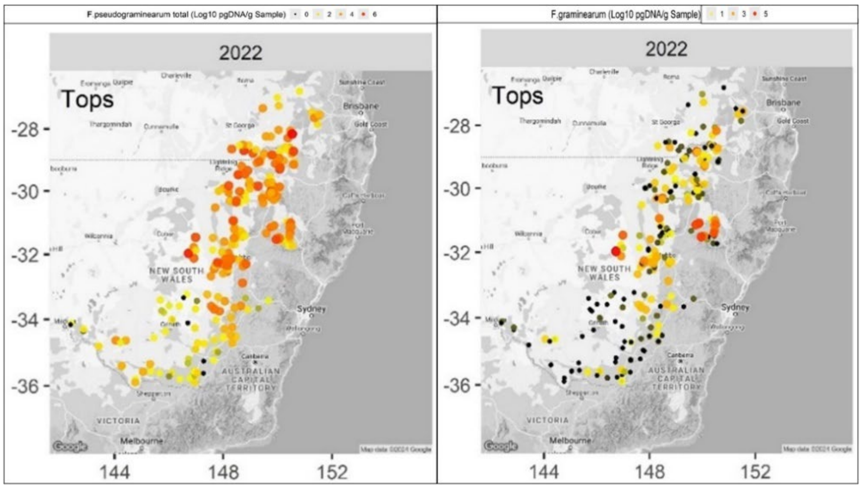

Figure 6. Levels of *Fusarium pseudograminearum* (left) and *F. graminarum* (right) within plant tops of randomly surveyed winter cereal crops across NSW – 2022

In contrast, *Fg* can produce fruiting structures called perithecia on infected stubble, especially maize and sorghum but also winter cereals, which are raised black structures which release airborne smaller spores (ascospores). These ascospores can be spread in wind (up to ~100 m) to infect heads during flowering so inoculum levels in adjacent paddocks can also present FHB risk from *Fg*. Determining FHB risk from *Fg* therefore relies on visually inspecting retained maize, sorghum and winter cereal stubble again around GS39 for the formation of perithecia.

Managing FHB in-crop

Prosaro® 420 SC foliar fungicide (or combination of actives prothioconazole + tebuconazole) are registered for FHB control and need to be applied to protect the flowers at heading following label instructions. Research has shown that spraying at flowering (GS61) was more effective and had more yield benefit than spraying seven days before flowering. The anthers (flowers) are the primary infection site for *FHB*, so spraying before flowering provides reduced protection of these plant structures.

Overseas research has demonstrated the importance of spray coverage in FHB control, with twin nozzles (forward and backward facing) angled to cover both sides of a wheat head and high volumes of water (≥100 L/ha) being critical to efficacy. However, at best this still provides ~80% control. Aerial application gives poor coverage of heads and at best provides ~40 to 50% control. Some agronomists who used this application method in 2022 are questioning if the efficacy is even this high following their experience.

Prosaro® 420 SC is only usually applied to durum wheat (very susceptible to FHB) in parts of northern NSW which have dealt with FHB since 1999. Application to bread wheats has never previously been deemed economical but infection levels in many bread wheat crops in 2022 challenged this thinking. Note, in north America strobilurin fungicides (e.g. azoxystrobin) are not recommended from booting (GS45) onwards in paddocks with FHB risk as this can increase mycotoxin accumulation in infected grain (Chilvers *et al.,* 2016).

Application timing is critical to fungicide protection but is also heavily dependent on predicted climatic conditions during flowering of prolonged high humidity above 80% for over 36 hours. That is, consecutive rain days not just total rainfall. This makes the application decision difficult as the product needs to be on hand without necessarily requiring application if dry conditions occur during flowering which prevents FHB infection. As a general rule, durum wheat is considerably more susceptible to FHB infection than bread wheats with barley having a lower risk again.

Summary

Cereal disease management is heavily dependent on climatic conditions between and within seasons. Therefore, the situation can be quite dynamic, including the unpredictable distribution of different stripe rust pathotypes across regions. Arm yourself with the best information available including the latest varietal disease resistance ratings.

FCR risk is high across much of the northern grain region. Widespread FHB in 2022 was predominantly the FCR fungus (*Fp*) letting you know that it does not go away with wetter and milder spring conditions. Do you know your FCR risk in paddocks sown to cereals in 2024, especially durum?

Keep abreast of in-season GRDC and NSW DPI communications which address the dynamics of cereal disease management throughout the 2024 season. Do not just focus on leaf diseases in 2024. Pull up a few plants randomly across paddocks when doing crop inspections and look for browning of the outer leaf sheathes and lower stems which is characteristic of FCR infection. This indicates your FCR risk if spring conditions are dry but also provides an indication of FHB risk if the 2024 spring is wet.

Further information

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

Chilvers M, Nagelkirk M, Tenuta A, Smith D, Wise K and Paul P (2016) Managing wheat leaf diseases and Fusarium head blight (head scab) - MSU Extension, Michigan State University, MSU Extension.

Simpfendorfer S & Baxter B (2023) Fusarium head blight and white grain issues in 2022 wheat and durum crops. GRDC Grains Research Update paper, accessed from https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2023/02/fusarium-head-blight-and-white-grain-issues-in-2022-wheat-and-durum-crops

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Fusarium crown rot genetic resistance in cereals - what is in the breeding pipelines?

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[1] CSIRO Agriculture and Food

Key words
Fusarium crown rot, QTL, resistant genes, cereal, breeding lines

GRDC code
CSP2104-004RTX

Take home message
- Breeding lines with enhanced resistance/tolerance to Fusarium crown rot (FCR) in adapted Australian backgrounds are available for breeding companies
- Introduced Fhb7 gene from a wheat relative showing significant yield and resistance/tolerance improvement under FCR pressure
- Additional sources of FCR resistance urgently needed to further improve Australian wheat and barley.

Background
Fusarium crown rot (FCR), mainly caused by *Fusarium pseudograminearum*, is a widespread and destructive disease impacting the production of many crop species including wheat, barley, durum, oat, and triticale. Its prevalence has increased significantly in recent years, particularly within conservation cropping systems, due to the increased frequency of cereal in rotations and stubble retention. In Australia alone, FCR in wheat causes an estimated cost of $404 million per year in lost yield. Enhancing genetic resistance in commercial varieties, coupled with appropriate crop management practices, is recognized as critical to the development of effective control measures for this economically important disease. However, the scarcity of high-quality resistance sources in cereal crops poses a challenge to successful breeding efforts.

What have we achieved?
Partial resistance to FCR has been observed in existing cultivars, wild relatives, and landraces. Despite the identification of numerous putative quantitative trait loci (QTL) associated with FCR resistance in wheat, a lingering question persists: 'why hasn't the FCR problem been resolved'. One reason is that many identified QTL are either with minor effects or only detected in a specific environment. In addition, various physiological and developmental traits, such as flower time and plant height, can influence FCR resistance, complicating the interpretation of identified QTL. Furthermore, reproducible and reliable phenotypic methods are essential for accurately mapping QTL.

To address the complexity of field trials, a high throughput and reliable seedling assay was developed by CSIRO to screen genetically diverse germplasm and detect QTL conferring FCR resistance. Using this seedling assay three major QTL were identified in wheat, one on chromosome 3B inherited from *Triticum spelta* and two QTL on chromosomes 2D and 5D inherited from EGA Wylie⊕. In barley, three QTL were also detected (one from wild barley and the other two from landrace) on chromosomes 1H, 4H and 6H. Given the aforementioned reasons, validating the effects of a given QTL is deemed essential before its incorporation into breeding programs. Consequently, we developed near isogenic lines (NILs) that are essentially identical except for the presence or absence of the resistant locus for each of these QTL. These NIL pairs were then subjected to intensive field testing to ensure the resistant locus increased resistance in the paddock. Resistant loci identified from our seedling assay showed a significant reduction in whitehead incidence in wheat and decreased stem browning, and yield loss in barley under field conditions (Figure 1) (Liu and Ogbonnaya*,* 2015; Zheng *et al.,* 2022).

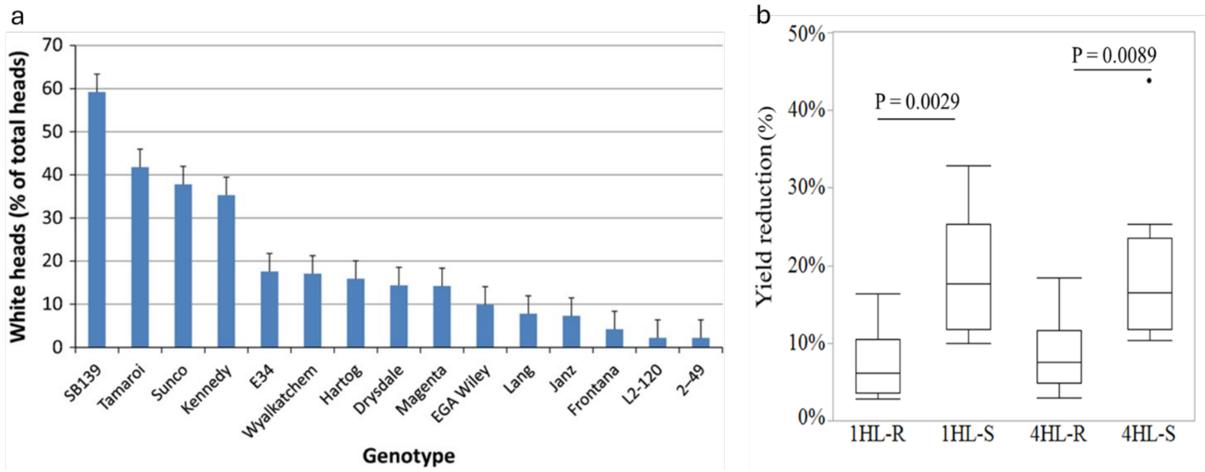

Figure 1. (a) Fusarium crown rot resistance (measured by percentage of whiteheads) of L2-120 (containing the resistant allele of 3B from CSCR6) compared to several other genotypes under field conditions (cited from Liu and Ogbonnaya 2015); (b) Box plot distribution of grain yield reduction between the isolines with (-R) or without (-S) the 1H and 4H resistant loci (cited from Zheng *et al.,* 2022).

In both wheat and barley, pyramiding all three FCR QTL into a single genetic background enhanced the resistance more strongly than the effect of a single locus or two separate loci. However, markers derived from the QTL mapping studies cannot be reliably used to tag a QTL due to limited resolution. Therefore, diagnostic markers targeting each of these resistant loci in wheat and barley were generated by analysing NIL-derived population and RNA-seq targeting multiple NIL pairs. With the assistance of the generated markers, breeding lines possessing four resistant loci (on 2B, 2D, 3B and 5D) for wheat and three resistant loci (on 1H, 4H, and 6H) for barley have been generated in adapted backgrounds and provided to commercial breeding companies.

What have we found recently?

Our current focus is on introducing the Fhb7 gene into Australian wheat and combining it with other loci already in wheat. This gene, derived from a wheat relative *Thinopyrum*, showed resistance to both Fusarium head blight and FCR. In our single-row field trials conducted in 2023 where FCR was severe, backcrossed (BC) lines with this gene had significantly higher grain yield compared to the lines without the gene in the presence of FCR. The largest difference between these two groups of lines was observed at Narrabri with the difference as high as 11.4%. Significant differences were also detected between these at both other field sites, 8.7% at Forest Hill and 7.2% at Boorowa (Figure 2). Similarly, disease severity based on whiteheads and stem browning also differed significantly, with the lines in the resistant group showing less severe symptoms.

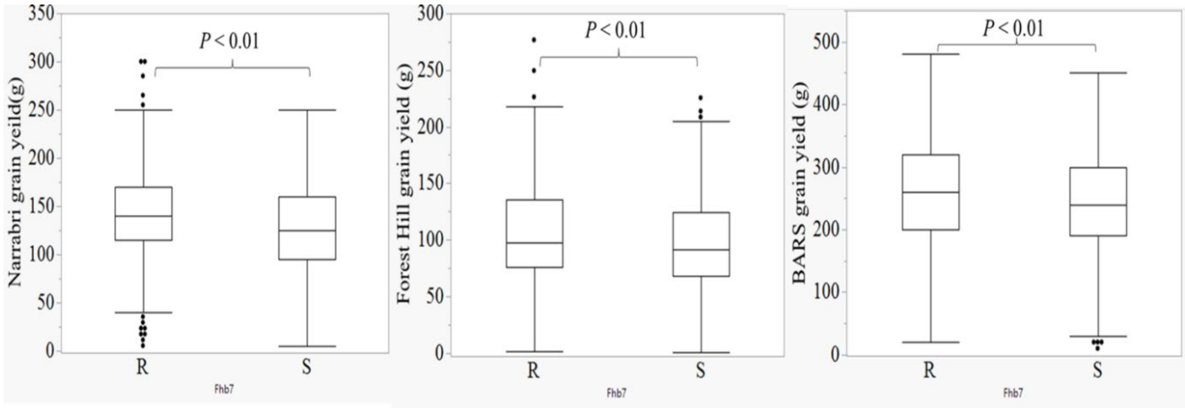

Figure 2. Comparison of grain yield from the two groups with (R) and without (S) Fhb7 genes at three sites (Narrabri, Forest Hill, Boorowa) under FCR pressure in 2023.

Breeding lines with five loci (on chromosomes 2B, 2D, 3B, 5D and 7D (Fhb7), respectively) were also assessed in 2023. The genotypes with Fhb7 and 3B locus had the highest grain yield in the presence of FCR, followed by the lines with all five resistant loci, which were significantly higher than the lines without any of these loci. Disease severity indicated the same trends. The lines without any of these resistant loci were the most susceptible to FCR infection among all the 32 combination groups. Similarly, the lines with all five resistant loci and lines with Fhb7 and 3B locus also showed the lowest disease severities in whiteheads or stem browning (Figure 3).

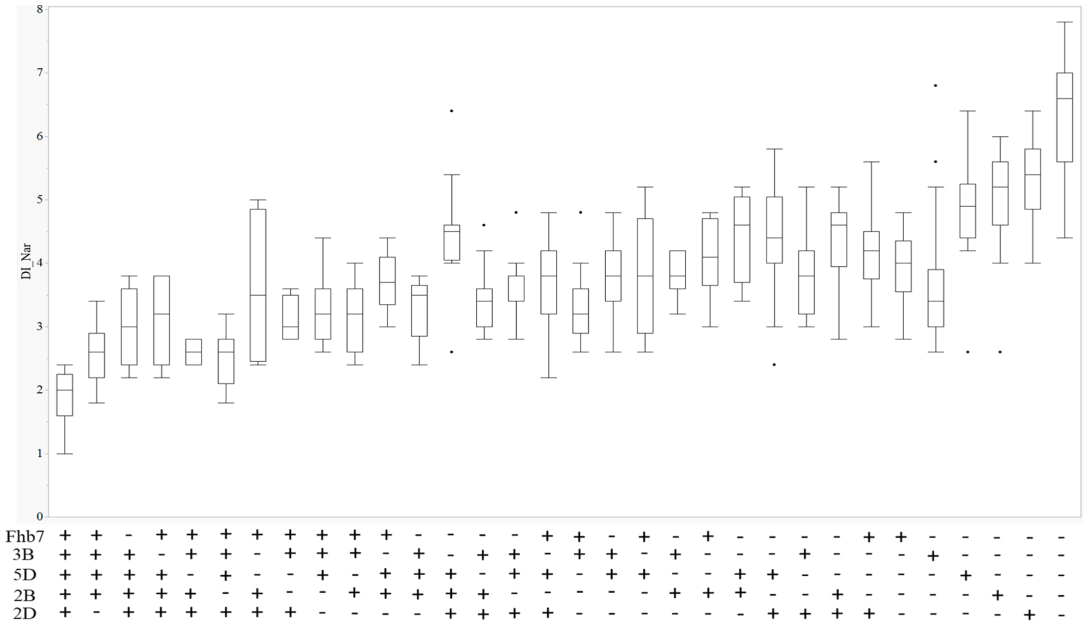

Figure 3. Box plot distribution of DI (stem browning) between the lines with various combinations of the breeding lines. Boxes indicate the 25 and 75 percentiles, respectively; the median is indicated by the solid horizontal line. '+' represents the lines presence of the resistant loci, while '-' represents the lines absence of the resistant loci.

Recently, we developed and analysed a pair of NIL targeting the 2D locus in wheat. This NIL pair showed significant differences in FCR resistance as well as drought tolerance (Su *et al.,* 2024). Analysis of the RNA-seq from this NIL pair revealed that similar regulatory frameworks were activated in coping with these two stresses.

Barley is a silent sufferer of FCR as few whiteheads occur. Results from previous studies showed that barley had more severe symptoms (stem browning and seedling death) and accumulated higher fungal biomass compared to wheat. Data from our field trials showed that barley suffered similar grain yield loss to that of wheat, but what caused such yield loss in barley is unknown. We showed for the first time that the reduction of fertile tiller numbers was mainly responsible for grain yield loss in barley infected by FCR (Figure 4). In addition, we recently identified a novel QTL conferring FCR resistance in barley, which was also found to be associated with drought tolerance.

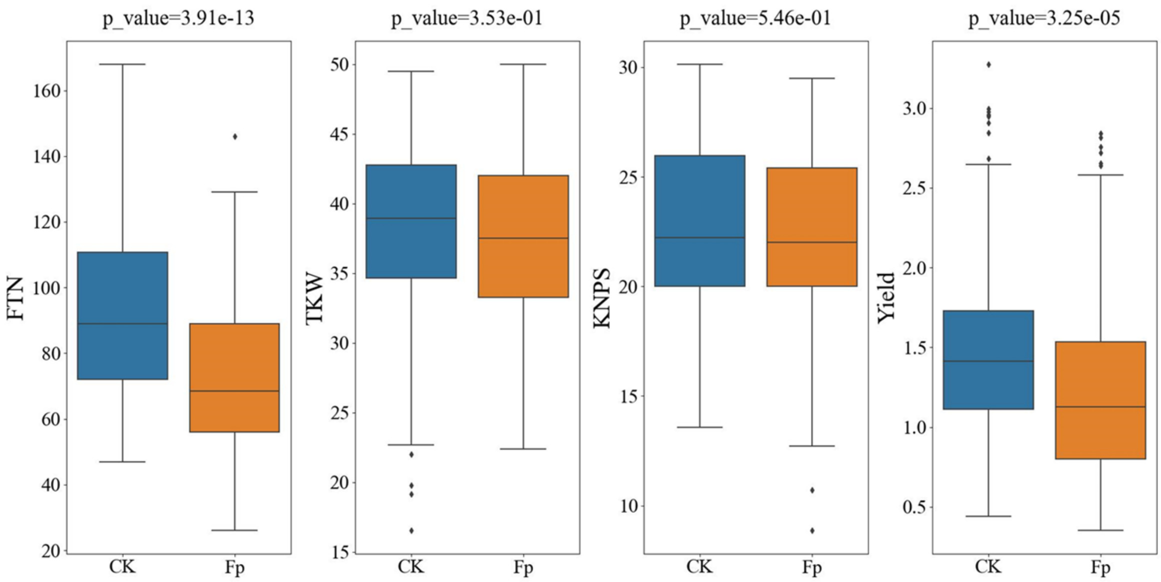

Figure 4. Box plots distributions of fertile tiller number (FTN), thousand kernel weight (TKW), kernel number per spike (KNPS), and yield between non-inoculated (CK) and *Fp*-inoculated (Fp) treatments at Narrabri, NSW and Gatton, QLD in 2019 and 2020.

What are the next steps?

Up until now, only five loci conferring FCR resistance are utilized in Australian breeding programs and three of them are derived from Australian varieties. This highlights the urgent need for additional sources of resistance, particularly those not yet present in Australian varieties, to provide breeders with a wider pool of resistance. Novel resistant sources have been identified by our team and CSIRO is actively pursuing the characterization of these novel resistance sources and incorporating them into Australian wheat/barley breeding programs.

Of all the FCR resistance reported so far, the one on chromosome 3B showed the largest effect. Working toward cloning the causal gene underlying this locus and developing perfect markers, we at CSIRO sorted and sequenced the 3B chromosome, as well as the donor genotypes itself. We have also obtained >6,000 M5 mutants from a line containing the R gene. By mapping a NIL-derived population, we have defined this locus within a 0.2 cM interval containing 14 high confident genes with SNP variations between the R and S isolines. Clearly, cloning the gene underlying the 3BL locus would advance our understanding of FCR resistance/tolerance mechanisms and minimize the damage from FCR infection.

We at CSIRO successfully cloned the first gene conferring FCR resistance in barley. Investigating the potential of transferring this resistance to wheat through gene editing represents an exciting avenue for further improving FCR resistance.

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

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

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

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

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

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

The mechanism of resistance to glyphosate may also influence the results of management strategies. There are three main mechanisms of glyphosate resistance that have been identified in weeds in Australia: target site mutations; reduced glyphosate translocation through vacuolar sequestration; and gene amplification. Recently, it was found that applying glyphosate to glyphosate resistant barley grass increased the level of glyphosate resistance through increasing the number of copies of the EPSPS gene in the plants (Figure 1).

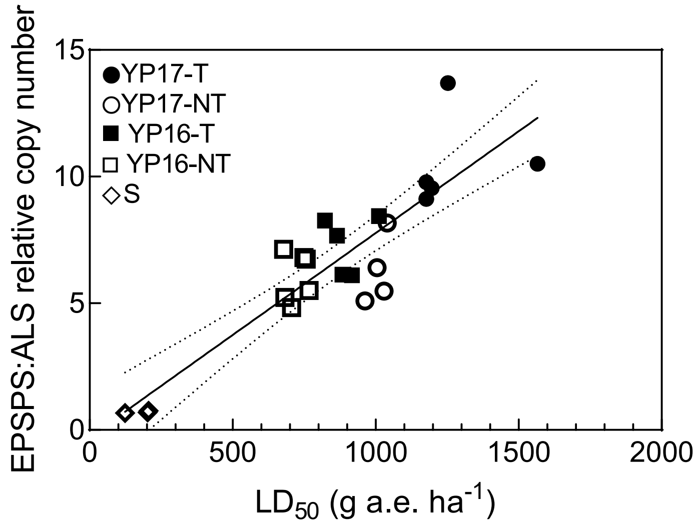

Figure 1. Increase of LD_{50} and EPSPS gene copy number in the progeny of glyphosate-resistant barley grass clones from 2 populations treated or not treated with glyphosate. Individual plants were divided into 2 clones. One clone from each individual was treated with 405 g ha^{-1} glyphosate and the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

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

Managing glyphosate resistant weed populations

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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