WESTMAR
QLD
WEDNESDAY 2
AUGUST 2023

# GRAINS RESEARCH UPDATE

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# GRDC 2023 Grains Research Update Welcome

Welcome to the July/August northern GRDC Grains Research Updates for 2023.

We are ecstatic to be able to offer growers and advisers from across the region the opportunity to attend a series of events that have been tailored with the latest grains research, development and extension (RD&E) to help boost their businesses and profitability.

One benefit of the COVID-19 pandemic is that it forced us to be more flexible with how we deliver this information to our key stakeholders, so 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 livestreaming and recording some of the events for anyone who is unable to attend in person.

The past 12 months have been a whirlwind for northern growers, with wet seasonal conditions continuing to impact productions during pivotal times on farm, including sowing and harvest.

We have heard some devastating stories from across the region of total crop loss and severe downgrades from untimely weather events, but we've also heard a lot of optimism from growers who have stepped into this year with high hopes for a productive season.

With that positive mindset comes a need to provide the latest information and advice from grains research and development. There's also been a significant push from the industry to make more informed management decisions to ensure productivity isn't impacted by the increasing costs of inputs.

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

For more than a quarter of a century the 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 the 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.

To ensure this research answers the most pressing profitability and productivity questions from the paddock, it is critical the GRDC is engaged with and listening to growers, agronomists and advisers. To this end, GRDC has established the National Grower Network Forums and I encourage you to look out for these forum opportunities in your local area.

We feel more connected to the industry than ever when we are out in the regions and encourage you all to take any opportunity to engage with us to help inform our important RD&E portfolio.

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.

Regards,
Gillian Meppem
Senior Regional Manager – North

# WESTMAR
# GRDC Grains Research Update
## Wednesday 2 August 2023

**Westmar Sports Club, 7160 Meandarra-Talwood Rd, Westmar, QLD 4422**
*Registration: 8:30am for a 9am start, finish 3:05pm*

**AGENDA**

| Time | Topic | Speaker(s) |
|---|---|---|
| 9:00 AM | **GRDC welcome** | *GRDC* |
| 9:10 AM | **Farming system sustainability** - grower and market expectations, risks and opportunities | *Richard Heath (Australian Farm Institute)* |
| 9:45 AM | **Optimising the nitrogen investment. Understanding and minimising N losses while feeding the crop what it needs.** | *Mike Bell (UQ)* |
| 10:30 AM | **MORNING TEA** | |
| 11:00 AM | **Fallow efficiency - how much impact does stubble height, crop type & plant population have?** | *Richard Daniel (NGA)* |
| 11:25 AM | **Farming systems of the future – how might our systems evolve to address threats and opportunities** | *Lindsay Bell (CSIRO)* |
| 11:55 AM | **Discussion on sorghum, chickpea impact on rotation profitability**<br>○ Nutrition, water use, disease and weed management | *Paul Gardoll, Richard Daniel, Lindsay Bell & Mike Bell* |
| 12:15 PM | **LUNCH** | |
| 1:15 PM | **Disease update for 2023: Rusts, barley & wheat disease & crown rot update** | *Steven Simpfendorfer (NSW DPI) & Lislé Snyman (DAF Qld)* |
| 1:55 PM | **Problem weed research**<br>○ Resistance statistics<br>○ Weed ecology of feathertop Rhodes and barnyard grass<br>○ Adding crop competition for managing glyphosate-resistant problem weeds | *Michael Widderick (DAF Qld)* |
| 2:35 PM | **SwarmFarm Robotics & sensors for spraying - a grower's experience.** | *Tom Coggan (Meandarra)* |
| 3:05 PM | **CLOSE** | |

# Contents

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# Farming system sustainability - grower and market expectations, risks and opportunities

*Richard Heath, Australian Farm Institute*

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## Notes

# Optimising the nitrogen investment.
# Understanding and minimising N losses while feeding the crop what it needs

*Mike Bell, University of Qld, Gatton campus*

**Key words**

fertiliser N, N use efficiency, residual value, N losses, N redistribution

**GRDC code**

UOQ2204-010RTX

**Take home message**

- Achieving co-location of water and available N within the soil profile are keys to maximizing efficient use of water and fertiliser N in rainfed grains cropping systems
- Seasonal rainfall (both amount and distribution) is the dominant factor driving fertiliser N use efficiency and environmental losses on clay soils employing these cropping systems
- This makes it difficult to successfully employ fertiliser N management strategies that attempt to manipulate N availability to match individual crop demands in individual seasons
- Increasing the mineralizable soil N pool through enhanced soil organic matter and greater legume frequencies in crop rotations, combined with manipulation of fertiliser rate, timing and mode of application, offer the best opportunities to improve system N use efficiency
- Soil sampling remains an important tool to determine when and how fertiliser N management strategy should change in response to particular events and wetter or drier seasonal conditions.

## Background

The processes that determine the availability, loss and cycling of nitrogen (N) in soils are complex, representing the interactions between management practices, the soil microbial community and seasonal conditions – especially temperature and moisture availability. These processes and interactions are illustrated in the diagram developed by Barton et al. (2022) and shown in Figure 1.

The N fertility of a soil is determined by the initial size of the soil N pool (a product of soil type and native vegetation), modified by the net effects of land management that have impacted on that starting condition. In the case of land opened to cropping, those management effects will be cumulative soil N inputs (fertilisers, fixed N in legumes, plant and animal residues, atmospheric deposition) minus the cumulative removal of N in harvested produce (forage, grain) and losses of N to the environment. The soil N pool is dominated by N stored in organic matter, which is itself not available for crop N uptake until microbial activity has broken down ('mineralised') that organic matter to release ammonium ($NH_4$) and nitrate ($NO_3$) N that are taken up by plants. These forms of N (collectively called mineral N) represent a small but critical fraction of the total soil N pool that can increase or decrease quite rapidly in response to prevailing conditions. These mineral N forms are typically found dissolved in soil water or held electrostatically to positively or negatively charged sites on clays and organic matter.

In Figure 1, two of the key parts of the soil N cycle have been highlighted and will be the focus of this paper:

1. the soil-plant N pool itself (within the solid yellow hexagon), where N is cycling between the organic and inorganic fractions under the influence of microbial processes, fertiliser N inputs and plant N uptake; and
2. the important processes by which N is lost from the soil N pool to the environment (in the dashed boxes). It is important to note that except for soil erosion, environmental losses are

almost exclusively from the mineral N pool (especially $NO_3$-N), and so the size of the mineral N pool at times when conditions favour different loss pathways will be critical. We will discuss these pools and processes and the key rate controlling factors, and then move onto discussing how the net effects of these processes, interacting with crop management, can influence crop N uptake and the efficiency of fertiliser N use in cropping systems.

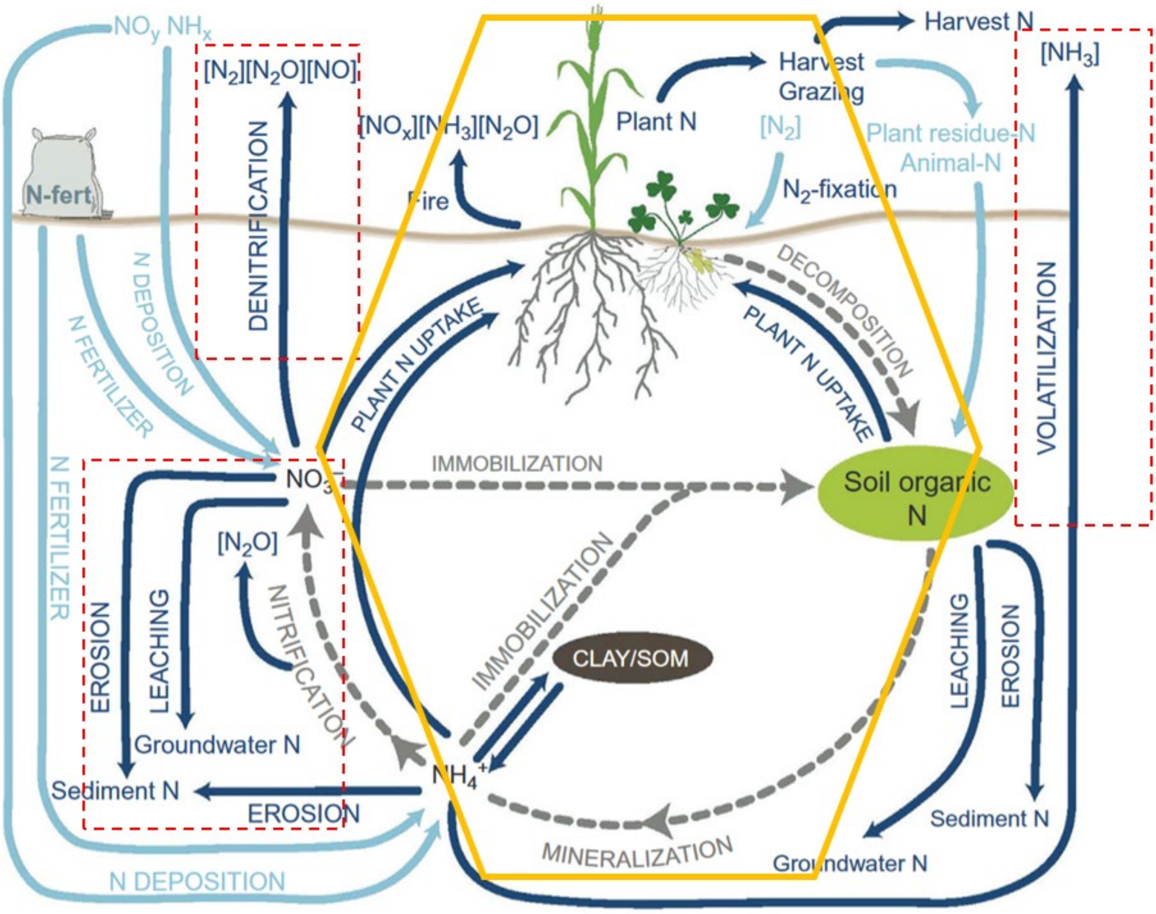

**Figure 1.** Terrestrial nitrogen (N) cycle showing pathways responsible for the supply and loss of N in soil and plants. Dashed lines indicate soil N transformations. Gases appear in square brackets.
(Reproduced from Barton et al. 2022)

## Cycling of N in the soil and availability to plants

The net gain or loss of soil organic matter is a function of the relative rates of addition of organic inputs (crop residues, manure) and the breakdown/mineralisation of these fresh materials and the resident soil organic matter by microbes that exploit these as sources of nutrients and energy. Soil organic matter acts as a reservoir of organically-bound N that must be mineralized to plant available forms [e.g. $NH_4^+$ and $NO_3^-$] before agricultural crops can access this stored N. The size of the mineralizable organic N pool and the rate of mineralisation relative to crop demand will determine the ability of this pool to meet crop needs. When the Vertosol soils of northern NSW and Qld were ‘new’ to cropping, the pool of soil organic matter was high and mineralisation of soil organic matter was able to generate enough surplus mineral N to meet, or exceed, crop N demand. Crops rarely responded to fertiliser N inputs. However, as soil organic matter contents have declined under cropping the pool of mineralizable organic N has declined, microbial mineralisation is increasingly unable to produce enough surplus mineral N to meet crop demand, and fertiliser N is increasingly needed to meet the N supply deficit. Application of N fertiliser can rapidly increase the pool of plant-available N, but there are a number of soil and environmental factors that determine whether that increase will result in more plant N uptake in the short term.

Soils in which there is a reduced pool of labile organic matter and mineral N availability can result in conditions where the microbial community can be a net consumer of mineral N (e.g., from fertiliser applications) rather than the source of a mineral N surplus. This microbial competition for mineral N may be sporadic (e.g., after the return of cereal crop residues with low N content), resulting in short term immobilisation of mineral N in organic matter and microbial biomass that is typically reversed over longer time frames. However, these shorter-term dynamics can be particularly important in terms of meeting the mineral N requirements of a crop at critical crop growth stages. The timing of fertiliser N application relative to the demand for N by the plant, combined with the relative rates of N immobilisation and mineralisation and the environmental conditions that influence the rates of microbial processes and environmental losses (e.g., soil moisture), will collectively determine whether that applied N will be actually taken up by plants, and when.

**Losses of N to the environment**

Essentially, nitrogen can be lost from cropping soils via downwards, sidewards or upwards movement. Nitrate N primarily moves down into the soil profile with soil water infiltration, with the rate and depth of movement a function of the rate of movement of the wetting front and the concentration of $NO_3$ in the soil solution. This process is called leaching. In lighter textured soils, especially those with low water holding capacities, wetting fronts and associated leaching of $NO_3$-N can be rapid and extend below the depth of the crop root zone. In this case, leaching can result in loss of plant available N, and depending on the connectivity of that deep water infiltration with drainage lines or water tables, can result in negative effects on environmental water quality. In other situations (e.g., in soils like the black and grey vertosols on which much of the northern cropping industry is based), this leaching of N is unlikely to penetrate beyond the depth of crop root access and is a critical success factor for cropping systems that rely on stored soil water rather than in-season rainfall. Crops extracting stored soil water during dry periods need access to N (and other nutrients) to continue to produce dry matter and grain.

Sideways movement can occur rapidly through erosion of topsoil rich in organic matter during intense rainfall events, or more slowly through lateral subsoil movement of nitrate-N in soil water. The widespread adoption of minimum or no tillage and the associated maintenance of surface cover in grains cropping, combined with the relatively dry seasonal conditions, means lateral N losses are typically minor.

Gaseous N losses to the atmosphere are of much greater significance and can occur through two main pathways viz. volatilisation of ammonia or denitrification of nitrate as dinitrogen ($N_2$) or nitrous oxide ($N_2O$).

- Ammonia volatilisation is a process that primarily occurs when urea or ammoniacal N fertiliser (DAP, MAP or UAN) is broadcast onto the soil surface without incorporation, or if shallow fertiliser bands are not covered with soil and left exposed to the air. Losses typically occur soon after fertiliser is applied to soil, with a range of factors influencing the actual amount of N lost. Simple models such as the one published by Fillery and Khimashia (2015) use a maximum potential loss figure (65% of applied N when urea is applied to moist soil) that is discounted according to factors such as clay content, soil pH, fertiliser rate, rainfall in the week after application, presence of a crop canopy and the placement of the fertiliser. This model was reasonably effective at predicting volatilisation losses from top-dressed urea fertiliser applied on vertosol soils in northern NSW (Schwenke 2014). In those studies, losses averaged 11% (5–19%) of applied N when urea was broadcast onto the surface of fallow paddocks, 5% (3–8%) when applied in a growing wheat crop (mostly when soils were dry), and as much as 27% when applied to pasture. In the latter situation, there had been little rain after spreading to wash the urea into the soil. This resulted in a significant proportion of the urea being suspended on the pasture thatch rather than in direct contact with soil particles, greatly increasing the risk of volatilisation loss. Wind-speed after fertiliser application was a critical factor determining the amount of N lost over time in all studies.

Schwenke (2021) recently concluded that ammonia ($NH_3$) volatilisation loss will be low when urea is broadcast onto dry, clay soil under non-humid, non-windy conditions followed within a few days of application by sufficient rainfall to move the urea/ammonium into the soil. In contrast, $NH_3$ loss will be higher when urea is applied to wet soil followed by dry, windy conditions with little or no follow-up rainfall. However, while recent laboratory studies suggest that risks of volatilisation loss may be greater on lighter textured soils with lower clay contents, there is real uncertainly extrapolating the losses from the NSW field studies to other soil types and climatic conditions.

- Nitrate denitrification losses can be large but require the simultaneous occurrence of low soil oxygen availability (e.g., when soil is waterlogged for an extended period, or in wet soils with a high level of microbial activity), high soil $NO_3$-N concentration (soon after soils have been fertilized) and readily available (labile) carbon to support an active microbial community. Clearly these set of circumstances do not coincide every year, but when they do (e.g., 2011, and more recently in 2022), denitrification losses can be high. Rates of loss are typically higher when soils are warmer in spring and summer rather than late autumn and winter.

  Unlike ammonia volatilisation, it is more difficult to quantify total N losses due to denitrification. This is because variable proportions of those losses can occur as $N_2$ or as $N_2O$. While direct measurement of $N_2O$ losses under field conditions is possible, losses as $N_2$ are far harder to quantify due to the high background atmospheric $N_2$ concentrations (~78% of the atmosphere). There are reports in the literature of the ratio of losses as $N_2$:$N_2O$ being anything from 1:1 to 70:1, depending on soil and environmental conditions. To put this uncertainty into perspective, measurements of annual $N_2O$ losses at fertilizer N rates delivering maximum yield of 1–2 kg $N_2O$-N/ha could be indicative of total denitrification losses ranging from negligible to >100 kg N $ha^{-1}$.

  The use of N fertilizers labelled with the stable $^{15}N$ isotope allows the fate of applied N to be studied in detail (e.g., Figure 2), with the difference between fertilizer N applied and that recovered in the plant (tops and roots) or remaining in the soil after harvest representing fertilizer N lost to the environment. In soils where fertilizer N has been banded below the soil surface and leaching losses are minimal (such as in the alkaline vertosols), most of the unaccounted-for fertilizer N (20–40% of N applied – Rowlings *et al.* 2022) is presumed to have been lost via denitrification. When cumulative $N_2O$ emissions data are available (such as in 12 of the 18 NANORP sites in Qld and NSW where $^{15}N$ was used), the ratio of total N lost (from $^{15}N$ results) to that lost as $N_2O$ can be used to estimate the ratio of $N_2$ to $N_2O$ for these summer cropping systems. Direct measurement of these $N_2$ and $N_2O$ losses is being undertaken in the project "Predicting nitrogen cycling and losses in Australian cropping systems - augmenting measurements to enhance modelling" UOQ2204-010RTX.

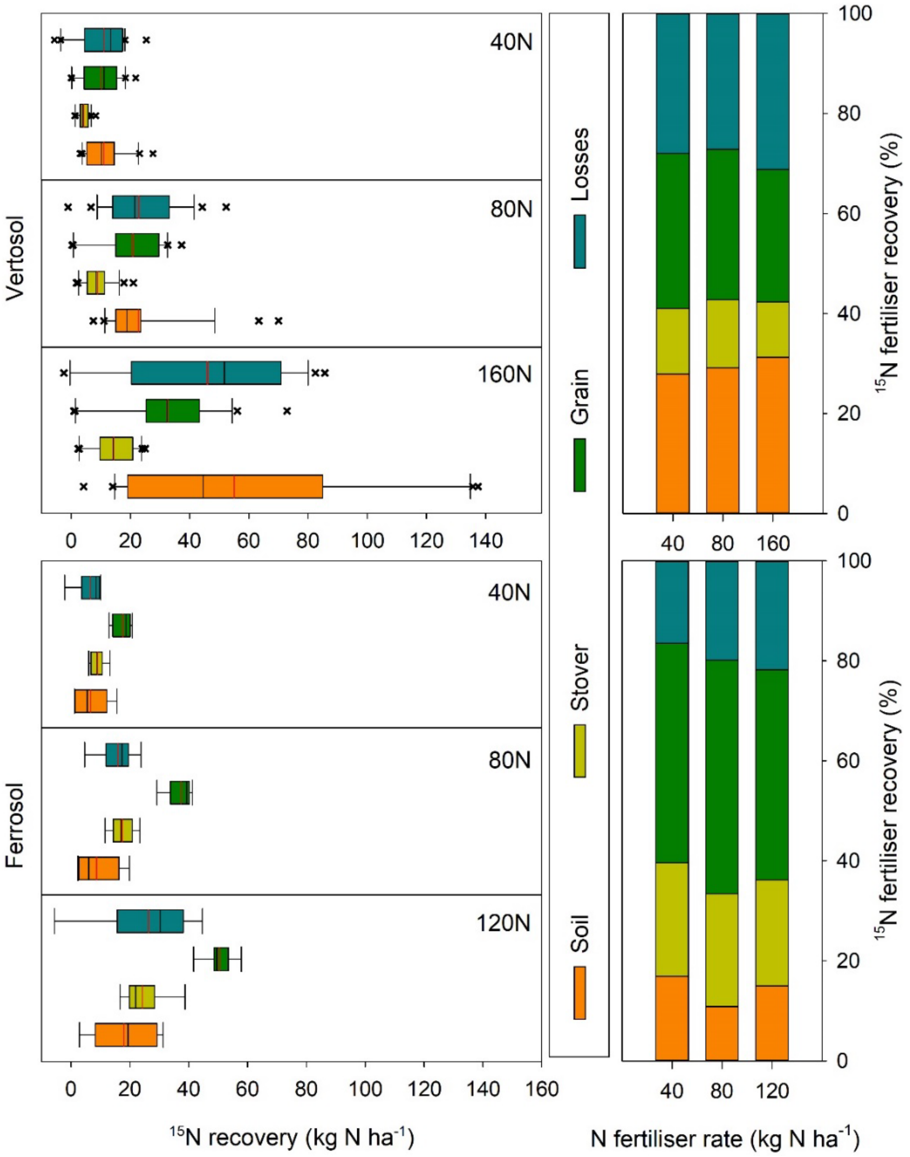

**Figure 2.** Fate of applied $^{15}$N fertiliser, expressed as both kg $^{15}$N ha$^{-1}$ recovered and as a percentage of total $^{15}$N applied for different N fertiliser rates applied in 4 farmer field sites and in 5 experiments conducted on research stations at Kingaroy (red ferrosol) and Kingsthorpe (black vertosol) from 2012–2014.
(Reproduced from Rowlings *et al* 2022)

## Implications for N management and efficient use of fertiliser N

In theory, achieving efficient use of N in our rainfed cropping systems should require the timing and amount of N supply via soil mineralization and N fertilizer addition to be tightly coupled to crop demand, consistent with the '4R' nutrient stewardship concept (Bruulsema et al., 2009). This should ensure minimal loss of surplus reactive N into the environment. Whilst fine in theory, achieving this synchrony presents challenges in our warmer climate and with systems that accumulate water during fallows. The combination of moist soil, warm temperatures and stubble/soil organic matter will result in N mineralisation (or immobilisation, depending on N availability) that primarily occur during the fallow, and indeed, production of mineral N (particularly $NO_3$-N) during the fallow will be essential if we are to achieve the necessary co-location of water and mineral N deeper in the soil profile.

In combination with this, we have the decisions about when and how to apply fertiliser N to top up the available N pool to achieve the water limited yield potential for that growing season. Our current practices are focussed on trying to finesse the 'right' N rate for this purpose, and on delaying our fertiliser application until a cropping decision is certain and seasonal yield indicators (stored soil water and seasonal climate forecasts) are locked in. In many ways, this strategy will effectively ensure the fertiliser recovery in the season of application is limited, unless in season rainfall distributions are favourable, as it limits the likely distribution of fertiliser N to topsoils that are often dry for significant parts of the growing season – especially in winter. Examples of the seasonal variability in the fate of applied N are shown in Figure 3 for summer sorghum.

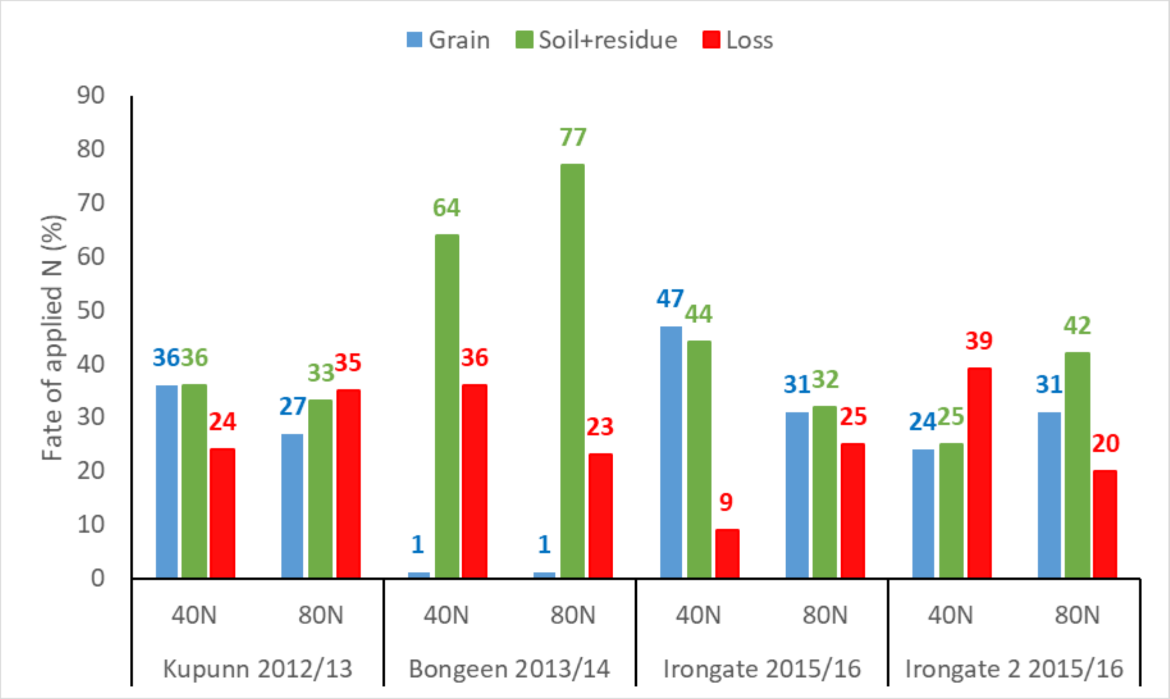

**Figure 3.** Percentages of fertiliser N either removed in sorghum grain, lost to the environment (presumably via denitrification) or carried forward to the following cropping seasons in soil and crop residue. Data were from sorghum crops grown on vertosols in commercial fields on the Darling Downs from 2012–2015.
(Bell *et al* 2015)

### Considerations for improving management of soil and fertiliser N

Some important principles to improve fertiliser nitrogen use efficiency (NUE) in northern cropping systems are:

- <u>Fertilise the soil and not just the crop</u> – this recognises that building a bank of labile N in the soil profile, both in organic and inorganic forms, is important to achieve water limited yield potentials. The current decline in soil organic matter and mineralizable N has resulted in less fallow N mineralisation and a greater reliance on fertiliser N to meet crop demand. Systems are now characterised by longer periods of immobilisation of N while crop residues with low N concentrations are broken down, and this is resulting in slower recharge of subsoil mineral N. Maximising the return of residues, improving the N content of residues through increasing legume frequency, and improving overall soil nutrient availability will help to maximise the building of soil organic matter and help fallow N recharge.

- Be more flexible with timing of fertiliser N application – this is particularly relevant in situations where profiles have been depleted of mineral N, much as they have been over the last 18 months. Combinations of wetter seasonal conditions, high crop yields and widespread denitrification losses have further increased the reliance on fertiliser N to meet current crop demands, so ensuring at least some of that N is distributed with water in deeper profile layers will be very important. This can be achieved by applying a proportion of the fertiliser N when soils are dry early in the fallow period, to ensure the wetting front moves nitrate N into deeper soil layers as the profile refills. While more research is needed to quantify the net benefits of early application, important considerations are likely to be: the extent to which immobilisation of N may delay nitrate leaching early in the fallow (e.g., with high cereal stubble loads); and the relative denitrification risk of early application with differing amounts and distributions of moisture in the soil profile.
- Consider the implications of different N formulations and application methods. There has been considerable recent focus on the relative merits of in-soil banding v top dressing in terms of crop N responses, with the results generally inconclusive and apparent crop recoveries from both application methods similarly poor (Daniel et al. 2019). We should not forget there are also considerations in choosing the right product (e.g., granules v liquids; enhanced efficiency fertilisers v conventional products). When N fertiliser is banded, there is little evidence of either coated or stabilised N fertilisers producing improved fertiliser N recovery by crops in rainfed systems. This is thought to be because these technologies either slow the formation, or release, of $NO_3$ into the soil solution, and so delay the movement of N into deeper soil layers that are accessible during drier periods (Dang et al. 2021). In the case of top-dressed N, there may be advantages in the use of urease inhibitors to coat urea granules (e.g., NBPT in products like Green Urea NV®) to reduce the risk of volatilisation losses – especially when stubble loads prevent direct soil-granule contact. However, the protection window for these products is short (e.g., <7–10 days) in field environments (Janke et al. 2020).

  With conventional fertilisers, comparisons between fluid and granular formulations are confounded by the different products that are typically used (e.g., urea-ammonium-nitrate (UAN) liquids *cf*. urea granules), and use is typically governed by convenience rather than performance. When fertiliser is sub-surface banded, use of products like UAN may limit the chemical changes in the band area and allow N to move deeper into the profile from early season rainfall events. Conversely, the more rapid conversion of UAN to $NO_3$-N may increase denitrification risks when wet conditions occur. Clearly the seasonal conditions will affect the impact of these formulation choices, and so developing principles for such variable conditions will be challenging.

  Similarly, the relative effectiveness of topdressing v subsurface banding will also vary. The delays in formation of $NO_3$-N that occur in concentrated N bands can be a benefit in situations where in-crop rainfall is an important yield determinant (mid-row banding in southern systems with winter rainfall) but can cause delays in movement of N into deeper soil layers and contribute to stranding of N in dry topsoils unless banding is done early in the fallow. Topdressing, particularly during a fallow, can overcome some of these issues and provide a greater volume of soil enrichment, but this application method also maximises the interaction with the microbial community, and can result in similar delays in N movement due to immobilisation. The relative benefits of each strategy will therefore change with the amount and type of crop residue, the timing of N application and subsequent rainfall.
- Soil sampling as a guide to fertiliser N management strategies – the to's and fro's of soil sampling to determine fertiliser N requirement have been discussed extensively over recent updates, but mainly in the context of trying to determine the 'right' rate in situations with unreliable seasonal rainfall forecasts. Hopefully this discussion has shown that while fertiliser responsiveness will

vary in response to crop sequences, seasonal conditions etc, so will the fertiliser application strategy required to give the best chance of meeting crop demand. Soil sampling to periodically check the performance of your fertiliser N strategy, or to determine the impact of an unusual set of seasonal conditions (like the recent wet seasons from 2020–2023), will be essential to determine when and how future N management should change. For example, the current extremely low soil mineral N, especially in the subsoil, will indicate problems meeting crop N demand from fertilisers unless seasonal conditions are exceptional. Fertiliser strategies will need to focus more heavily on timing and placement of fertiliser N, and perhaps cause a rotational shift to a higher legume intensity in coming seasons. Once profile mineral N returns to more normal amounts and distribution, a more conventional approach can be adopted.

## Current research to develop better guidelines for N decision support

The focus of current fertiliser N research nationally is to improve our understanding of the fate of applied N fertiliser in grains cropping systems with investment by GRDC in project : Predicting nitrogen cycling and losses in Australian cropping systems - augmenting measurements to enhance modelling" – UOQ2204-010RTX. This involves studying N transformations and how these vary in different soils, climatic conditions and cropping sequences, and what this means for crop N demand, fertiliser use efficiency and environmental losses. There are a total of 15 experimental sites established across the country, with $^{15}$N labelled urea fertiliser used to track the fate of applied fertiliser across up to 3 consecutive growing seasons. Soils and crop residues from these sites are being provided to undertake more fundamental studies under controlled conditions, to better quantify the key processes involved in soil and crop N dynamics. Detailed monitoring of denitrification and volatilisation losses are being undertaken in the field and controlled conditions. Collectively, the data generated in this intensive research program will be used to validate and improve our ability to accurately simulate N dynamics in grains cropping systems nationally, with this improved capability to be used to improve decision support systems for fertiliser N management.

An additional DAWE-funded project in Qld (Project 4-H4T03F0: Understanding impacts of contrasting cropping systems on soil organic matter and the dynamics of soil water and nitrogen in rainfed cropping systems on vertosols in northeast Australia) runs in parallel with this work. It is using $^{15}$N-labelled fertilisers applied at different times during the fallow to track the leaching, crop recovery and environmental losses of fertiliser N in vertosol soils. It is collaborating with the GRDC farming systems sites at Pampas and Mungindi to explore these dynamics under contrasting crop sequences, with information also to be utilised to test the ability of crop models to predict these dynamics, and ultimately to evaluate contrasting fertiliser N strategies.

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# Fallow efficiency – impact of harvest stubble height

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[1] Northern Grower Alliance
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**Key words**

fallow, stubble height, soil water

**GRDC code**

NGA00003, NGA00004 and NGA2009-001RTX

**Take home message**

- Fallow efficiency is a key driver of crop production in the northern grains region
- Increasing groundcover to 100% (i.e. a stubble mulch) can significantly increase fallow efficiency but how can it be done commercially ?
- Increase in adoption of stripper fronts allowed for an evaluation of the impact of harvest stubble height on fallow efficiency
- Paddocks harvested with a stripper front with extra treatments then imposed by 'harvesting' using conventional headers with dry matter spread in plots by straw spinners
- EM38 used to assess conductivity differences between treatments (as surrogate for soil moisture changes)
- No clear differences in soil moisture accumulation due to harvest stubble height in any trial
- No significant difference in yield of following crop in any trial
- Changing harvest stubble height may impact on other agronomic practices but did not provide a measurable impact on fallow efficiency or yield of the following crop.

## Background

The farming system in the northern region relies heavily on stored soil water for production, particularly during grain fill. Are there any approaches that could reliably increase water storage and then improve yields?

This project was initiated from the frequent observations of extra soil moisture under the increased stubble loads in header trials. Proof of concept validation trials commenced in January 2014 with small plot trials assessing the impact of added stubble on soil water in a low stubble situation. Results from these trials showed an increase in soil moisture with increasing ground cover (treatments added from 5-40 t/ha) with increases of up to ~50-60mm in gravimetric soil water in a number of the stubble-added treatments.

Given the magnitude of impact seen in these trials, the next step was to work with growers and try to find a practical way to apply the concept in commercial situations. One option proposed was to examine the impact of harvest stubble height on fallow efficiency.

## Aim

This paper summarises the impact of harvest stubble height on soil water accumulation and storage (~fallow efficiency).

## Trial details

- All trials were carried out in commercial paddocks of wheat or barley stubble using commercial equipment
- Capacitance probes were used in the first 18 months of the Walgett trial to monitor impact on soil water
- EM38 assessment was subsequently used in all trials due to the high cost, inconvenience and poorer spatial representation from the capacitance probes.

An EM38 is a geophysical surveying instrument that provides a rapid measure of soil electrical conductivity. Factors affecting this measure are soil water and soil salt and clay content contents. Given that salt and clay contents remain largely stable in the soil, repeated measurements at a trial site allow for any changes in electrical conductivity to be attributed to changes in soil water. EM38 readings provide a conductivity measure at 3 depths: 0-37.5cm, 0-75cm and 0-150cm. Similar patterns of results were generally evident at all 3 depths in each trial.

**Figure 1.** Stubble height treatments: Bullarah February 2021

## Trial results

### *Walgett 2016*

- Trial in a paddock following Suntop⟑ wheat, grown on 40cm row spacings in 2016
- Paddock harvested in late November using a Shelbourne stripper, leaving tall stubble (~85 cm height)
- Additional treatments imposed approximately two weeks later using a conventional header
- Plots were 12 m wide x full field length with 5 replicates
- All straw 'cut' by conventional header was left in plots as spread by straw spinners
- Compared impact of stubble at three heights: short (~20cm), medium (~50cm) and tall (~85cm)
- ~14.5 t/ha of dry matter in tall stubble treatment
- Initial groundcover ranged from ~65% (short stubble) to ~50% (medium stubble) and ~35% (tall stubble)
- Next crop was unable to be planted until winter 2020 due to drought conditions

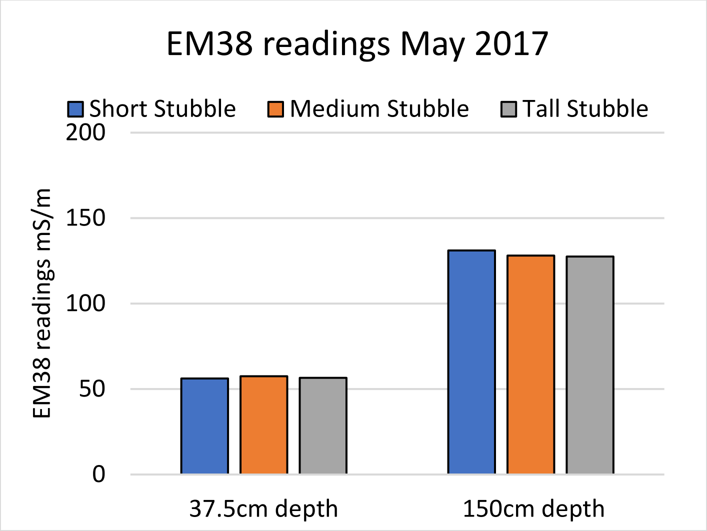

**Figure 2.** EM38 readings at Walgett May 2017

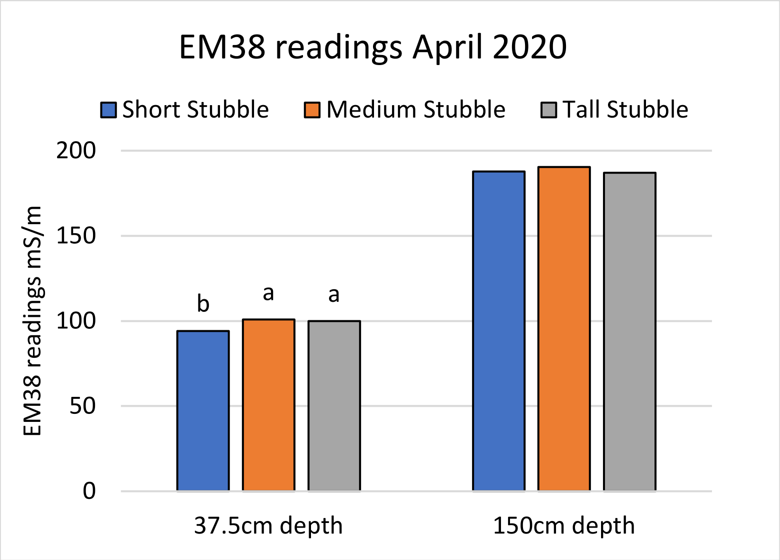

**Figure 3.** EM38 readings at Walgett April 2020

- Negligible difference in ‘soil water’ between stubble height treatments in EM38 readings throughout trial (NB only initial and final assessment dates shown)
- No clear difference in soil water from capacitance probe assessment between stubble height treatments (data not presented)

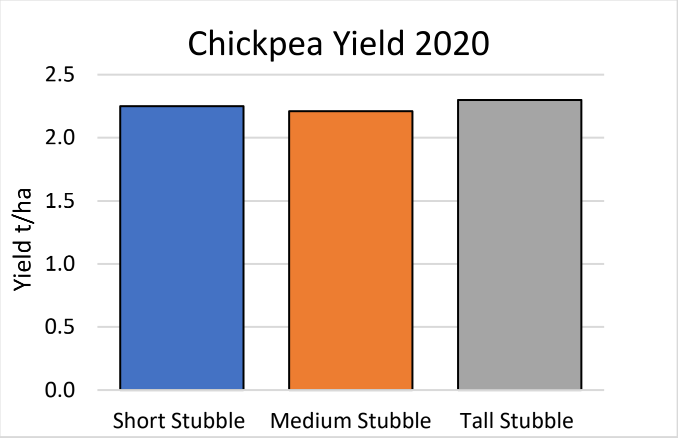

**Figure 4.** Chickpea yield at Walgett November 2020

- No significant difference in yield due to harvest stubble height

***Crooble 2019***

- Established following Planet⦶ barley, grown on 38cm row spacings in 2019
- Plots were 12 m wide x full field length with 6 replicates
- Treatments imposed in January 2020 using a conventional header
- Compared impact of stubble at three heights: short (~10cm), medium (~29cm) and tall (~51cm)
- All straw ‘cut’ by conventional header was left in plots as spread by straw spinners
- Only ~4.5 t/ha of dry matter in tall stubble treatment
- Initial groundcover ranged from ~49% (short stubble) to ~40% (medium stubble) and ~43% (tall stubble)
- Next crop sorghum planted in September 2020.

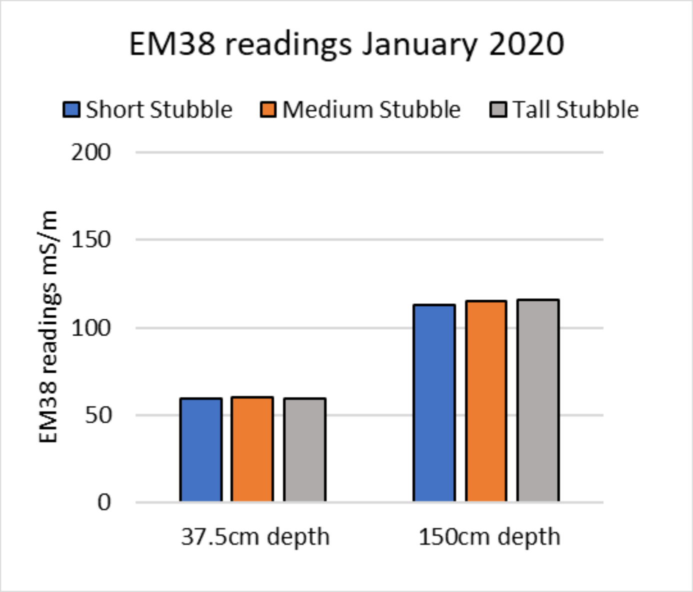

**Figure 5.** EM38 readings at trial initiation at Crooble Jan 2020

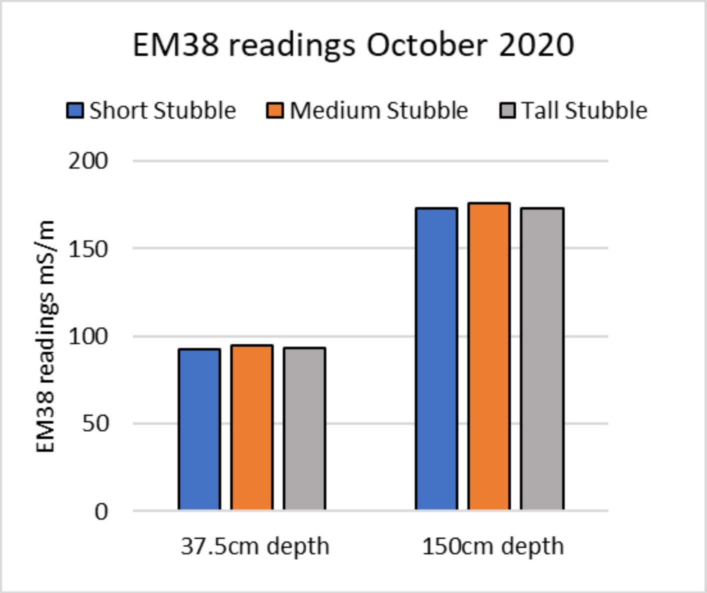

**Figure 6.** EM38 readings prior to sorghum planting at Crooble Oct 2020

- No significant difference in EM38 reading at any depth or assessment timing indicating no impact on soil water due to stubble height (NB only initial and final assessment dates shown)

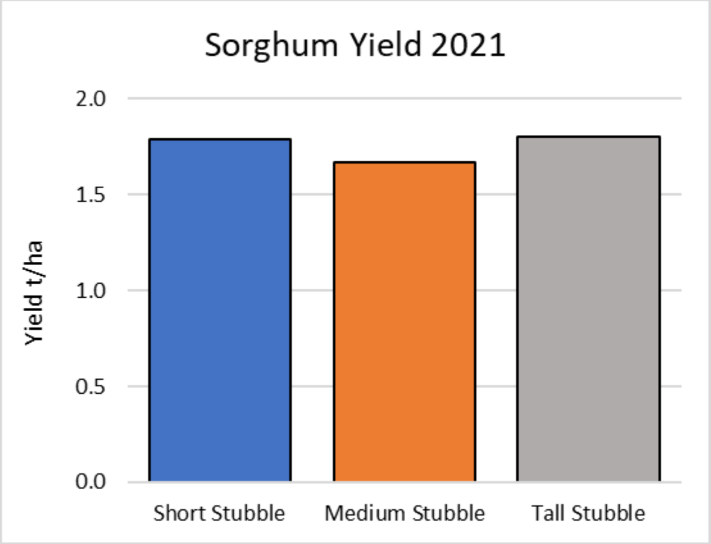

**Figure 7.** Sorghum yield at Crooble February 2021

- No significant difference in yield due to harvest stubble height.

***Bullarah, Mallawa and Crooble 2020***

- Nine trials established after the 2020 winter cereal harvest
- Plots 12 m wide x full field length with 6 to 9 replicates
- Initiation of trials was delayed due to the wet harvest, with treatments not imposed until Jan/Feb 2021
- Conventional headers or slashers used to create stubble height differences with straw remaining in plots
- All sites commenced with groundcover levels of greater than 60-70%

- Compared impact of stubble at three heights: short (~10-15cm), medium (~40-55cm) and tall (~85-95cm)
- Large rainfall totals were received at all sites in February and March 2021
- Interim EM38 assessments were not possible during that period and soil profiles may have been nearly full by April 2021
- One site abandoned due to flooding and yield data was compromised in three trials

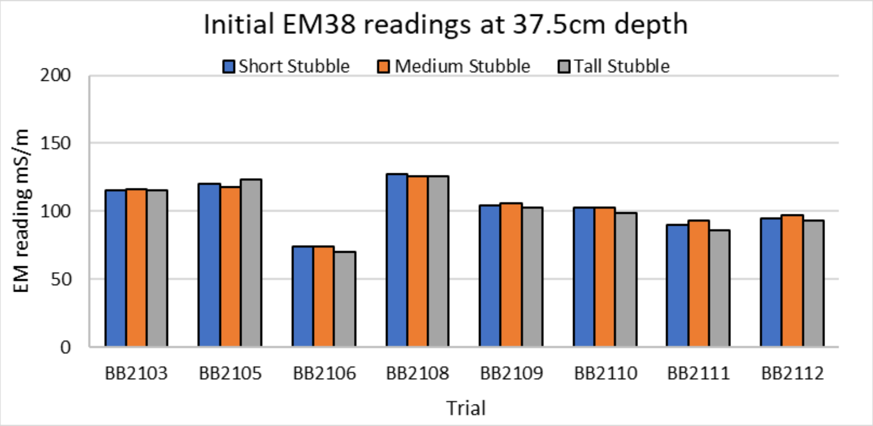

**Figure 8.** EM38 readings at 37.5cm depth at trial establishment across 9 trials (Jan/Feb 2021)

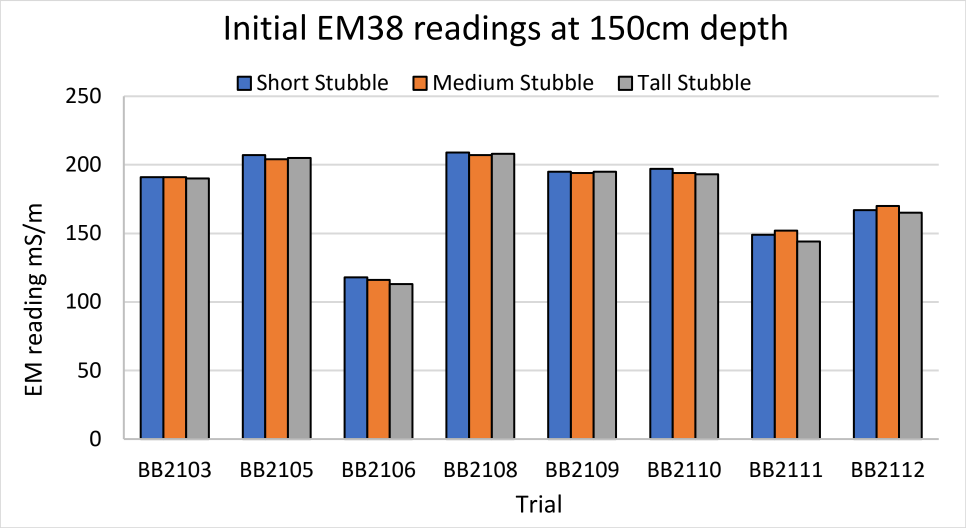

**Figure 9.** EM38 readings at 150cm depth at trial establishment across 9 trials (Jan/Feb 2021)

- No difference evident in EM38 between treatments at either depth, shortly after trial commencement

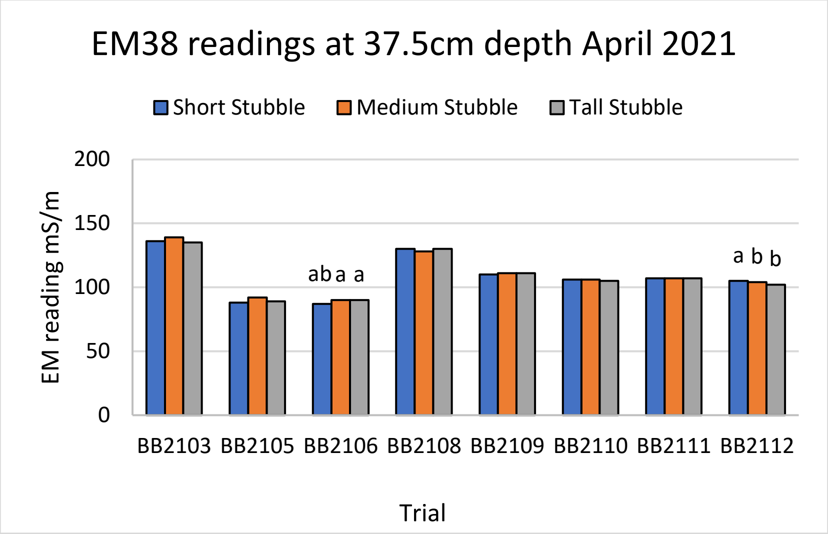

**Figure 10.** EM 38 readings at 37.5cm depth at end of summer fallow across 9 trials (April 2021)

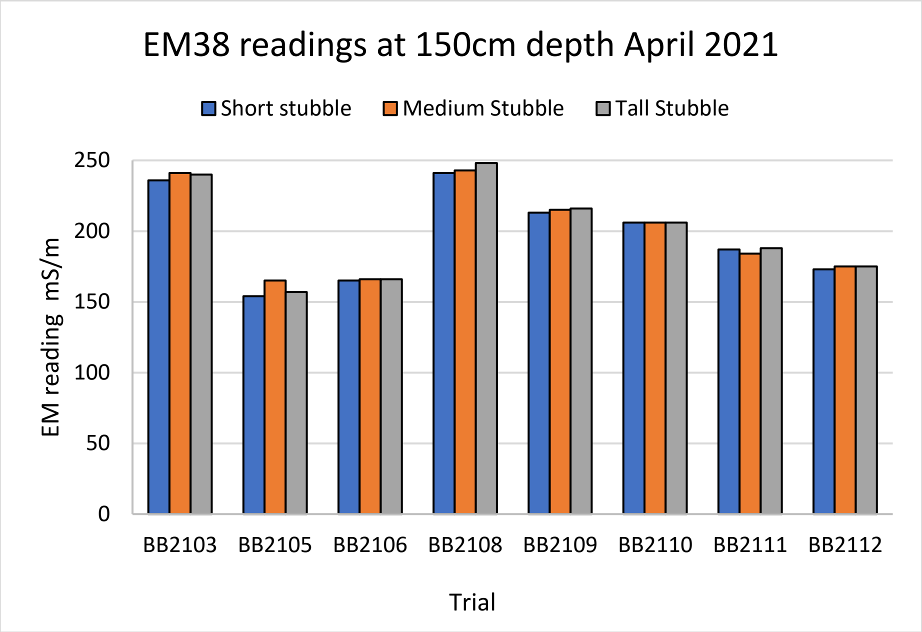

**Figure 11.** EM38 readings at 150cm depth at end of summer fallow across 9 trials (April 2021)

- Two trials had statistical differences at 37.5cm: one indicated a trend to **reduced soil water under short stubble**, the other indicated **increased soil water under the short stubble** treatment
- No significant difference in EM38 readings at 150cm depth in any trial indicating no impact evident on total soil water due to stubble height
- Two trials fallowed to dryland cotton in summer 2021/22

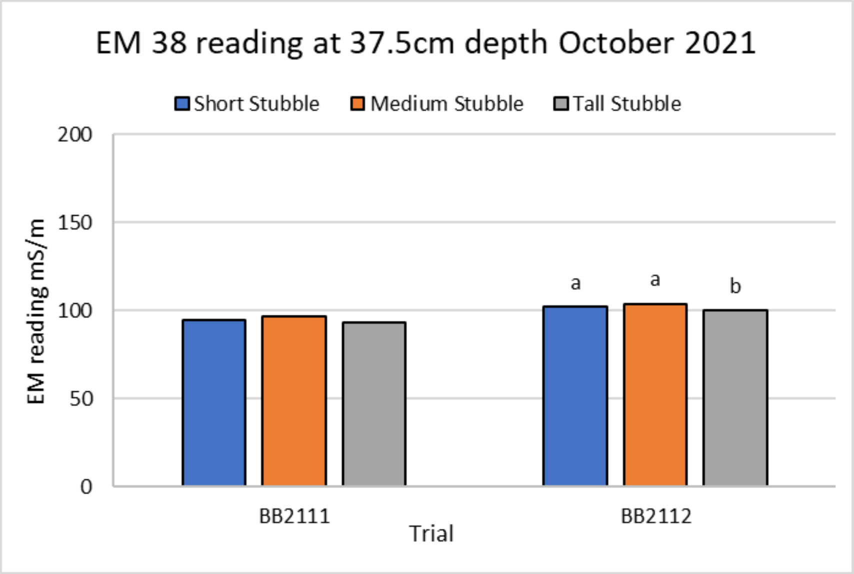

**Figure 12.** EM38 readings at 37.5cm depth prior to cotton (October 2021)

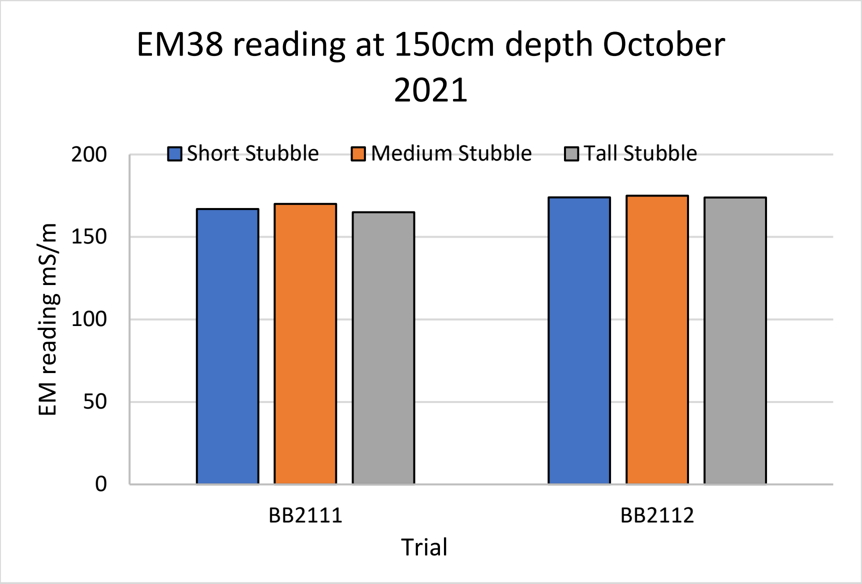

**Figure 13.** EM 38 readings at 150cm prior to cotton (October 2021)

- Trial BB2112 had significantly higher EM38 readings at 37.5cm in the short stubble at April 2021 and significantly higher for both short and medium stubble at October 2021
- No significant difference in EM38 readings at 150cm depth in either trial indicating no apparent difference in total soil water due to stubble height
- Header/harvest complications and wet weather impacted on yield data collection

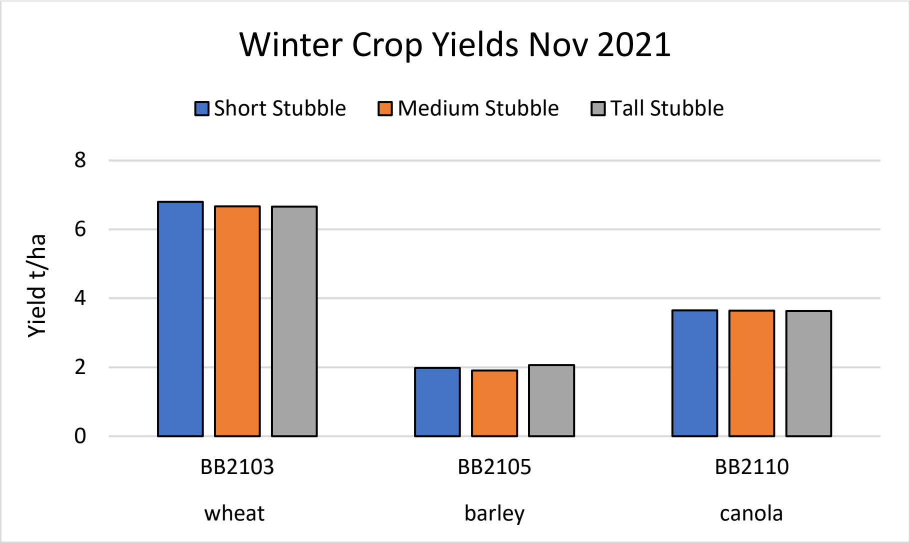

**Figure 14.** Yield (t/ha) from winter crop trials in 2021

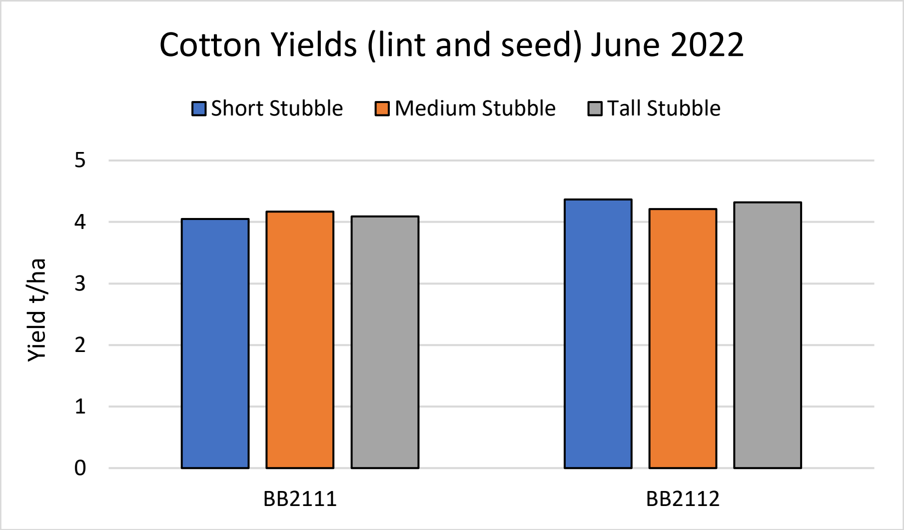

**Figure 15.** Yield (t/ha) from stripper picked cotton trials in June 2022

- No significant differences in yield at any site due to harvest stubble height

### Conclusions

This project was conducted to evaluate the level of impact of harvest stubble height on soil water or fallow efficiency. Trials were conducted under a range of conditions:

- Walgett 2016 started with good stubble loads but very poor fallow rainfall with the following crop not sown until winter 2020
- Crooble 2019 started with low stubble levels and experienced relatively low fallow rainfall
- Trials in 2020 started with high stubble loads and received large amounts of fallow rainfall shortly after commencement

Although none of the situations were considered ideal, the key messages to emerge from the trial series were:

1. **Harvest stubble height** - where the cut stubble was spread in the same treatment - **did NOT appear to provide any useful benefit in fallow efficiency as measured by EM38**
2. **There was NO indication of harvest stubble height impacting on the yield of the following crop**

**Did these results conflict with those from the pilot study in 2014 and 2015? In hindsight – NO**

The pilot study assessed the amount of extra soil water that could be captured by ADDING stubble in a low standing stubble situation to achieve more than 100% groundcover. The harvest stubble height treatments DID NOT vary the amount of stubble in each treatment but just changed where it was located. Although a harvest stubble height approach would be relatively easy to implement on a commercial scale, it did not appear to be sufficient to result in a measurable impact on fallow efficiency.

It was clear that harvest stubble height can have other agronomic impacts:

1. Reduced weed emergence was noted in the tall stubble height plots at one site but knockdown weed control appeared more challenging due to poorer coverage
2. Short stubble height persisted longer in the Walgett 2016 trial as it appeared to remain ‘anchored’ in the soil despite over 3 years of fallow
3. Tall stubble height reduced canola emergence at one site with mouse damage suspected as the actual cause

In addition, recent studies from NSW DPI have shown that tall stubble height may increase the amount of crown rot infected stubble as the fungus can saprophytically colonise during the fallow.

Harvest stubble height can be influenced by a range of factors including header type, previous variety, growing conditions, presence of lodging or even by the intended following crop in the rotation. However, the data generated in this project would strongly suggest that harvest stubble height is unlikely to have any significant impact on the fallow efficiency achieved or on the following crop yield.

**Figure 16.** Stubble height treatments: Crooble April 2021

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# Farming systems in the future: how will systems evolve to address emerging threats and opportunities

*Lindsay Bell, CSIRO, Toowoomba*

**Key words**

crop rotation, soil water, economics, costs, farming systems, break crops, greenhouse gas, threats, opportunities, future

**GRDC code**

DAQ2007-004RMX

**Take home message**

- Adaptability and flexibility in farming systems is required to respond to climate, market and other drivers in the future.
- Future farming systems are going to be more diverse, providing more crop opportunities to help manage diseases, weeds and support more functional landscapes and soils.
- Legumes are likely to constitute a larger proportion of our crop sequences, provided we have viable options.
- Sensors and other digital information will be available to provide critical information to allow more site-specific, effective and timely decision making and management.
- Future systems will increasingly need to balance production goals with environmental impacts such as greenhouse gas (GHG) emissions, pesticide use, biodiversity, soil and landscape management.
- Data & information systems are needed to enable farmers and industry to defend or demonstrate their environmental credentials, GHG footprint and food safety.

## Introduction

Agricultural systems are always evolving in response to markets, production environments and technologies. Consider how much our farming systems have changed in the last 30 years with the wide-spread adoption of reduced tillage, large-scale machinery, decline of the wool industry, advent of cost-effective herbicides, new crops developed (e.g. chickpea), and emerging disease and weed challenges.

It is inevitable that farming systems will continue to evolve into the future and continued gains in system productivity will remain vital. Without significant and ongoing commodity price increases we need to maintain increases in productivity to ensure economic viability for farms and feed the growing world population. Hence, while markets like ‘organics’ may continue to grow, this cannot replace the bulk of agricultural systems, because the lower production output from these systems would have wide-reaching consequences for food availability and security.

Increasingly over the next 20 years, there are likely to be numerous drivers that will influence our farming system. Clear drivers that are increasing include the need to reduce waste, optimise use of external inputs, and maintain ‘license to operate’ by demonstrating to the public that systems meet animal welfare, environmental management, and food safety & provenance expectations. Several emerging trends are suggested below, and what they might mean for our farming systems in southern Qld and northern NSW. There are likely to be a range of technologies that emerge (e.g. genome edited crops), that may not alter our farming systems in predictable ways. Hence, this is not an exhaustive list, and forecasts have not received comprehensive analysis – they are thoughts about what is likely to occur, and the opportunities or challenges this may present.

### Resilience in future climates

We are all aware that the climate is changing. The Northern grains region may not see large changes in the average rainfall but it is likely to see increased variability along with hotter and longer summers. While most farmers are accustomed to managing climate variability, this is likely to put even greater focus on how we manage our key limiting resource – water. One way to imagine this evolving climate is to look 200-400 km northward; the current farming systems in central Queensland might be a good indicator of our future farming system.

#### *What is likely to change?*

*Changes in the mix of crops or land use*. The combination of climate and soil drive the production potential and viable crop options in each environment. Hence, with changes in climate (and markets), there will be some regions or situations where the land use and crop options may need to shift. Many soils with lower soil water storage capacities have been retired from dryland grain cropping over the last 2 decades. There is likely to be more use more summer crops in environments where winter cropping has previously dominated.

*Changes in our cropping season boundaries.* To avoid heat stresses in both winter and summer crops, we are likely to see a shift to earlier sowing, allowing crops to flower during cooler conditions. However, this may involve greater exposure to frost risk at critical times. The boundaries between summer and winter crop windows are likely to further blur. The prospects of winter-sown sorghum are an example. However, with these shifts there is a need to balance the frequency of sowing opportunities, soil water at sowing, and cultivar choice.

*Flexible options and tactics to manage systems in a variable climate*. If rainfall is likely to become more variable,farming systems will need to respond to triggers such as soil water rather than employing strict or programmed crop sequences. Hence, a greater variety of crop options may be needed (varieties, crop types or species) to allow us to make use of these opportunities when they present themselves. This might involve using long-season winter type cultivars for early autumn sowing or using forage crops that have a wide sowing window. There is also likely to be increasing value in seasonally responsive practices, such as using crops for silage or grazing during dry seasonal conditions.

### Soil resources & natural capital

The health and fertility of soils and landscapes continues to decline under our current farming practices. Even with the adoption of stubble retention and no-till farming, soil carbon continues to decline. Most modern farming systems remain in negative nutrient balance, meaning the soil chemical pool is being ‘mined’ to support our agricultural outputs. Increasingly crop nutrition needs to be supplied from synthetic sources rather than from the soil pool, meaning many of those nutrients are provided less efficiently to our crops. For example, we know that soil mineral N is used more efficiently by crops than fertiliser applied in that year.

Banks and agri-finance sectors are increasingly looking at how well farmers manage their land, and this is influencing availability and cost of finance. Large scale monocultures and increases in cropping area has negative impacts on the ecosystem services such as those provided by beneficial insects like pollination and pest control. There is also likely to be increasing opportunities for farmers to participate in markets for biodiversity or environmental management outcomes.

### *What is likely to change?*

*Soil functionality will need to be monitored & managed.* Soil sampling for nutrient analysis, and increasingly for biological insights using tools like Predicta®B are now fairly common place. These tools give some insights, but the capacity to understand more broadly the physical and biological status of our soil will help management of overall fertility. For example, there is still lots to be captured from greater understanding of our soil's microbiome (*i.e.* microbes and biology of the soil), how to measure what biology contributes to our production system, the critical thresholds that need to be avoided, and how management can influence this for improved function.

*Restorative practices to rebuild soil fertility may be required*. As soil fertility declines, it will reach a point where we need to employ practices that go some way towards restoring or maintain its function to allow us to then return to cropping. This will mean practices such as ley pasture rotations, cover crops, green manures, manure/biosolid or biochar applications will become more common. However, because these often come with an economic cost, we need to understand the holistic benefits of such practices, to better understand when they might be used for maximum benefit.

*Farmers will have to demonstrate their environmental credentials*. Stewardship of biodiversity and the environment will increasingly become critical across the agricultural value chain, potentially providing an income source associated with favourable management practices. With suppliers and purchasers of farm products wanting to incentivise sustainable land management practices, farmers will need to have ways of quantifying or demonstrating how their management is meeting these expectations to access higher value markets and lower-cost finance.

### Green-house gas emissions and accounting

The 'de-carbonisation' of the economy will come to agriculture. Farmers and the industry as a whole will need to quantify the emissions associated with production systems, and potentially move to systems that optimise production per unit of GHG emitted (i.e. GHG intensity). This will mean that most farms will need to collect critical data used to calculate their GHG footprint and report this to their customers. Given that nitrogen fertilisers contribute about 40% of the GHG emission in most grain production systems, this will be a critical input to manage (Sevenster et al. 2022). Other important contributors (e.g. losses from residue decomposition, farm operations, and crop protection) are much more difficult to mitigate.

### *What is likely to change?*

*Nitrogen management practices and efficiency will be critical.* While N fertiliser is the largest single GHG emission source in our farming systems, removing it will not be a viable solution to optimise GHG intensity. Stopping N fertiliser would cause a dramatic reduction in productivity, and further hasten the decline in soil carbon. In fact, analysis suggests that where N fertiliser use is insufficient, then increasing N inputs to better match crop demand would improve the GHG intensity of the farming system. This is because the grain yield benefits would increase more than the associated GHG emissions (Sevenster et al. 2022). Further, by growing more crop biomass, the change in soil C would offset on-farm nitrous oxide emissions. All this suggests, that optimising our N management practices avoiding emissions that occur from N fertiliser application, and to better match crop demand, will be critical to managing GHG emissions whilst maintaining system productivity.

*Growing legumes may help offset GHG footprint*. Obviously, using legumes in the farming system to provide N for subsequent crops may help mitigate the amount of synthetic N inputs required. However, the whole system implications of this are not straight forward. Most grain legumes or legume hay crops leave little additional N for subsequent crops, but as they don't require fertiliser this can reduce total N fertiliser inputs. However, legumes are also likely to induce higher emission from the breakdown of their residues, they grow less biomass to maintain soil C, and they often require more crop protection and other fertiliser inputs – these factors will reduce or counteract their overall benefit. Grazed forage/pasture legumes provide the largest legacy N benefits, but farmers may need to account for the emissions of the animals grazing these pastures in their GHG balance.

### Herbicide and pesticide use

Increasing scrutiny or policy settings will influence the range and use of herbicides and pesticides available to Australian farmers. There are several chemicals we commonly use that are now banned elsewhere in the world. This is likely to affect our international market access (and hence prices), but also there will be increasing scrutiny from the public about the use of agri-chemicals in our food systems, and particularly the risk of environmentally active chemicals finding their way into other parts of the eco-system.

#### *What is likely to change?*

*Non-chemical weed control options will need to diversify*. While there will inevitably be a range of non-chemical options available in the future (e.g. microwaves, precision tillage, lasers), we are still likely to need to focus more on cultural techniques for weed management. This will mean the use of options like sacrificial cover crops, tactical grazing, mechanical seed destruction or hay/silage options to reduce seed set, and planting configurations to increase crop competition. However, these practices are likely to induce other risks, such as having insufficient water to support higher biomass competitive crops grown for weed suppression. Ultimately, other supporting crops/practices will be needed in our farming systems that reduce weed populations, but we may also need to learn to live with higher weed numbers in our systems.

*Herbicides as a desiccation option in crops will become problematic*. We will need to find and demonstrate other options (e.g. windrowing) particularly in crops for human consumption. Without timely termination of crops like sorghum and many legumes, they will continue to use water during grain ripening that may have been left as residual at harvest.

*Crop protection products will require more consideration before use*. Prophylactic applications of insecticides and fungicides are likely to be under increasing scrutiny, meaning that growers and advisors will need to make more tactical judgements about when their use is justified. Hence, guidelines or regulations will require yield driven thresholds for these products.

### Digital technologies & information

Technology is moving quickly, and the agricultural tech sector is working on a plethora of new technologies targeting on-farm applications, from robotics and automation, to satellite imaging, to local sensor networks. A huge range of data and information sources (e.g. satellite, sensors) are going to be available to farmers and their advisors – the challenge will be how to use this effectively. How these will change our farming systems is less clear, but the most impactful technologies will overcome pain points or open opportunities that are currently constrained by imprecise information.

#### *What is likely to change?*

*Robotics and automation will reduce labour requirements*. Labour availability and efficiency is a key constraint to many farming operations. Robotics may allow labour intensive crops to be used more widely. However, potentially high capital cost or buy-in for such technology is likely to be a large disincentive unless there is sufficient scale of application.

*New/better information will be available to make more informed decisions*. Information will enable monitoring our farms with greater precision and allow more specific inputs or management to be applied (similar to sensor sprayers). It is hoped that improvements in climate forecasting will allow more timely and efficient use of inputs and operations. While none of these in their own right will transform the farming system, they are likely to offer gains in efficiency, reduce risk and uncertainty, or reduce costs of key inputs (e.g. improving fertiliser and other input application and responses).

### Future protein – plant-based foods & other markets

Clearly new markets are evolving to fill the increasing consumer demands for plant-based or alternative protein sources. Industries like aquaculture are looking to alternatives to fish meal to provide protein in their feedstocks. Presumably this will mean there will be a growing opportunity for using more pulses and grain legumes in our farming systems. The challenge in many environments is the lack of currently viable and economic options, except for chickpea, mungbean, and faba bean perhaps.

#### *What is likely to change?*

*An opportunity for a greater diversity of viable grain legumes*. It is still unclear how a range of potential legume crops may fit into future market needs, and the degree that their prices and agronomics may combine to elevate them to become a viable crop for growers in the future – more research is required. Nonetheless, there are several under-utilised grain legumes that that could be used that could bring additional value to our dryland sub-tropical farming systems if appropriate markets can be developed – examples include cowpea, pigeon pea, soybean, field pea, lentils, lablab, lupins, vetch.

### Conclusions

What is clear is that there are a variety of forces and trends that will impact farming systems over the next decade or two. Preparing and proactively managing for several of these will be far better than trying to respond as they 'break' upon us. Nonetheless, adaptability and flexibility in our farming systems will be critical. Further, robust and science-based tools and information at the farming system level will be vital to guide and provide confidence that new systems and practices are overall beneficial. There are many potential trade-offs in our decision making on farm, and looking at issues through a single lens with partial truths, is likely to overlook important aspects.

### Acknowledgements

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

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# Discussion on sorghum, chickpea impact on rotation profitability

**Notes**

# Barley disease update 2023

*Lislé Snyman, Dept. Agriculture and Fisheries Queensland*

## Key words

leaf rust, net form net blotch, spot form net blotch, disease management

## GRDC code

National Variety Disease Screening (NVT)
UOA2003-008: Program 2: Minimizing the impact of major barley foliar pathogens on yield and profit – surveillance and monitoring of pathogen populations
DAQ2106-007: Disease surveillance and related diagnostics for the Australian grains industry within the northern region

## Take home messages

- Epidemic leaf rust levels in 2022 barley crops – high inoculum loads possible in 2023
- Low levels of both net blotches in 2022 – will be present in barley stubble
- Do not plant barley into barley stubble
- Management strategies for foliar diseases includes resistant varieties, crop rotation, seed treatment, regular crop monitoring and timely fungicide application
- Resistance to fungicides has previously been reported in powdery mildew, both net blotch pathogens and more recently in the leaf rust pathogen of both barley and wheat
- Fungicide resistance development should be managed by using an Integrated Disease Management (IDM) strategy.

## Background

The seasonal outlook for 2023 is forecast to bring below median rainfall and possible drier and hotter spring and summer conditions. Epidemic levels of barley leaf rust observed in susceptible varieties in 2022, could result in the presence of high inoculum loads early in the 2023 cropping season. Both the net blotches were present at low levels in 2022 crops; however, where barley is planted into barley stubble from last season, this could cause infection early in the growing season. Spot form net blotch has been observed in early barley crops planted into barley stubble in QLD.

## Leaf rust

Leaf rust of barley is widely distributed and a common disease in all Australian barley-growing regions. It is considered one of the five major barley diseases in Australia and can significantly reduce grain yield and quality, with yield losses in excess of 50% reported under experimental conditions. Leaf rust was widespread in Queensland in 2016, but due to the prolonged drought conditions, was only present at very low levels until 2021. Since then, environmental conditions favourable for disease establishment and spread have led to an increase in leaf rust inoculum, with epidemic levels observed in susceptible varieties in 2022.

A new pathotype of leaf rust (5457P+), virulent on *Rph3* was identified in eastern Australia in 2009 (Cereal Rust Report 2009, Vol 7, Issue 5). This virulence is present in all major production areas. The emergence of this pathotype had a major impact on not only production, but also on barley breeding as it rendered a large portion of elite breeding material susceptible. Many current commercial varieties are still reliant on *Rph3* (Cereal Rust Report 2020, Vol 17, Issue 1).

In the presence of a green bridge, the pathogen can survive over summer and be present at high levels early in the growing season. Leaf rust is favoured by moist conditions with temperatures ranging between 15°C and 22°C.

The disease is caused by the obligate parasite, *Puccinia hordei.* It can be identified by small circular to oval pustules on upper leaf surfaces. It can also develop on leaf sheaths later in the season. As the crop matures, pustules turn dark, producing black teliospores. Rust spreads by means of airborne spores, able to travel long distances. The pathogen spreads rapidly when conditions are favourable and large areas are planted to susceptible varieties, resulting in the development of epidemics. High inoculum levels put pressure on major resistance genes and can lead to the development of new, more virulent pathotypes.

Large areas sown to S to VS varieties across a range of environments almost ensures that leaf rust will be a problem in some regions contributing to high inoculum levels causing epidemics, whilst adding selection pressure on the pathogen to mutate and acquire new virulences.

### Net blotch

Net blotches exist as one of two forms, net form net blotch (*Pyrenophora teres* f. *teres*) or spot form net blotch (*P. teres* f. *maculata*). They are stubble-borne diseases where primary infection is derived from barley crop stubble. Net form net blotch (NFNB) can also be seed-borne. Spot form net blotch (SFNB) however, has not been shown to be seed-borne.

Net blotches are economically important diseases in most barley growing regions in the world. Yield loss associated with NFNB generally range between 10% and 40%. However, losses in excess of 60% have been reported in QLD and up to 70% in South Australia on susceptible varieties under epidemic conditions. Yield loss due to SFNB is not well documented; but has been reported up to 44% in WA.

The spore morphology of the two forms is very similar, hence symptom expression is used to distinguish between the two forms. At early stages of disease development, it can be difficult to distinguish between the two forms. Both diseases start off as small black-brown spots. In net form net blotch, they elongate into a distinctive net-like pattern. In spot form lesions enlarge into round to oval shapes with an often darker centre surrounded by a chlorotic margin.

The net blotch pathogens, in particular the net form net blotch pathogen is very variable and can frequently overcome resistance in varieties. It is well known that they adapt and increase virulence on varieties grown over large areas.

### Powdery mildew

Powdery mildew (*Blumeria graminis* f. sp. *hordei*) is synonymous with barley cultivation in the northern region and often appears early in the growing season. It prefers mild and humid conditions and can be seen as white, fluffy mycelia growth on leaves and leaf sheaths. It generally does not persist once conditions turn to warm and dry. Hence, in Queensland yield loss is usually less than 15%.

Powdery mildew survives between crops on volunteer barley and on barley stubble. Older fungal colonies become dull grey and produce small, black fruiting bodies (cleistothecia). When cleistothecia mature and conditions are favourable, they release ascospores to infect the new crop. These soon produce conidia (asexual spores) that spread the disease within and between crops.

Unless a variety is very susceptible to powdery mildew and conditions are very favourable for disease development, it is unlikely that the disease will progress to upper leaves of adult plants. In 2022, environmental conditions remained favourable until late in the season, resulting in very high infection levels in susceptible varieties.

The powdery mildew fungus can evolve rapidly and can form new races/pathotypes that infect previously resistant varieties. In Australia, varieties such as Commander$^{\phi}$, Compass$^{\phi}$, La Trobe$^{\phi}$ and Shepherd$^{\phi}$ were all resistant when released; but changes in the powdery mildew population have rendered these susceptible. Continuous monitoring of the powdery mildew population provides knowledge on the virulences in the Australian barley powdery mildew population. This information guides the breeders when choosing resistance sources and facilitates screening of breeding material with new, relevant virulences.

### Fungicides - resistance risk and timing

The development of resistance and reduced sensitivity to fungicides is an increasing problem in many pathogens. Without intervention, more fungicides are likely to become ineffective.

Fungicides are essential in cropping and are used almost routinely in barley crops. The choice of fungicide is determined by registration, efficacy, availability and price.

The risk of developing fungicide resistance varies between mode of action (MoA) groups, fungal pathogens and environments. Repeated use of fungicides with the same MoA selects for individuals in the fungal population with reduced sensitivity to the fungicide. Higher disease pressure indicates larger pathogen populations and increased probability of developing resistance to fungicides.

In Australia, fungicide resistance and reduced sensitivity in barley pathogens have been identified to date in powdery mildew, spot form net blotch and net form net blotch. Most recently fungicide insensitivity has been reported in leaf rust of both barley and wheat in Australia (Cereal Rust Report 2022, Vol 19, Issue 3). This will have a major impact on the management of leaf rust epidemics in cereal crops in future.

Fungicide resistance can be managed using an integrated disease management (IDM) strategy to reduce disease pressure and reliance on fungicides. This includes:

- Resistant varieties
- Crop rotation
- Clean seed
- Managing green bridge
- Stubble management
- Use fungicides only when necessary and apply strategically
- Rotate and mix fungicide MoA groups
- Monitor regularly for disease - fungicides are more effective at lower disease levels.

### Conclusion

Barley foliar pathogens cause devastating yield and quality loss worldwide. Research has proven that the more susceptible a variety, the bigger the yield and quality loss resulting from disease. The most economic and environmentally friendly means of controlling disease is by growing a high-yielding well-adapted resistant variety. It has been proven that growing varieties with some level of resistance can limit yield and quality loss. The most up-to-date disease ratings are available on the NVT website (https://nvt.grdc.com.au/nvt-disease-ratings).

Thus, growing a susceptible variety increases risk and requires dedicated effort towards persistent monitoring and decision making. The presence of a green bridge will present an opportunity for many pathogens to survive and be present at high levels early in the growing season. Planting barley on barley will increase the risk and disease pressure of stubble-borne pathogens and may aid the survival of fungicide resistant individuals.

The epidemiology of the pathogen, the biology of the host and environmental conditions all impact disease management. Foliar fungicides are very effective but need to be applied early in the epidemic as disease can increase rapidly. The use of an integrated disease management approach will not only limit the development of fungicide resistance but will also reduce economic input and support sustainable farming.

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# Fungicide resistance in wheat powdery mildew in Qld and NSW in 2022

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fungicide resistance, reduced sensitivity, disease, varietal resistance, management

**GRDC code**

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**Take home messages**

- The wheat powdery mildew (WPM) pathogen has a high risk of developing fungicide resistance
- The 2022 season, with frequent rainfall and prolonged mild temperatures in spring, was conducive to WPM development in susceptible wheat varieties across southern Qld and NSW
- Widespread resistance or reduced sensitivity to Group 3 DMIs is considered a high risk and a DMI 'gateway' mutation was detected at a high frequency (range 53 to 100%) in all samples collected across southern Qld and NSW in 2022
- Resistance to Group 11 (QoI) fungicides has been detected across most of the southern growing region and was detected at a lower frequency than DMI resistance in 9 of 10 southern Qld samples (range 7 to 56%) and 8 of 9 NSW samples (range 10 to 58%)
- Careful use and rotation of available fungicide actives will help control the spread of resistance in WPM
- Agronomic practices that minimise disease pressure reduce the need to apply fungicides
- Good management will help protect the long-term efficacy of current fungicides.

## Introduction

Wheat powdery mildew (WPM), caused by *Blumeria graminis* f. sp. *tritici* (*Bgt*), is favoured by susceptible wheat varieties growing in mild and humid weather (15° to 22°C, relative humidity >70%), with a dense crop canopy, high nitrogen levels, good soil moisture profiles and extended periods of damp, humid conditions under the canopy. *Bgt* survives on wheat stubble and volunteer wheat plants. Spores can be spread to crops by the wind over moderate distances (kilometres). The pathogen is crop specific and only infects wheat, not barley or other grain crops.

In 2020, there were concerns across wheat-growing regions of New South Wales and northern Victoria on the performance of fungicides from the DMI group. Despite crops receiving 2–4 fungicide applications during the season, wheat powdery mildew remained a problem for growers in some areas.

DMI fungicide resistance was detected at very high frequencies in samples collected from paddocks around Edgeroi, Wee Waa, Albury, Rennie, Balldale, Deniliquin, Jerilderie, Hillston and Yenda in NSW, and Cobram and Katamatite in Victoria. Genetic and phenotypic analyses of the isolates obtained from these locations revealed a combination of mutations in the DMI fungicide target gene that were associated with the observed resistance to some DMIs. Additionally, all samples tested had some level of strobilurin fungicide resistance (Simpfendorfer *et al.* 2021). Further research by the Centre for Crop Disease Management (CCDM) has associated the DMI mutations to reduced sensitivity to some triazole fungicides such as propiconazole under glasshouse conditions (Lopez-Ruiz *et al.*2023). The 2022 season was conducive to the development of WPM due to frequent rainfall and prolonged mild temperatures during spring. This favoured the development of WPM across parts of NSW and into Qld, so the opportunity was taken to conduct a further survey of fungicide resistance in collaboration with CCDM. This was particularly important for Qld production areas where the status of fungicide resistance within the WPM population has not been previously characterised (Poole *et al.* 2022).

## What we did

WPM samples were collected by collaborating agronomists, sent to Tamworth for processing to help ensure viability in transit, then sent to CCDM for molecular analysis of frequency of mutations for DMI (F136 'gateway' mutation, triazoles) and QoI (A143 mutation, strobilurins) resistance within the WPM population in each sample. In 2022, nineteen viable WPM samples were analysed by CCDM from across Qld and NSW, with sample distribution being Qld (10), SW NSW (3), SE NSW (2), CE NSW (2), NE NSW (1) and NW NSW (1) (Table 1).

## What we found

The F136 mutation, also known as a 'gateway', has been previously associated with reduced sensitivity to some DMI (Group 3, triazole) fungicides. This mutation is normally found together with other mutations that are ultimately responsible for the resistant phenotype observed in the field. Once the frequency of the F136 and other mutations in a WPM pathogen population reach moderate levels, then reduced sensitivity to DMI fungicides is possible under field conditions. Very high frequencies may result in resistance to WPM and spray failure under field conditions with some DMI actives. The F136 'gateway' mutation itself does not necessarily mean field failure. It is however an initial warning that issues with continued DMI fungicide use exist. Field efficacy of different DMI fungicides in the presence of this 'gateway' mutation, can vary considerably, depending on what other mutations exist once this 'gateway' mutation occurs within a WPM population.

**Table 1:** Location of 19 wheat powdery mildew samples collected across Qld and NSW in 2022 along with frequency of DMI (triazole) 'gateway' and QoI (strobilurin) mutations

| Location | Year | Region | Variety | Frequency of mutation | |
|---|---|---|---|---|---|
| | | | | DMI F136 | QoI A143 |
| Bell | 2022 | Qld | Sunflexⓟ | 53% | 10% |
| Bell | 2022 | Qld | Sunchaserⓟ | 99% | 17% |
| Chinchilla | 2022 | Qld | Sunmaxⓟ | 100% | 22% |
| Chinchilla | 2022 | Qld | Sunchaserⓟ | 100% | 7% |
| Gatton | 2022 | Qld | LongReach Hellfireⓟ | 100% | 51% |
| Jandowae | 2022 | Qld | Sunchaserⓟ | 90% | 38% |
| Jandowae | 2022 | Qld | Sunchaserⓟ | 83% | 16% |
| Macalister | 2022 | Qld | LongReach Hellfireⓟ | 100% | 56% |
| Macalister | 2022 | Qld | Sunchaserⓟ | 99% | 29% |
| Surat | 2022 | Qld | Sunmaxⓟ | 72% | 0% |
| Ashley | 2022 | NW NSW | Westcourtⓟ durum | 66% | 18% |
| Narrabri | 2022 | NE NSW | Breeding line | 100% | 10% |
| Grenfell | 2022 | CE NSW | Sunflexⓟ | 100% | 20% |
| Grenfell | 2022 | CE NSW | Breeding line | 100% | 0% |
| Balldale | 2022 | SE NSW | Scepterⓟ | 100% | 28% |
| Tocumwal | 2022 | SE NSW | Livingstonⓟ | 100% | 47% |
| Deniliquin | 2022 | SW NSW | Scepterⓟ | 100% | 11% |
| Finley | 2022 | SW NSW | Scepterⓟ | 100% | 58% |
| Widgelli | 2022 | SW NSW | Breeding line | 100% | 47% |

All Qld and NSW WPM samples collected in 2022 had a DMI F136 mutation frequency of between 53 and 100% (Table 1). A lower frequency of the QoI A143 mutation was detected in 17 of the 19 WPM samples in 2022 which ranged from 7 to 58% (Table 1). This is the first report of DMI and QoI resistance within WPM in Qld but has been previously reported in NSW from testing conducted in 2020 and 2021. Presence of the QoI A143 mutation in the WPM pathogen population is associated with complete resistance to strobilurin fungicides (e.g., azoxystrobin), with the strobilurin fungicides becoming ineffective under field conditions at pathotype resistance frequencies above 50%. This is concerning; as 2 of the 10 WPM samples tested from Qld (Gatton and Macalister) and 1 of 9 from NSW (Finley) had 100% resistance mutations to DMI (Group 3) in combination with >50% QoI (Group 11) modes of action (MoA), which could potentially result in dual resistance to both fungicide MoA groups. The strobilurins are known to rapidly succumb to fungicide resistance, which is why they are always mixed with another MoA fungicide group (usually DMIs, Group 3). The high frequency of DMI F136 in Qld and NSW WPM pathogen populations is likely increasing the rate of selection for QoI resistance. A concerning aspect in relationship to the QoI A143 resistance gene, is that it confers cross resistance to all fungicides within the group 11 mode of action group (strobilurins) whether applied as a foliar spray or seed treatment.

### Fungicide resistance terminology

To address the ‘shades of grey’ surrounding fungicide resistance and how it is expressed as a field fungicide failure, some very specific terminology has been developed.

When a pathogen is effectively controlled by a fungicide, it is defined as sensitive to that fungicide. As fungicide resistance develops, that sensitive status can change to:

- **Reduced** sensitivity
  When a fungicide application does not work optimally but does not completely fail.
  This may not be noticeable at field level, or the grower may find previously experienced levels of control require higher chemical concentrations up to the maximum label rate. Reduced sensitivity must be confirmed through specialised laboratory testing.
- **Resistance**
  When a fungicide fails to provide disease control in the field at the maximum label rate.
  Resistance must be confirmed by laboratory testing and be clearly linked to a loss of control when using the fungicide correctly in the field.
- **Lab detection**
  A measurable loss of sensitivity can often be detected in laboratory *in vitro* tests before or independent of any loss of fungicide efficacy in the field. Laboratory testing can indicate a high risk of resistance or reduced sensitivity developing in the field.

The Australian grains crop protection market is dominated by only three major mode of action (MoA) groups to combat diseases of grain crops; the DMIs (Group 3), SDHIs (Group 7) and strobilurins (or quinone outside inhibitors, QoIs, Group 11). Having so few MoA groups available for use increases the risk of fungicide resistance developing, as growers have very few alternatives to rotate in order to reduce selection pressure for these fungicide groups.

With two of the three fungicide MoA groups now compromised or heading towards increased selection of dual resistance within WPM populations in some paddocks in southern Qld and NSW, all growers and advisers need to take care to implement fungicide resistance management strategies to maximise their chances of effective and long-term disease control.

The Australian Fungicide Resistance Extension Network (AFREN), a GRDC investment, suggests an integrated approach tailored to local growing conditions. AFREN has identified the following five key actions, 'The Fungicide Resistance Five', to help growers maintain control over fungicide resistance, regardless of their crop or growing region:

1. Avoid susceptible crop varieties
2. Rotate crops – use time and distance to reduce disease carry-over
3. Use non-chemical control methods to reduce disease pressure
4. Spray only if necessary and apply strategically
5. Rotate and mix fungicides/MoA groups.

### Managing fungicide resistance

It is important to recognise that fungicide use and the development of fungicide resistance, is a numbers game. That is, as the pathogen population increases, so does the likelihood and frequency of naturally resistant strains being present. A compromised fungicide will only control susceptible individuals while the resistant strains within the population continue to flourish.

As a result, it is best if fungicides are used infrequently and against small pathogen populations. That way, only a smaller number of resistant individuals will be present to survive the fungicide application, with many of these remaining vulnerable to other competitive pressures in the agro-ecosystem.

Keeping the pathogen population low can be achieved by taking all possible agronomic steps to minimise disease pressure and by applying fungicide at the first sign of infection once the crop has reached key growth stages. In cereals, the leaves that contribute most to crop yield are not present until growth stage 30 (GS30/start of stem elongation.) Foliar fungicides applied prior to this are more often than not a waste of money and unnecessarily place at risk the longevity of our cost-effective fungicide resources by applying an unneeded selection pressure on fungal pathogens for resistance.

### Integrated management strategies

Management practices to help reduce disease pressure and spread include:

- **Planting less susceptible wheat varieties**
  Any level of genetic resistance to WPM slows the rate of pathogen and disease development within a crop and reduces the reliance on fungicides to manage the disease. Avoid growing susceptible–very susceptible (S–VS) and VS wheat varieties in disease-prone areas.
- **Inoculum management**
  Killing volunteer wheat plants during fallow periods and reducing infected wheat stubble loads will reduce the volume of spores spreading into an adjacent or subsequent wheat crop.
- **Practicing good crop rotation**
  A program of crop rotation creates a dynamic host environment that helps reduce inoculum levels from year to year. Rotating non-susceptible wheat varieties can also provide a more dynamic host environment, forcing the pathogen to adapt rather than prosper.
- **Disease levels can be higher with early planting**
  Later planting can delay plant growth until after the initial warm and damp period of early winter that favours WPM. This is important as infection of young plants can lead to increased losses at maturity. Later sown crops also tend to develop smaller canopies which are less conducive to powdery mildew infection. However, delayed sowing can have an associated cost of reduced yield potential in some environments which should be carefully considered by growers.
- **Careful nitrogen management**
  As excess nitrogen favours disease development, nitrogen application should be budgeted to measured soil N levels and target yield so as to be optimised to suit the growing purpose.

- **Encouraging air circulation**
  Actions that help increase airflow into the crop canopy can help lower the relative humidity. This can include wider row spacing, reduced plant populations (note yield potential should still be maximised). In mixed farming systems grazing by livestock can be used to reduce and open up the early season crop canopy, with potential to reduce the level of disease inoculum present at commencement of stem elongation when the 'money leaves' start to appear.

### Fungicide recommendations for wheat

Planning of fungicide rotations needs to consider all fungal pathogens that may be present in the crop. Otherwise the fungicide treatment for one pathogen may select for resistance in another. For example, whilst there is little evidence of the development of fungicide resistance in rust populations globally, growing S–VS rust varieties means the only control option is fungicides. This can potentially have off-target selection pressure on the development of other fungal pathogens such as *Bgt* which is very prone to developing fungicide resistance.

Careful fungicide use will minimise the risk of fungicide resistance developing in WPM in Australia and help ensure the longevity of fungicides.

Advice to NSW and southern Qld wheat growers includes:

- **Avoid using Group 11** fungicides in areas where resistance to QoIs has been reported.
- **Minimise** use of the **Group 3** fungicides that are known to have compromised resistance.
- **Monitor Group 3** fungicides closely, especially where the 'gateway' mutation has been detected.
- **Rotate Group 3** fungicide actives within and across seasons. In other words, do not use the same Group 3 product twice in succession.
- **Avoid** more than three applications of fungicides containing a **Group 3** active in a growing season.
- **Group 11** fungicides should be used as a preventive, rather than for curative control and should be rotated with effective **Group 3** products.
- **Avoid** applying **Group 7** and **Group 11** products more than once per growing season, either alone or in mixtures. This includes in-furrow or seed treatments that have substantial activity on foliar diseases, as well as subsequent foliar sprays. Combined seed and in-furrow treatments count as one application.

Growers and agronomists who suspect DMI reduced sensitivity or resistance should contact the CCDM's Fungicide Resistance Group at frg@curtin.edu.au. Alternatively, contact a local regional plant pathologist or fungicide resistance expert to discuss the situation. A list of contacts is on the AFREN website at grdc.com.au/afren.

Further information on fungicide resistance and its management in Australian grains crops is available at the AFREN website at grdc.com.au/afren.

### Conclusions

NSW and southern Qld growers need to be aware that issues with fungicide resistance already exist with WPM which could result in reduced fungicide sensitivity or potentially spray failures with DMI (triazoles) and to a lesser but developing extent QoI (strobilurin) fungicides. Fungicide resistance is real and needs to be managed using an integrated approach to limit further development of fungicide resistance within WPM pathogen populations and in other at-risk fungal pathogens (e.g., net-blotches in barley and yellow spot or Septoria tritici blotch in wheat). Further information on fungicide resistance and its management in Australian grain crops is available at the AFREN website at grdc.com.au/afren.

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# Cereal disease management in 2023: what does a return to a 'normal' spring mean?

*Steven Simpfendorfer, NSW DPI Tamworth*

**Keywords**

leaf diseases, perspective, Fusarium head blight, Fusarium crown rot, climatic conditions

**GRDC codes**

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

**Take home message**

- The 2022 season was very conducive to a range of cereal leaf diseases and Fusarium head blight (FHB) during flowering and grain fill
- However, this exceptional season for cereal diseases needs to be kept in perspective
- Leaf disease pressure, especially stripe rust, will likely be high again in 2023 requiring management early in the season, but plans need to be responsive to spring conditions
- Widespread FHB in 2022 was the Fusarium crown rot (FCR) fungus letting you know that it has not gone away with wetter and milder spring conditions the last few seasons
- It was important to test seed retained from any crop where FHB or white grains were evident in 2022 as Fusarium infection negatively impacts on germination and vigour but can also introduce FCR into paddocks
- However, retained cereal stubble is still likely to be the main source of FCR inoculum
- Help is available with testing, and stay abreast of cereal disease management communications throughout the season, as 2023 is likely to be another dynamic year

## Introduction

Cereal disease management has been more complicated over the past three consecutive wet seasons with multiple stripe rust pathotypes blowing around and an increase in diseases not frequently seen in central and northern areas (e.g., Septoria tritici blotch, wheat powdery mildew and Fusarium head blight). This has all occurred in combination with the added stress of increased input costs, with many growers stating that '2022 was the most expensive wheat crop they have ever grown'. This certainly created an elevated level of anxiety for growers and their agronomists.

So, if 2022 taught us nothing else, it is that we cannot control the weather. However, nothing has changed and in 2023 growers need to have extra focus on 'controlling the controllable'. The 2022 season needs to be kept in perspective, as it was the year for leaf diseases and by default multiple fungicide applications in susceptible varieties. However, what are the chances of a wet and prolonged mild spring again in 2023? Current long-term Bureau of Meteorology (BoM) forecasts are indicating a warmer and drier spring for much of the northern grain region in 2023 which needs to be considered in cereal disease management and other decisions this year.

## 2022 – an exceptional season

The 2022 season was wet! Records were broken and flooding was widespread in some areas. 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, even compared with 2020, which remained mild (Figure 1).

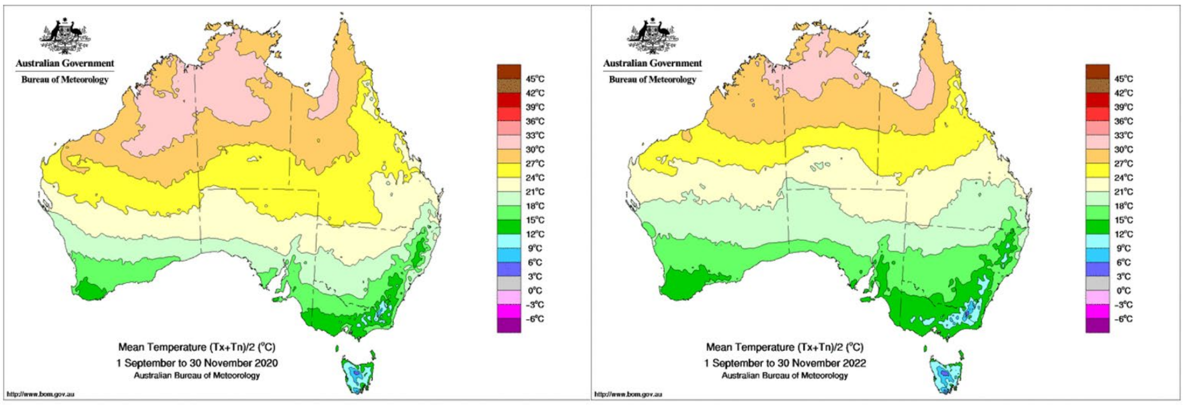

**Figure 1.** Mean daily temperature for spring (Sep–Nov) in 2020 (left) compared with 2022 (right).

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 these temperatures 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 (Table 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 also beyond the curative activity (~1/2 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 taken out by the limited curative activity of fungicides. At optimum temperatures, stripe rust has a 10-day cycle time in an S rated variety, whereas it is a 14-day cycle in a MRMS variety. Disease cycles quicker in more susceptible varieties!

Reliance on fungicides for management made susceptible (S) wheat varieties critically 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 in in-crop management, because the disease is not on speed dial when climatic conditions are optimal. The 2022 season has certainly challenged the risk vs reward of growing susceptible varieties – the management of which does not fit logistically within all growers' systems.

The prolonged cool conditions in spring 2022 also extended the flowering period in wheat and durum varieties, which in combination with extended high humidity, was very conducive to Fusarium head blight (FHB). The prevalence of FHB and white grain disorder (*Eutiarosporella* spp.) across large areas of eastern Australia in 2022 is unprecedented. However, what is the likelihood of these specific conditions occurring at a time-critical growth stage (early flowering) again in 2023?

### Can we really grow susceptible varieties in the long term?

Always a solid topic for debate. From a plant pathologist viewpoint, the following are simply fact.

- Pathogens with longer distance wind dispersal (e.g., stripe rust and powdery mildew) are 'social diseases'. What you do impacts your neighbours and the rest of industry. Yes, 'it blows'
- Stripe rust has a shorter cycle time in more susceptible varieties which increases disease pressure
- More susceptible varieties can place increased disease pressure on surrounding MS, MRMS and MR varieties
- The more susceptible the variety, the greater 'green bridge' risk volunteer plants are to survival of biotrophic pathogens such as stripe rust and wheat powdery mildew during fallow periods
- Mutations within the pathogen population which lead to 'break down' of resistance genes or development of fungicide resistance is all a numbers game. More susceptible varieties produce more fungal spores, which increase the risk of mutations
- Susceptible varieties have less flexibility with in-crop fungicide timings. The yield penalty is much larger if application is delayed (i.e., increased production risk)
- Susceptible varieties are reliant on fungicides, often multiple within conducive seasons, to control leaf diseases. This increases selection for fungicide resistance or reduced sensitivity within the pathogen population either directly (e.g., with rust) or indirectly on other fungal pathogens also present at the time of application (e.g., powdery mildew)
- Rust pathogens CAN develop fungicide resistance!! (Park *et al.* 2023)

### Keep the 2022 season in perspective

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 of 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 returns are not guaranteed from fungicide use in 2023. What's your disease management plan if spring returns to closer to normal temperatures and rainfall? There is no talk of La Niña again in 2023 and seasonal outlook must be part of disease management planning. Early leaf disease pressure is likely to be high again in 2023, given elevated inoculum levels from 2022 and decent levels of stored soil moisture. However, dry conditions during April-May and into June in some areas, especially more western regions, has been less conducive to green bridge survival of rusts and leaf disease development in cereal seedlings. Manage early leaf disease pressure in 2023 if present, then adapt management to spring conditions. The most effective fungicide can often be 2 to 3 weeks of warmer and dry weather in spring.

### Where has Fusarium crown rot gone?

Fusarium crown rot (FCR) has NOT disappeared with the last few seasons of wetter and milder spring conditions. FCR risk was particularly elevated in more northern areas leading into planting in 2022. Increased frequency of cereal crops within rotations following drought conditions from 2017–2019, along with reduced sowing of chickpea crops being underlying causes. However, FCR requires moisture for infection, so inoculum levels have progressively been building up within paddocks (Figure 2). The wetter and milder spring conditions have limited the expression of FCR infection as whiteheads.

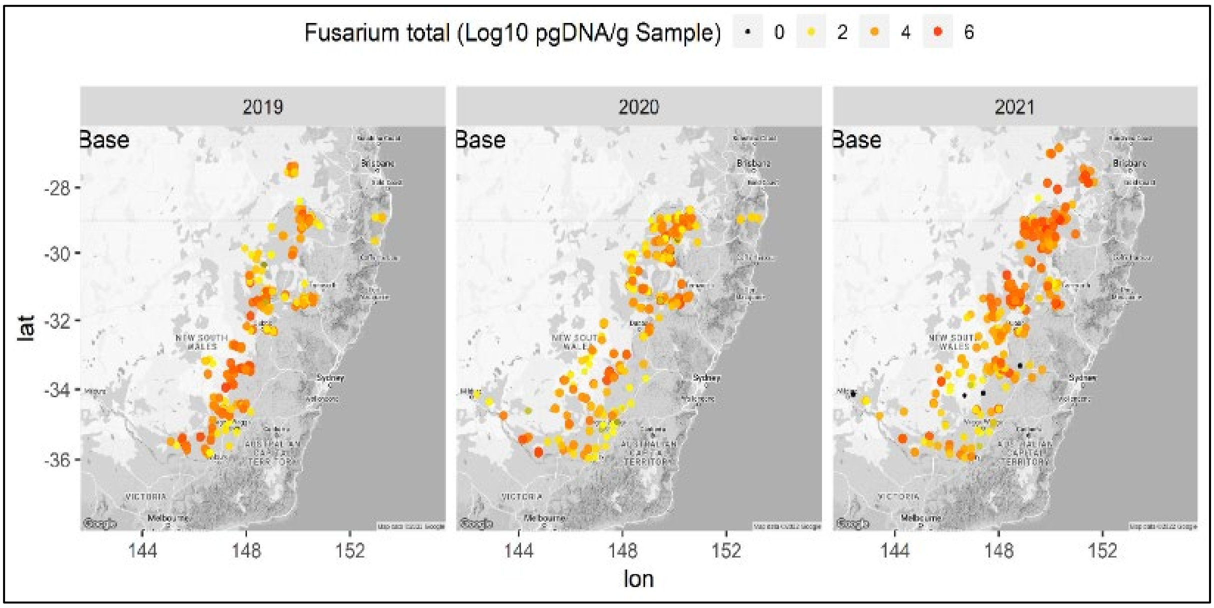

**Figure 2.** Levels of Fusarium crown rot within the base of randomly surveyed winter cereal crops (2019 to 2021) as assessed using quantitative PCR of pathogen DNA levels. Map from collaborative surveys conducted with Dr Andrew Milgate and Brad Baxter, NSW DPI Wagga Wagga.

Fusarium head blight (FHB) which caused premature partial bleaching of heads and white or pink grains was widespread at varying levels across eastern Australia in 2022 along with white grain disorder (WGD) caused by *Eutiarosporella* spp. in some regions, especially southern Qld. More detailed information around the specific causes, management and implications of this epidemic in 2022 are available (Simpfendorfer and Baxter 2023). Testing of 1880 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 the wetter/milder conditions during flowering and grain fill. This basal Fusarium infection would have expressed as whiteheads if crops had been temperature and/or moisture stressed during this period in 2022. This was a massive warning sign of the levels of FCR risk that have developed and largely gone unnoticed within some cropping systems over the past three wetter seasons.

**Why was seed testing so important prior to sowing in 2023?**

FHB was widespread in 2022 with implications for seed retained from infected crops. Fusarium grain infection reduces germination and vigour of seed retained for sowing along with causing seedling blight (death) in plants arising from infected grain. The fungus replaces the contents of infected seed with its own mycelium, so while seed treatments can help reduce the level of seedling blight, they cannot restore the quality of heavily infected seed sources. Sowing Fusarium infected seed also introduces FCR into paddocks. The level of pink or white grains in a grain sample is likely an underrepresentation of the true level of Fusarium grain infection, as later infections (i.e., high humidity) during grain fill, can allow some fungal spread into formed grains which appear normal. Sourcing quality seed for sowing in 2023 created issues in some regions.

General advice if retaining seed for sowing is:

- <1% Fusarium grain infection = no issues;
- 1% to 5% Fusarium grain infection = consider using seed treatment (full rate Vibrance® or EverGol® Energy) to limit seedling blight and slightly increase sowing rate;
- >5% Fusarium grain infection = source cleaner seed if possible.
- Same values apply for Eutiarosporella and are additive for mixed infections where the combined Eutiarosporella + Fusarium infection level should not be greater than 5% in a seed source.

A ‘free’ seed testing service was offered to growers to support them in determining Fusarium grain infection levels. In total 1,880 grower retained seed lots from 2022 and 64 from the 2021 harvest were tested through the NSW DPI laboratory at Tamworth under a collaborative project with GRDC. Fusarium grain infection levels were considerably lower in seed retained from 2021 (average 0.75%; range 0 to 9%) compared with 2022 harvested grain (average 6.5%; range 0 to 70.5%). This highlights that FHB was also present in 2021 but went largely unnoticed. If available, seed retained from 2021 was likely a good source of planting seed with low Fusarium infection levels. However, appropriate storage of seed over this extended period appears to have impacted on germination of some 2021 retained seed. With 2021 retained seed 63% of grower seed lots had greater than 90% germination, 17% had 70 to 90% germination, 14% had 50 to 70% germination and 6% had less than 50% germination.

In total, 1,880 seed lots from the 2022 harvest were tested, consisting of 1,566 bread wheat, 183 durum and 131 barley samples (Table 2). The biggest issue with Fusarium grain infection levels was in durum wheat, which is very susceptible to FCR and FHB, with 81% of 2022 seed lots having greater than the recommended 5% level of Fusarium infection (average 20.3% infection, range 0 to 70.5%). Fusarium grain infection levels were still a widespread issue in bread wheat and barley seed retained from 2022 with 33% of bread wheat (average 5.0% infection, range 0 to 43%) and 29% of barley (average 4.2% infection, range 0 to 49%) seed lots having greater than the recommended 5% level of infection (Table 2).

**Table 2.** *Fusarium* spp. grain infection levels in bread wheat, durum wheat and barley seed lots harvested across eastern Australia in 2022.

| Region | Bread wheat | | | Durum wheat | | | Barley | | |
|---|---|---|---|---|---|---|---|---|---|
| | <5% | >5% | Max | <5% | >5% | Max | <5% | >5% | Max |
| **SE NSW** | 163 | 27 | 16% | | | | 3 | 1 | 6% |
| **SW NSW** | 144 | 56 | 43% | 12 | 45 | 71% | 12 | 4 | 9% |
| **CE NSW** | 141 | 74 | 37% | 0 | 2 | 30% | 17 | 4 | 49% |
| **CW NSW** | 259 | 169 | 43% | 0 | 2 | 45% | 20 | 14 | 45% |
| **NE NSW** | 81 | 94 | 42% | 16 | 83 | 69% | 13 | 11 | 34% |
| **NW NSW** | 61 | 39 | 28% | 1 | 15 | 68% | 13 | 4 | 13% |
| **Sth Qld** | 117 | 24 | 26% | 0 | 1 | 23% | 9 | 0 | 4% |
| **Vic** | 71 | 36 | 33% | 1 | 1 | 35% | 6 | 0 | 5% |
| **SA** | 10 | 0 | 2% | 5 | 0 | 2% | | | |

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

Levels of FHB infection and resulting Fusarium grain infection were prevalent across eastern Australia in 2022 but varied between regions. For example, in bread wheat the incidence of grain infection levels greater than 5% was most common in north-east NSW (54% of samples) followed by north-west and central-west NSW (both 39% of samples), then central-east NSW and Victoria (both 34% of samples) and south-west NSW (28% of samples). Fusarium grain infection levels in bread wheat greater than 5% were less prevalent in Qld (17% of samples) and south-east NSW (14% of samples) with the lowest level in South Australia (0% of samples; maximum 2% infection) from limited testing (10 samples) conducted from that state (Table 2).

WGD and resulting grain infection by *Eutiarosporella* spp., although detected in all regions except South Australia, was predominantly an issue within southern Qld bread wheat crops in 2022. In southern Qld, 19% of bread wheat samples had greater than 5% Eutiarosporella grain infection (Table 3). Eutiarosporella grain infection levels were only greater than 5% in one south-east NSW bread wheat, three south-west NSW durum and four north-east NSW durum grain samples (all maximum 8% infection)(Table 3).

**Table 3.** *Eutiarosporella* spp. (white grain disorder) grain infection levels in bread wheat, durum wheat and barley seed lots harvested across eastern Australia in 2022.

| Region | Bread wheat | | | Durum wheat | | | Barley | | |
|---|---|---|---|---|---|---|---|---|---|
| | <5% | >5% | Max | <5% | >5% | Max | <5% | >5% | Max |
| **SE NSW** | 189 | 1 | 8% | | | | 4 | 0 | 0% |
| **SW NSW** | 200 | 0 | 1% | 54 | 3 | 8% | 16 | 0 | 0% |
| **CE NSW** | 215 | 0 | 4% | 2 | 0 | 1% | 21 | 0 | 0% |
| **CW NSW** | 428 | 0 | 2% | 0 | 2 | 0% | 34 | 0 | 1% |
| **NE NSW** | 175 | 0 | 5% | 95 | 4 | 8% | 24 | 0 | 2% |
| **NW NSW** | 100 | 0 | 2% | 16 | 0 | 2% | 17 | 0 | 1% |
| **Sth Qld** | 114 | 27 | 48% | 1 | 0 | 0% | 9 | 0 | 0% |
| **Vic** | 107 | 0 | 2% | 2 | 0 | 0% | 9 | 0 | 0% |
| **SA** | 10 | 0 | 0% | 5 | 0 | 0% | | | |

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

### Identifying FCR risk prior to sowing in 2023

It was recommended to test any paddock planned for a cereal-on-cereal crop for FCR risk prior to sowing in 2023, using either PreDicta® B (SARDI) or 'free' cereal stubble plating by NSW DPI with GRDC co-investment. This was particularly imperative in any paddock where FHB was noticed in 2022, as there is a high probability that the infection came from FCR in the base of plants. A random survey of 198 cereal crops conducted across central/northern NSW in 2022 found that 5% had nil (0%), 39% had low (1 to 10%), 26% moderate (11-25%), 16% high (26-50%) and 14% very high (>50%) FCR infection at the time of sampling during grain filling.

In total, growers and their agronomists collected and submitted for 'free' testing of FCR infection levels, 152 cereal stubble samples after harvest in 2022 (Table 4).

High (>26%) FCR infection levels were most prevalent in cereal crops in north-east NSW (100% of crops), then south-west NSW (89%), central-west NSW (75%), north-west NSW (63%), southern Qld (50%) and central-east NSW (42%) in 2022. The prevalence of high FCR infection levels was lowest in south-east NSW (31%), Victoria (29%) and South Australian (14%) cereal crops in 2022 (Table 4). This was important information for the collaborating grower and their agronomist who used this individual paddock data to consider appropriate management options. The picture provided by these two surveys of FCR infection levels in 2022 has further implications across regions given that the 2022 season did not favour FCR expression as whiteheads. FCR infection often goes unrecognised in wetter seasons when significant levels of whitehead expression does not occur. However, significant infection levels and inoculum build-up within retained cereal stubble still occurs. FCR inoculum load and, hence, disease risk in 2023 is a function of the percentage of plants infected in 2022 (Table 4) and the stubble load produced in that season. This is particularly concerning as much higher cereal stubble loads were produced in 2022 and the prediction of drier or even El Niño conditions in spring 2023 is likely to favour expression and yield loss from FCR infection. These levels of underlying FCR infection across the survey regions also appeared to have some link to the prevalence of Fusarium head blight within these same areas in 2022 (Table 2).

**Table 4.** Percentage of paddocks with varying levels of Fusarium crown rot infection across eastern Australia from 152 cereal stubble samples submitted post-harvest in 2022.

| **Region (no. crops)** | **Nil** | **Low** | **Medium** | **High** | **Very High** |
|---|---|---|---|---|---|
| | **0%** | **1-10%** | **11-25%** | **26-50%** | **>50%** |
| **SE NSW (26)** | 27 | 8 | 35 | 23 | 8 |
| **SW NSW (9)** | 0 | 11 | 0 | 33 | 56 |
| **CE NSW (12)** | 0 | 17 | 42 | 42 | 0 |
| **CW NSW (16)** | 0 | 6 | 19 | 56 | 19 |
| **NE NSW (17)** | 0 | 0 | 0 | 35 | 65 |
| **NW NSW (24)** | 0 | 17 | 21 | 29 | 33 |
| **Sth Qld (20)** | 0 | 35 | 15 | 25 | 25 |
| **Vic (14)** | 0 | 21 | 50 | 29 | 0 |
| **SA (14)** | 0 | 43 | 43 | 7 | 7 |
| **Total (152)** | 5 | 17 | 25 | 30 | 23 |
| Data based on plating of 50 surface sterilised primary tillers/crop from cereal stubble collected after harvest in 2022. | | | | | |

FCR integrated disease management, all options are prior to sowing so knowing the risk level within paddocks is important.

If medium to high FCR risk, then:

1. Sow a non-host break crop (e.g., faba bean, chickpea, canola).

If still considering sowing a winter cereal:

1. Consider stubble management options
2. Sow more tolerant bread wheat or barley variety (not durum)
3. Sow at start of recommended window for each variety in your area
4. If previous cereal rows are intact – consider inter-row sowing (cultivation is bad as it spreads inoculum)
5. Be conservative on N application at sowing (urea exacerbates FCR and 'hyper yielding' is potentially 'hyper risk' when FCR is present)
6. Apply zinc at sowing – ensure that crops are not deficient
7. Current fungicide seed treatment is suppression only – useful but limited control
8. Determine infection levels around GS39 to guide other in-crop management decisions.

## 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 at record highs across much of the northern grain region. Widespread FHB in 2022 was predominantly the FCR fungus letting you know that it has not gone away with wetter and milder spring conditions the last few seasons. Do not ignore the signs. Did you know your FCR risk in paddocks planned for cereals in 2023, especially if sowing durum? We cannot keep banking on wet and mild spring conditions as our main FCR management strategy. Sowing seed with as low a level of Fusarium grain infection as possible was an important first step to maximising crop establishment but also restricting the level of FCR introduced into paddocks. However, seed is only one source of inoculum with retained cereal stubble still likely to be the dominant source of FCR infection in 2023. It is not too late to submit cereal stubble for 'free' testing to NSW DPI. This is particularly important for any cereal-on-cereal rotations and could be useful data to assist understanding of where FCR infection arose from if we have a season conducive to disease expression. Contact details below if you want further information around 'free' stubble sampling.

Keep abreast of in-season GRDC and NSW DPI communications which address the dynamics of cereal disease management throughout the 2023 season. Do not just focus on leaf diseases in 2023. 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. Unfortunately, this is already being observed in cereal crops during the seedling stage in 2023.

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## Further resources

PreDicta®B sampling procedure - https://www.pir.sa.gov.au/__data/assets/pdf_file/0007/291247/Sampling_protocol_PreDicta_B_Northern_regions.pdf

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# The crucial role of weed ecology and biology in managing awnless barnyard grass and feathertop Rhodes grass

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**Key words**

phenology, seed bank, seed biology, temperature, tillage

**GRDC codes**

UA00156, US00084

**Take home messages**

- The surface seeds of awnless barnyard grass (ABYG) and feathertop Rhodes grass (FTR) exhibit the highest germination rates, indicating an increased likelihood of infestation in conservation agriculture systems
- An effective control strategy for managing ABYG and FTR seed banks involves burying the seeds below their maximum depth (6 to 8 cm) of emergence
- Burial extends the life of the seed bank compared to surface seeds; therefore, tillage operations should be avoided after seed burial
- ABYG and FTR are unlikely to develop persistent seed banks and can be depleted rapidly if new seed inputs are prevented for 2-3 years
- Small rainfall events will trigger germination of some FTR seeds, suggesting the need for implementing control measures
- Although ABYG and FTR are primarily spring and summer-emerging weeds, their seasonality is expanding in Queensland
- Close monitoring of emergence is necessary throughout the year to prevent the spread of seeds and replenishment of the soil seed bank.

## Background

Weeds pose a significant biological constraint to crop production on a global scale. In Australia, they inflict an annual cost exceeding $3.3 billion for grain growers (Llewellyn *et al.*, 2016). Among the grass weed species in the northern grain region of Australia, awnless barnyard grass (ABYG, *Echinochloa colona*) and feathertop Rhodes grass (FTR, *Chloris virgata*) are the most problematic in summer crops and fallows. These two species alone contribute to annual revenue losses surpassing $22 million in this region. In addition to the northern grain region, these weed species occur in other states also (Figure 1). Recent studies have demonstrated that infestations of approximately 40 plants/m$^2$ of ABYG and 25 plants/m$^2$ of FTR can result in a 50% reduction in grain yield for mungbean when compared to weed-free plots (Mahajan and Chauhan, 2022; Manalil *et al.*, 2020).

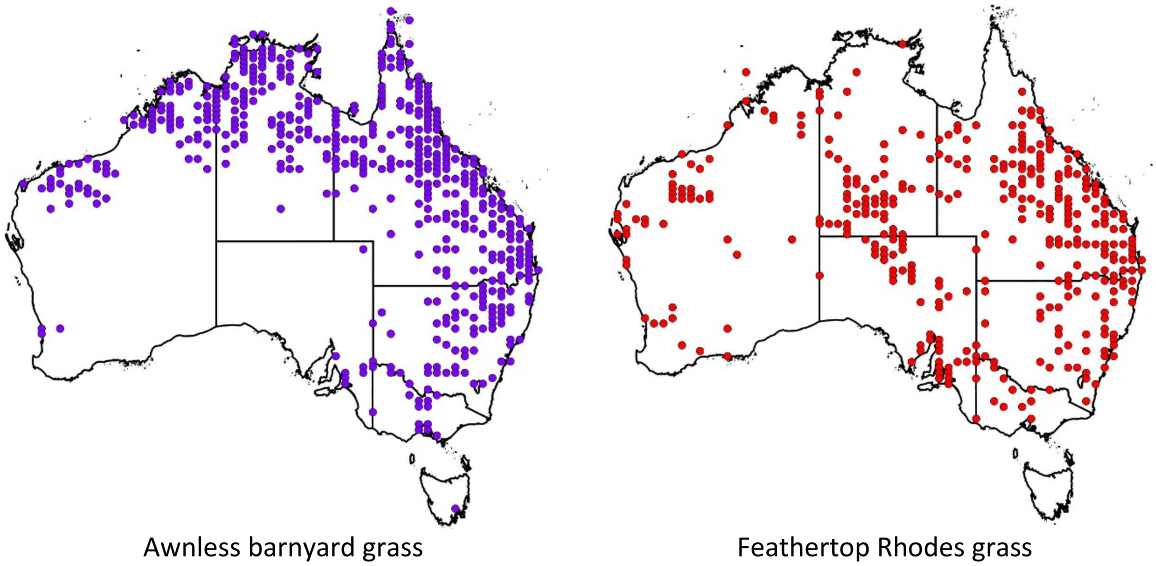

**Figure 1.** Distribution of awnless barnyard grass and feathertop Rhodes grass in Australia (Australasian Virtual Herbarium 2023; http://avh.ala.org.au).

Aside from their highly competitive nature, ABYG and FTR exhibit prolific seed production capabilities. Under fallow and well-irrigated conditions, ABYG can produce up to 150,000 seeds/plant, while FTR can produce as many as 143,000 seeds/plant (Chauhan, 2022; Squires *et al*., 2021).

Chemical management remains the predominant approach for weed control in the northern grain region. However, due to the consistent use of herbicides with the same mode of action, multiple ABYG and FTR populations have evolved resistance to commonly used herbicides, including glyphosate (Chauhan and Mahajan, 2023; Ndirangu Wangari *et al*., 2022). Furthermore, the availability of herbicides with new modes of action is limited. Concerns regarding environmental pollution further compound the issue. These observations highlight the urgent need to reduce dependence on herbicides and develop effective and sustainable weed management strategies. To achieve this, a comprehensive understanding of the ecology and biology of ABYG and FTR is imperative.

## Ecology and biology of ABYG and FTR

Biology and ecology are vast subjects, and not all-encompassing information regarding ABYG and FTR is readily available. Hence, this article will focus specifically on seed ecology and phenology. Weed biology also encompasses research on how weeds respond to crop competition. Since there is a separate paper on this topic in this proceeding, the results and their implications will not be presented here.

### Seed ecology

Several factors, including light, temperature, rainfall and seed burial depth, influence seed germination.

#### *Light*

Both species, ABYG and FTR, exhibit light-dependent germination (Fernando *et al.*, 2016; Mutti *et al.*, 2019). This suggests that their emergence in conservation agriculture systems, such as no-till practices, may be stimulated since most seeds remain on or near the soil surface after shedding. Although germination in dark conditions is lower compared to light conditions, it is evident that some seeds of ABYG and FTR can still germinate under a crop canopy and crop residue.

### *Temperature*

Temperature is another crucial factor that impacts weed seed germination. Different weed species have specific temperature requirements for optimal germination. Understanding the temperature conditions that favour weed seed germination enables managers to predict and time control measures effectively. For instance, if a weed species exhibits higher germination rates at specific temperatures, growers/agronomists can plan herbicide applications or cultural practices to coincide with those conditions, thereby maximizing weed control efficacy. Additionally, a better understanding of ABYG and FTR's response to different temperatures can aid in predicting their potential invasiveness beyond their current boundaries.

Controlled experiments have shown that ABYG seeds can germinate within a temperature range of 20/10 to 35/25°C (alternating day/night temperatures), indicating that ABYG can emerge during spring, summer, and autumn in the northern region (Mutti *et al.*, 2019). While the previous study (Mutti *et al*., 2019) did not observe germination at 15/5°C, a recent field study conducted in Gatton reported ABYG emergence in the months of May and July, suggesting its ability to emerge even in the colder temperatures of late autumn and winter (Chauhan, 2022). Similarly, seed germination of FTR was observed within a temperature range of 15/5 to 35/25°C (Figure 2; Desai and Chauhan, 2022). The data for both species suggests that ABYG and FTR can germinate throughout the year in the northern region, potentially expanding their invasion in winter crops and fallows.

It is important to note that germination and growth are distinct parameters. Seed germination under low temperatures does not guarantee successful growth and seed production during winter. To address this, it is necessary to understand the effects of low temperatures on growth and seed production through phenology studies.

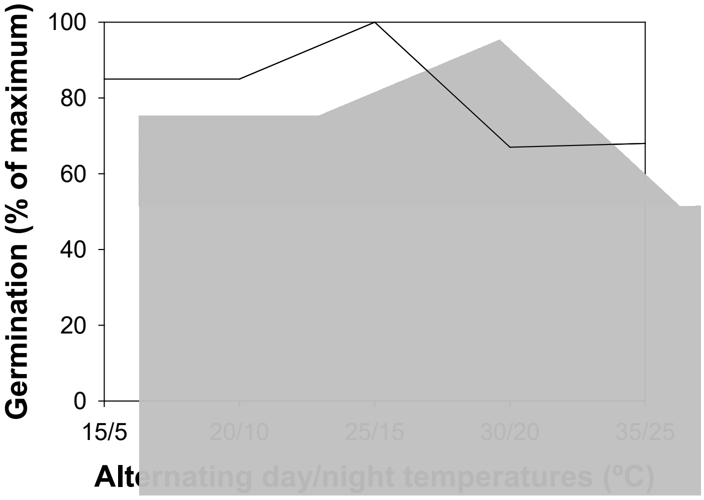

**Figure 2.** Effect of alternating day/night temperatures (12 h/12 h) on seed germination (% of maximum germination) of feathertop Rhodes grass (Desai and Chauhan 2022).

### *Rainfall*

Rainfall events and amounts play a crucial role in weed seed germination. When the rainfall meets or exceeds the moisture threshold required by a specific weed species, it can trigger the germination process. Moreover, the timing and frequency of rainfall events during the optimal germination window significantly affects the success of weed seed germination. For instance, in a controlled experiment, it was observed that ABYG seeds did not germinate with a rainfall event of 5 mm, while some FTR seeds did germinate at this level of rainfall (Werth *et al.*, 2017). These findings suggest that a small proportion of FTR emergence, such as 1 or 2 plants per 10 m$^2$, may occur after minor rainfall events. In such cases, growers might overlook controlling them and wait for further emergence during subsequent rainfall events. However, by that time, the FTR plants have already grown large and become difficult to manage with knockdown treatments. These plants can contribute to replenishing the soil seed bank. Understanding these factors enables growers to plan and implement more effective weed control measures to mitigate the growth and spread of problematic weeds like ABYG and FTR.

### *Seed burial depth*

Seed burial depth can significantly influence the germination and emergence of weed species by altering the environmental conditions surrounding the seeds. Understanding how weed seeds respond to different burial depths helps predict seedling emergence patterns. Some weed species have specific depth requirements for optimal germination and emergence, while others exhibit a wider range of depths within which they can successfully emerge. By knowing the preferred or optimal burial depth for a particular weed species, growers can anticipate when and where seedlings are likely to emerge, enabling timely implementation of control measures.

In the case of ABYG and FTR, the highest germination occurs for surface seeds, and emergence drastically decreases with increasing burial depths (Mutti *et al.*, 2019; Ngo *et al*., 2017). To completely inhibit their emergence, ABYG seeds require a burial depth of 8 cm (Figure 3), while FTR seeds need to be buried at a depth of 6 cm. Due to their small seed size, ABYG and FTR may lack sufficient energy reserves to push the coleoptile through deep burial. The observation of highest emergence from surface seeds, coupled with their response to light, suggests that conservation farming systems (e.g., no-till) could enhance the emergence of ABYG and FTR. If their seed banks are concentrated on the soil surface, these weeds could be managed by burying their seeds below their maximum depth of emergence (i.e., 8 cm or deeper). However, in the northern region, most cultivation systems do not bury all of the weed seeds. When multiple passes are made, it further mixes the seeds within the cultivated soil. Therefore, when deep burial is implemented as a management strategy, it becomes crucial to employ additional tactics to effectively handle any seeds that may still remain in the germination zone.

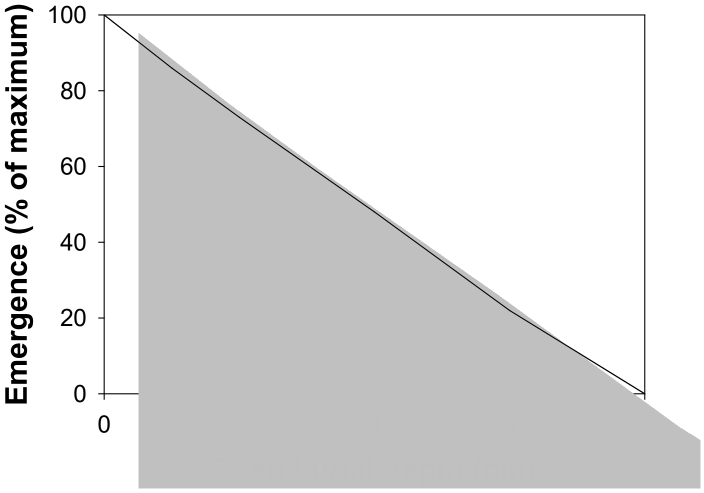

**Figure 3.** Effect of seed burial depths on seedling emergence (% of the maximum) of awnless barnyard grass (Mutti *et al.* 2019).

### *Seed bank*

Knowledge of weed seed persistence is invaluable for planning long-term control strategies, targeting weed seeds during germination windows, timing cultural practices, assessing control success, preventing seed bank replenishment, and developing site-specific weed management strategies for ABYG and FTR. By incorporating this knowledge into weed management plans, the effectiveness and efficiency of weed control efforts can be significantly enhanced. This, in turn, leads to reduced weed populations and minimized impact on crop yields and ecosystem health.

In a recent study conducted in St. George, it was found that ABYG took approximately 2.5 years to deplete all seeds at depths ranging from 1 to 15 cm (Mahajan and Chauhan, unpublished data). In another study conducted in Gatton, FTR seeds on the soil surface depleted faster (1 year vs 1.5 years) compared to buried seeds (Chauhan and Manalil, 2022). While the rate of depletion varies across burial depth (0 to 10 cm), all seeds of FTR depleted within 1.5 years after placement in the Gatton study.

Leaving seeds on the soil surface facilitates more rapid depletion of the seed bank, as burial enhances seed bank longevity. Based on seed persistence data of ABYG and FTR, it can be inferred that these weeds are unlikely to develop persistent seed banks and could be depleted relatively quickly if no new seed inputs are allowed for 2-3 years (Chauhan and Manalil, 2022). These observations also suggest that once ABYG and FTR seeds are buried below their maximum depth of emergence, subsequent tillage operations should be avoided for at least the next 2.5 years to prevent viable seeds from resurfacing.

## Phenology

Phenology is another crucial aspect to consider in weed management. Knowledge of weed phenology provides critical insights into weed growth stages, timing, and behaviour. This information enables better implementation of control measures, including cultural practices, prevention of seed production, early detection in different cropping situations, understanding the life cycle, and optimizing herbicide application by aligning it with the most susceptible growth stage. Although ABYG and FTR are primarily spring and summer-emerging weed species, recent studies suggest that their seasonality is expanding (Chauhan, 2022; Chauhan, unpublished data).

A study was recently conducted at UQ, Gatton, to assess the effect of emergence dates (every second month from September 2020 to July 2021) on the phenology, growth, and seed production of ABYG (Chauhan, 2022). It was observed that ABYG produced the highest number of seeds when emerged in January under fallow conditions, but a considerable number of seeds were also produced for other planting months (Figure 4). Most plants of ABYG from the May planting died due to cold temperatures, but some plants survived and produced seeds (4,750 seeds/plant). Similar results are being observed in an ongoing study conducted in Gatton (Queensland) on FTR, where some plants that emerged in May and July (winter) survived and produced seeds (Chauhan, unpublished data). In Wagga Wagga (New South Wales), however, FTR plants sown in early March (autumn) did not produce seeds (Asaduzzaman *et al.*, 2022). This differential response could be due to cooler temperatures occurring in Wagga Wagga compared to Gatton. These responses also suggest the need for multi-location trials in the northern grain regions.

The results align with recent observations by growers and agronomists in Queensland. These studies suggest that while greater emphasis should be placed on controlling spring and summer-emerging ABYG and FTR plants, close monitoring of their emergence is necessary throughout the year. Any surviving plant can contribute to the soil seed bank, and therefore, all efforts should be made to prevent the introduction and spread of ABYG and FTR seeds to non-infested fields (Spaunhorst *et al.*, 2018). Most herbicides for ABYG and FTR are recommended for summer crops and fallows, highlighting the need to develop management options that integrate both chemical and non-chemical tools for winter crops and fallows.

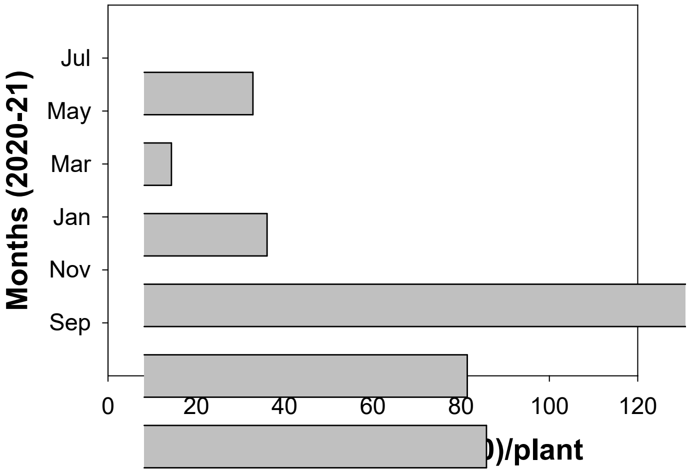

**Figure 4.** Seed production of awnless barnyard grass as affected by planting dates (2020-21) at the University of Queensland, Gatton (Chauhan 2022).

## Conclusions

Understanding the seed ecology, phenology, and biology of ABYG and FTR is essential for developing and implementing effective weed management strategies. Factors, such as light, temperature, rainfall, and seed burial depth, play significant roles in their germination and emergence patterns. Both ABYG and FTR exhibit light-dependent germination, suggesting that their emergence can be stimulated in conservation agriculture systems where seeds remain on or near the soil surface. Temperature requirements for germination vary, but studies indicate that ABYG and FTR can germinate and emerge throughout the year, potentially expanding their invasion in winter crops and fallows. Germination of some FTR seeds can occur after small rainfall events, highlighting the necessity for implementing control measures. Seed burial depth also influences their emergence, with surface seeds exhibiting the highest germination rates. This knowledge highlights the importance of burying seeds below their maximum depth of emergence to manage these weeds effectively. In situations where complete seed burial by tillage is not achieved, it becomes essential to employ additional tactics to effectively address the seeds in the germination zone.

Additionally, understanding the phenology of ABYG and FTR is crucial for timing control measures. While they are primarily spring and summer-emerging species, recent studies suggest their seasonality is expanding. Continuous monitoring and preventive measures are crucial to prevent the introduction and spread of ABYG and FTR seeds to non-infested fields, ensuring long-term weed control success. Integration of chemical and non-chemical tools in weed management is essential, especially for winter crops and fallows where herbicide options are limited.

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# Crop competition effects on weeds and crops – key trends from six years of research in the northern region

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**Key words**

crop competition, sowthistle, chickpea, faba bean, row spacing, crop density

**GRDC code**

US00084

**Take home message**

- There is convincing evidence that increased faba bean or chickpea crop competition due to narrower row spacing (23 – 25cm row spacing) and/or increased crop density (30 plants/m$^2$) reduces sowthistle growth and seed production.
- Importantly in most instances, narrower row spacing and increased plant density of faba bean and chickpea crops did not have a negative impact on grain yields. In situations where resources (e.g. water) were not limiting, more competitive crops were often higher yielding.
- The impact of different cultivars on sowthistle growth, sowthistle seed production and crop yield were not consistent for either faba bean or chickpea across trials and is likely a reflection of differences in cultivar adaptation to specific environments.

## Background

In-crop weed control in the northern grain region (NGR) is heavily reliant on herbicides. However, this practice is not sustainable due to resistance. Herbicide resistance is becoming more common and is predicted to increase if there is an ongoing reliance on herbicides for weed control. To prevent further resistance, and for herbicides to remain an important tactic for weed control, a combination of chemical and non-chemical weed control tactics is required.

An often overlooked weed management strategy is the use of agronomic management for more competitive crops. Increased crop competition can be achieved by narrowing row spacing, increasing plant density or the use of more competitive crop species and cultivars. A competitive crop is able to compete against weeds to reduce weed growth (biomass) and seed production. While this general principle is commonly known, a 2015 review of data in Australia (Widderick *et al* 2018) revealed a lack of data for the key crop:weed combinations of the NGR.

As such, research was undertaken to quantify the effects of growing competitive crops for the following scenarios:

- Pulse crops (winter and summer),
- Sorghum, and
- Early emerging summer weeds in winter crops (wheat and chickpea)

This paper summarises results from the winter pulse (faba bean and chickpea) research conducted across 6 years and multiple sites and implications for growing competitive crops as a weed management tactic.

## Methodology

Over the 2016 to 2021 winter growing seasons, replicated field trials were established across the NGR at three locations (Narrabri, Wagga Wagga and Hermitage) to provide data on crop competition across different seasons and sites. The impact of crop row spacing, crop density, cultivar and a combination of row spacing and crop density was measured on weed growth (biomass), weed seed production and crop yield.

At each site, common sowthistle were established either with the crop by sowing weed seeds, or by transplanting weeds into the crop. Exact crop and weed densities were established in fixed quadrats from which weed and crop measures were taken. To measure weed growth and seed production, destructive samples were taken. Crop yield was also measured at each trial. No herbicides were applied in the crops and background non-target weeds were manually removed.

For chickpea and faba bean, the row spacings compared were 23/25cm and 46/50cm (differences due to available planting equipment). For chickpea, the crop densities compared were 15 and 30 plants/m$^2$, and for faba bean 20 and 30 plants/m$^2$. Cultivar comparison for chickpea included PBA Boundaryᶲ, Kyabraᶲ, PBA Seamerᶲ and PBA Slasherᶲ, and for faba bean PBA Wardaᶲ, PBA Samiraᶲ, PBA Nanuᶲ and PBA Marneᶲ..

The seasons encountered during the research ranged from severe drought to flooding. In drought seasons, supplementary irrigation was applied. In some cases, crop establishment and survival was greatly impacted by the season and any compromised data has been excluded from analyses.

The research produced a large quantity of data with a total of 49 winter crop trials. To establish key trends in data, a combined trial analysis across sites and seasons was undertaken. Separate analyses were done for each agronomic factor (i.e. row spacing, crop density and row spacing × crop density) and each crop. For these analyses, separate 'environments' were considered and compared. Within each year and location, an environment was where both levels of the crop agronomy were present. For example, when investigating narrow versus wide row spacing, trial H19 at Hermitage in 2019 included 12 environments (3 cultivars x 2 crop densities x 2 sowthistle densities). By pooling data in this way, we have been able to assess the impact of different agronomic factors (row spacing and/or crop density) over a range of different growing conditions.

When significant interactions between crop agronomy and environment occurred, a summary of pair-wise comparisons between the levels of crop agronomy practice (narrow vs wide row spacing, low vs high crop density, poor vs high competition) within each environment was undertaken using t-tests (i.e. a subset of least significant difference comparisons) to investigate trends in response to crop agronomy.

## Results

### *Faba bean*

A more competitive faba bean crop, due to narrower row spacing (23/25cm) and/or increased crop density (30 plants/m$^2$), consistently reduced sowthistle growth (biomass) and seed production, while maintaining grain yields in most cases. The greatest impact was evident when faba bean was grown at both a narrower row spacing and increased density where reduction in sowthistle growth and seed production were not only more frequent, but greater (Table 1). Our research showed an inconsistency in results relating to faba bean cultivar.

**Table 1.** Impacts of different agronomic factors in faba bean on sowthistle biomass, sowthistle seed production and faba bean yield. Agronomic factors: Row spacing – Narrow = 23/25cm vs Wide = 46/50cm; Crop density – Low = 20 vs High = 30 plants/m$^2$; Row spacing × crop density – Poorly competitive = 50cm + 20 plants/m$^2$, Highly competitive = 25cm + 30 plants/m$^2$; Cultivars – PBA Warda, PBA Nasma, PBA Samira, PBA Nanu and PBA Marne.

| **Agronomic factor** | **Sowthistle biomass** | **Sowthistle seed production** | **Faba bean yield** |
|---|---|---|---|
| **Row spacing**<br>(55 to 68 environments from 9 to 11 trials) | Narrow row spacing reduced sowthistle biomass.<br>- Reduction in 87% of environments* (6 – 83% biomass reduction)<br>- Significant reduction in 44% of environments (35 – 83% biomass reduction) | Narrow row spacing reduced sowthistle seed production.<br>- Reduction in 87% of environments* (3 – 85% seed reduction)<br>- Significant reduction in 24% of environments (36 – 71% seed reduction) | Narrow row spacing resulted in a significant increase in faba bean yield.^ |
| **Crop density**<br>(36 to 48 environments from 3 or 4 trials) | High crop density reduced sowthistle biomass.<br>- Reduction in 83% of environments* (8 – 74% biomass reduction)<br>- Significant reduction in 33% of environments (37 – 74% biomass reduction) | High crop density reduced sowthistle seed production.<br>- Reduction in 77% of environments* (3 – 95% seed reduction)<br>- Significant reduction in 23% of environments (44 – 89% seed reduction) | Increased crop density resulted in a significant increase in faba bean yield.^ |
| **Row spacing × crop density**<br>(28 to 34 environments from 10 or 11 trials) | Highly competitive faba bean reduced sowthistle biomass (Figure 1).<br>- Reduction in 97% of environments* (4 – 87% biomass reduction)<br>- Significant reduction in 60% of environments (47 – 87% biomass reduction) | Highly competitive faba bean reduced sowthistle seed production (Figure 2).<br>- Reduction in 90% of environments* (12 – 95% seed reduction)<br>- Significant reduction in 53% of environments (45 – 95% seed reduction) | Highly competitive faba bean maintained or increased crop yield (Figure 3).<br>- Significant increase in yield at 25% of environments (15 – 43% yield increase)<br>- No change in yield at 71% of environments<br>- Significant reduction in yield at 4% of environments (21% reduction in yield) |
| **Cultivar** | Inconclusive results, likely due to cultivar adaptation to different environments. | | |

* - includes both statistically significant and non-significant reductions.
^ - Statistical main effect across environments.

### *Row spacing x crop density effect*

*Sowthistle biomass*

Highly competitive faba bean, combining narrow row spacing (23/25cm) with high crop density (30 plants/m$^2$), resulted in a lower sowthistle biomass in all but one environment (Figure 1).

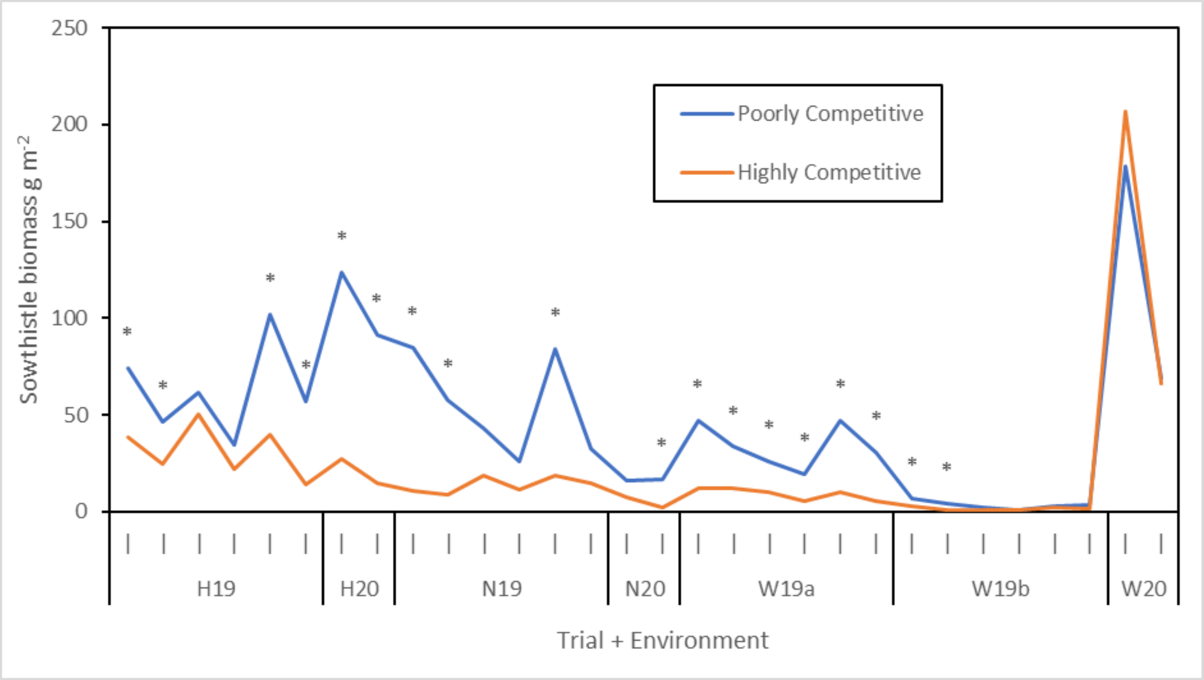

**Figure 1.** Impact of faba bean row spacing × crop density on sowthistle biomass production. Where Poorly competitive = 46/50cm row spacing and 20 plants/m$^2$, Highly competitive = 23/25cm and 30 plants/m$^2$, * = significant difference. The x-axis represents both the trial (location – H=Hermitage, N=Narrabri or W=Wagga Wagga) and year, and the 'Environment' represented by 'I' is a combination of faba bean cultivar and sowthistle density.

*Sowthistle seed production*

The seed production of sowthistle was reduced in a highly competitive faba bean crop (23/25cm row spacing and 30 plants/m$^2$) in all but three environments (Figure 2). For these three environments, the difference was significant in only one environment where production was high compared to other environments. At this site (W20) the 2020 growing season was favourable with the growing season rain (April to October) very close to the long-term average.

*Faba bean yield*

Growing faba bean at the highly competitive configuration of 23/25cm row spacing and 30 plants/m$^2$, either maintained or increased faba bean yield in all but three environments (Figure 3). For these three environments, this reduction in yield was significant for one environment where yield was high for both competition treatments compared to other environments.

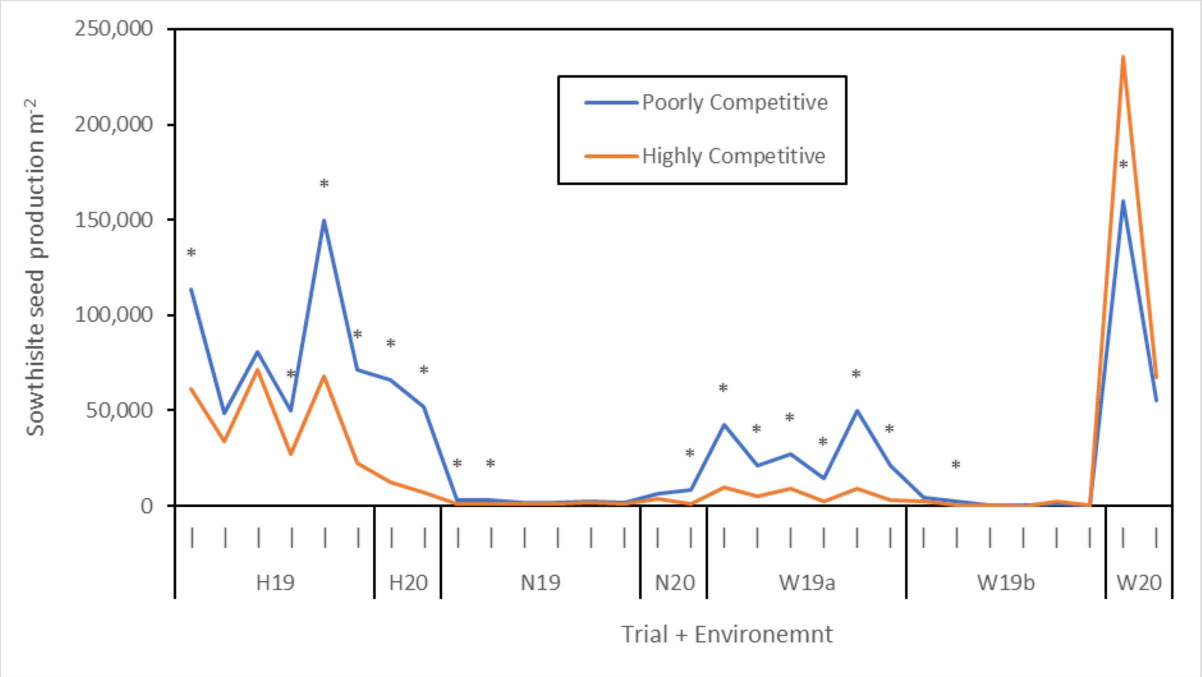

**Figure 2.** Impact of faba bean row spacing × crop density on sowthistle seed production. Where Poorly competitive = 46/50cm row spacing and 20 plants/m$^2$, Highly competitive = 23/25cm and 30 plants/m$^2$, * = significant difference. The x-axis represents both the trial (location – H=Hermitage, N=Narrabri or W=Wagga Wagga) and year, and the 'Environment' represented by 'I' is a combination of faba bean cultivar and sowthistle density.

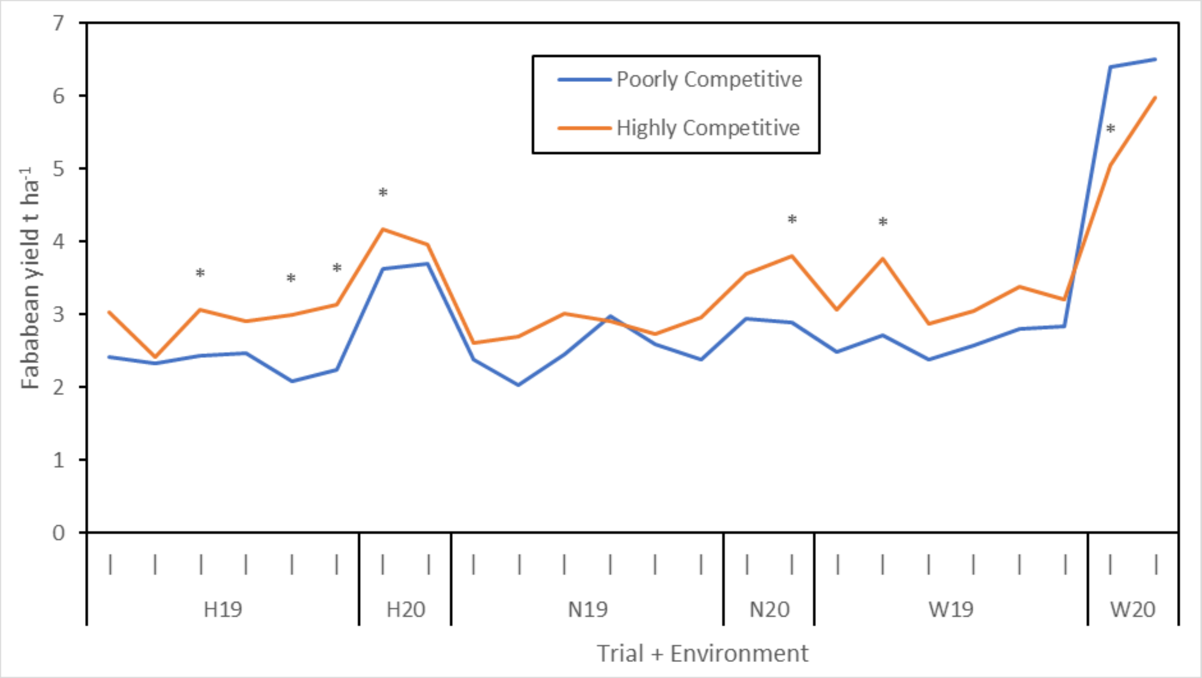

**Figure 3.** Impact of faba bean row spacing × crop density on faba bean yield. Where Poorly competitive = 46/50cm row spacing and 20 plants/m$^2$, Highly competitive = 23/25cm and 30 plants/m$^2$, * = significant difference. The x-axis represents both the trial (location – H=Hermitage, N=Narrabri or W=Wagga Wagga) and year, and the 'Environment' represented by 'I' is a combination of faba bean cultivar and sowthistle density.

### *Chickpea*

A more competitive chickpea crop, due to a narrower row spacing (23/25cm) resulted in a reduction in sowthistle biomass but had no effect on sowthistle seed production (Table 2). Chickpea grain yields were either maintained or increased at this narrower row spacing. An increased chickpea density from 15 to 30 plants/m$^2$, resulted in a reduction in sowthistle growth (biomass) and seed production and an overall increase in chickpea yield. When narrow row spacing and increased crop density were combined, sowthistle biomass and seed production were reduced to a greater degree than either alone, and yield was maintained in most cases. Our research showed an inconsistency in results relating to chickpea cultivar.

**Table 2.** Impacts of different agronomic factors in chickpea on sowthistle biomass, sowthistle seed production and chickpea yield. Agronomic factors: Row spacing – Narrow = 23/25cm vs Wide = 46/50cm; Crop density – Low = 15 vs High = 30 plants/m$^2$; Row spacing × crop density – Poorly competitive = 46/50cm + 15 plants/m$^2$, Highly competitive = 23/25cm + 30 plants/m$^2$; Cultivars – PBA Boundryᶲ, Kyabraᶲ, PBA Slasherᶲ, and PBA Seamerᶲ.

| Agronomic factor | Sowthistle biomass | Sowthistle seed production | Chickpea yield |
|---|---|---|---|
| **Row spacing**<br>(41 to 49 environments from 9 or 10 trials) | Narrow row spacing reduced sowthistle biomass.^ | No difference between narrow and wide row spacing across environments. | Yield maintained or increased with no evidence of yield reduction due to narrow row spacing.<br>• No difference in yield at 90% of environments.<br>• Significant yield increase at 10% of environments (19 – 193% yield increase) |
| **Crop density**<br>(28 to 36 environments from 5 or 6 trials) | High crop density reduced sowthistle biomass.<br>• Reduction in 92% of environments* (3 – 74% biomass reduction)<br>• Significant reduction in 36% of environments (37 – 74% biomass reduction) | High crop density reduced sowthistle seed production.<br>• Reduction in 88% of environments* (5 – 74% seed reduction)<br>• Significant reduction in 27% of environments (39 – 74% seed reduction) | High crop density resulted in a significant increase in chickpea yield.^ |
| **Row spacing × crop density**<br>(19 to 23 environments from 7 or 8 trials) | Highly competitive crop reduced sowthistle biomass (Figure 4).<br>• A reduction in 91% of environments* (13 – 84% biomass reduction)<br>• A significant reduction in 44% of environments (40 – 84% biomass reduction) | Highly competitive crop reduced sowthistle seed production (Figure 5).<br>• Reduction in 83% of environments* (7 – 85% seed reduction)<br>• Significant reduction in 30% of environments (39 – 85% seed reduction) | Yield maintained or increased with little evidence of yield reduction due to a highly competitive crop (Figure 6).<br>• No difference in yield in 63% of environments.<br>• Significant yield increase in 26% of environments (11 – 154% yield increase)<br>• Significant yield reduction in 11% of environments (20-30% yield reduction). |
| **Cultivar** | Inconclusive results, likely due to cultivar adaptation to different environments. | | |

* - includes both statistically significant and non-significant reductions.
^ - Statistical main effect across environments.

***Row spacing x crop density effects***

*Sowthistle biomass*

Highly competitive chickpea grown at 23/25cm row spacing and density of 30 plants/m$^2$, reduced the biomass of common sowthistle in all but one environment compared to chickpea grown at the wider row spacing of 50cm and density of 15 plants/m$^2$ (Figure 4). In this environment, the sowthistle biomass was large for both competition treatments compared to most other environments.

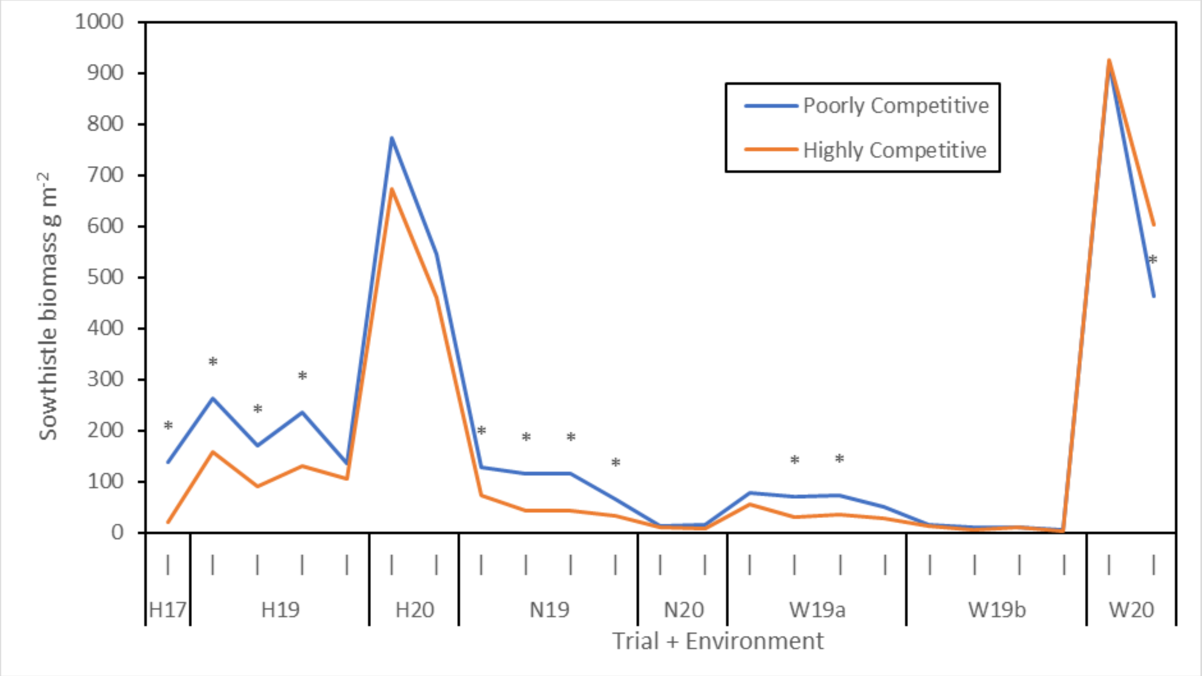

**Figure 4.** Impact of chickpea row spacing × crop density on sowthistle biomass production. Where Poorly competitive = 46/50cm row spacing and 15 plants/m$^2$, Highly competitive = 23/25cm and 30 plants/m$^2$, * = significant difference. The x-axis represents both the trial (location – H=Hermitage, N=Narrabri or W=Wagga Wagga) and year, and the 'Environment' represented by 'I' is a combination of chickpea cultivar and sowthistle density.

*Sowthistle seed production*

Competitive chickpea grown at a row spacing of 23/25cm and a density of 30 plants/m$^2$ reduced seed production of sowthistle in all but four environments (Figure 5). In only one of these environments was this difference significant and in this environment the sowthistle seed production was great in both competition treatments and generally greater than other environments.

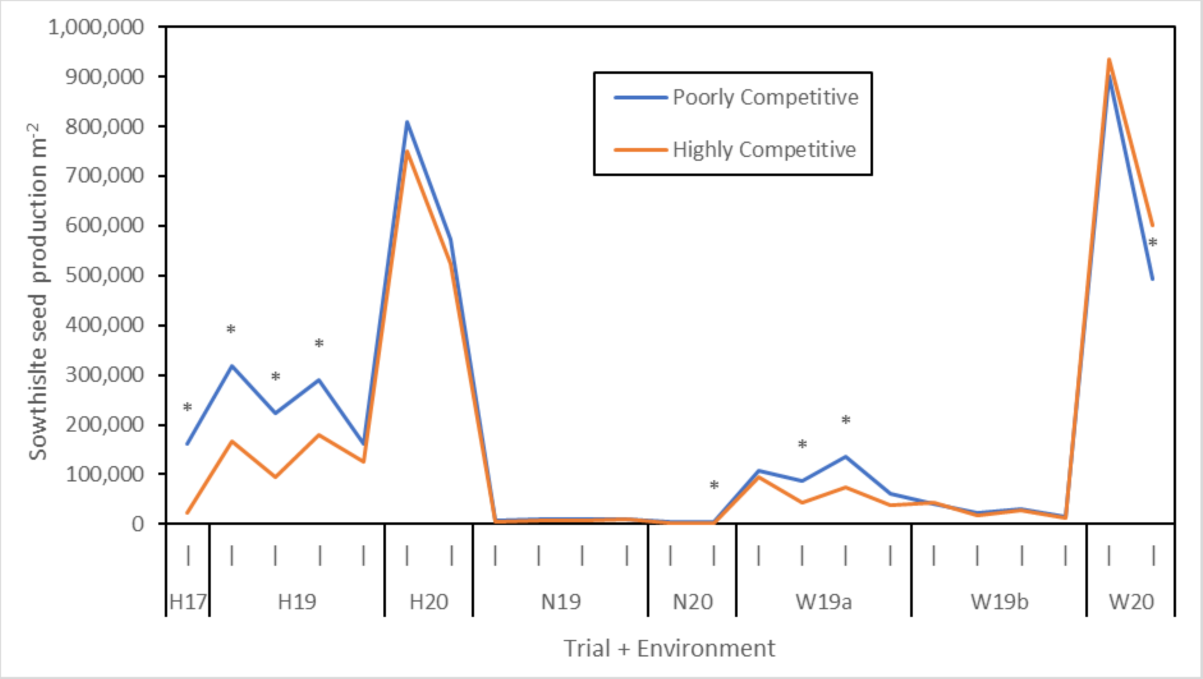

**Figure 5.** Impact of chickpea row spacing × crop density on sowthistle seed production. Where Poorly competitive = 46/50cm row spacing and 15 plants/m$^2$, Highly competitive = 23/25cm and 30 plants/m$^2$, * = significant difference. The x-axis represents both the trial (location – H=Hermitage, N=Narrabri or W=Wagga Wagga) and year, and the 'Environment' represented by 'I' is a combination of chickpea cultivar and sowthistle density.

*Chickpea yield*

A competitive chickpea crop at a row spacing of 23/25cm and a density of 30 plants/m$^2$, maintained chickpea grain yield in most environments and increased grain yield in 5 environments (Figure 6). In contrast, in only 4 environments was there a decrease in crop yield in the highly competitive crop, and in only 2 of these environments was the yield reduction significant.

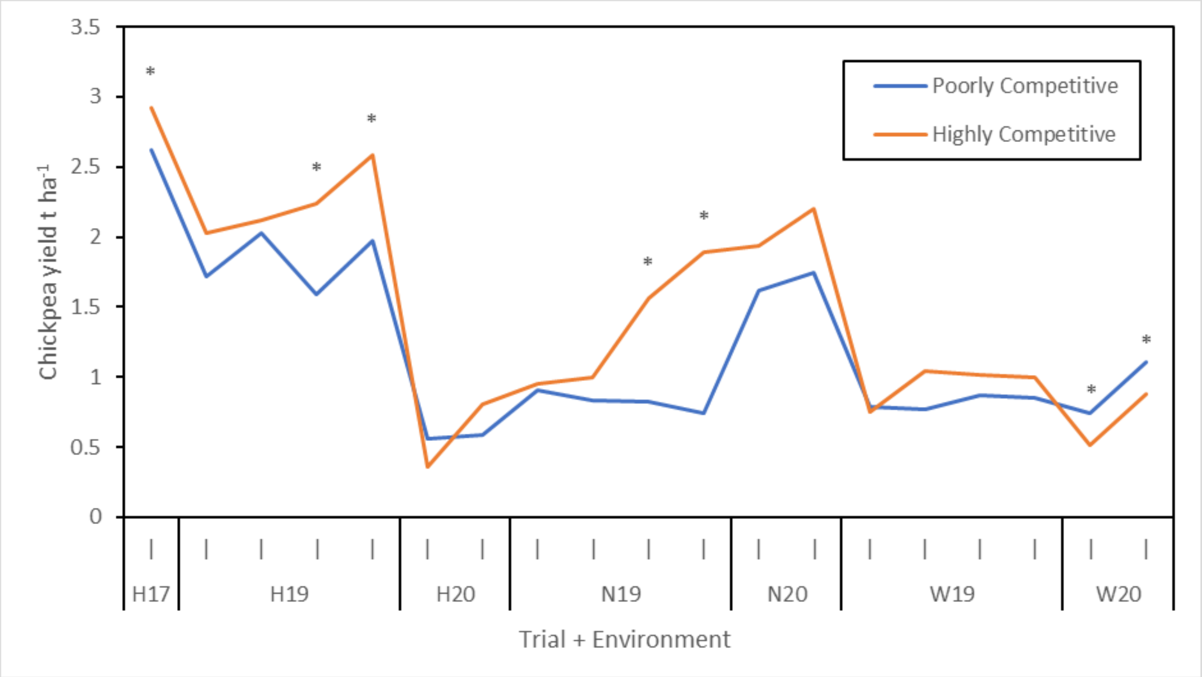

**Figure 6.** Impact of chickpea row spacing × crop density on chickpea yield. Where Poorly competitive = 46/50cm row spacing and 15 plants/m$^2$, Highly competitive = 23/25cm and 30 plants/m$^2$, * = significant difference. The x-axis represents both the trial (location – H=Hermitage, N=Narrabri or W=Wagga Wagga) and year, and the 'Environment' represented by 'I' is a combination of chickpea cultivar and sowthistle density.

## Discussion

Growing a competitive faba bean or chickpea crop at a narrow row spacing (23/25cm) and/or increased crop density (30 plants/m$^2$) is likely to reduce in-crop growth (biomass) and seed production of common sowthistle. Favourably, these competitive crop configurations maintained crop yield in most environments, and in some environments resulted in significant yield gains. In a minority of environments, competitive crop configurations resulted in crop losses. A more competitive crop will require more resources (e.g. water) in order to retain or increase crop yield and grain quality.

Reducing sowthistle growth via a competitive crop takes the reliance off herbicides for in-crop weed control. In reality, herbicides (either pre- and/or post-emergence) will be applied in crop. A competitive crop will provide complimentary weed control and reduce the growth and seed production on any survivors of herbicide treatment, thus preventing weed spread and persistence. This is important for keeping weed densities low and also for preventing the spread of herbicide resistance, should these survivors possess resistance.

One of the barriers to adopting competitive crops is the required change in machinery, especially for narrow row spacing. Our research has shown an increased crop density, which doesn't require machinery change, can provide competitive advantages against weeds that equal the effects of narrowing row spacing. However, combining a narrow row spacing with an increased crop density provided the greatest weed suppression advantages in our research.

To spread yield loss risk, grow competitive crops when resources are likely to be plentiful or only in select paddocks rather than the whole property. A competitive crop may be used as a replacement for in-crop herbicides if weed densities are low, or in a situation of high weed density, combining a competitive crop with pre- and post-emergence herbicide will minimise weed survival and seed production.

Our research has shown little consistency in effect of different faba bean and chickpea cultivars. This is not surprising given the adaptability of different cultivars to different growing environments. Although there may be weed control gains through cultivar selection, the gains achieved through narrow row spacing and increased crop density are likely to surpass those of changing cultivar.

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

# Herbicide resistance update – northern region

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**Key words**

herbicide resistance, weeds, glyphosate

**GRDC code**

UCS2008-001

**Take home message**

- Widespread glyphosate resistance has been found in awnless barnyard grass (*Echinochloa colona*) (50% of populations), feathertop Rhodes grass (*Chloris virgata*) (99%), flaxleaf fleabane (*Conyza bonariensis*) (100%) and sweet summer grass (*Brachiaria eruciformis*) (58%)
- Paraquat and paraquat + diquat resistance has been identified, for the first time as part of this industry wide survey, in feathertop Rhodes grass (8% of populations) and flaxleaf fleabane (2%)
- 2,4-D resistance was identified in common sowthistle for the first time in the northern grains region.

## Background

In 2020 and 2021, field surveys were conducted across Australian grain production regions, as part of a GRDC investment, to detect herbicide resistance in key weeds of grain production. In the northern region, the survey took place in both winter and summer crops at or near harvest time and in summer fallows. In the random survey, weed seeds were collected from surviving plants and screened for susceptibility/resistance to commonly used herbicides.

The collected seeds were germinated and/or transplanted, and then treated with each herbicide at the recommended upper label rate (Table 1). Populations were assessed for survival and classified as resistant (>19% survival), developing resistance (1 – 19% survival), or susceptible (0% survival). The majority of testing has been finalised with a small number of repeats underway to confirm resistance.

Results from this study provide important information to land managers and industry on the presence and distribution of herbicide resistance. This information helps to inform weed management decisions including which herbicides are still effective and which ones are at greatest risk for resistance development.

## Results

Glyphosate resistance was identified as endemic in the summer grass weeds feathertop Rhodes grass (99% of populations), awnless barnyard grass (50%), sweet summer grass (58%) and 100% of flaxleaf fleabane populations (Table 1). These results are similar to the detected glyphosate resistance in these weeds in a 2016/17 survey with an increase in the proportion of resistant populations for both awnless barnyard grass and sweet summer grass.

For sowthistle, the 2016/17 survey identified widespread resistance in sowthistle to glyphosate. However, in this 2020/21 collection, no glyphosate resistance was detected. Further work is planned to compare populations from each study to further explain differences.

Paraquat resistance has been identified in a number of feathertop Rhodes grass populations, and for flaxleaf fleabane resistance to the mixture of paraquat + diquat has been found in two populations. Populations resistant to the Group 22 herbicides (paraquat and diquat) have previously been identified independently of the national survey. However, these are the first cases identified as part of this random survey.

For 2,4-D, 9% of sowthistle populations were identified as resistant and an additional 36% were identified as developing resistance. For flaxleaf fleabane, 2,4-D is still effective on all populations. The previous survey did not identify any 2,4-D resistance to either species.

Chlorsulfuron is no longer registered to control sowthistle; however, testing is undertaken to confirm resistance is still widespread. The high proportion of sowthistle populations with resistance to chlorsulfuron is consistent with previous survey results.

Haloxyfop was effective in controlling all summer grass populations with no resistance detected. In contrast, resistance to other Group 1 herbicides was identified in wild oats where 20% of populations were resistant to clodinafop and 7% resistant to pinoxaden. In addition, 3% of wild oat populations were resistant to flamprop-M-methyl.

**Table 1.** Percent (%) of weed populations from the northern grain region identified as resistant (>19% survivors) to a range of commonly used herbicides.

| **Weed** | **Herbicide** | **Resistant (%)** |
|---|---|---|
| Feathertop Rhodes grass (*Chloris virgata*) | Glyphosate | 99 |
| | Paraquat | 8 |
| | Haloxyfop | 0 |
| Awnless barnyard grass (*Echinochloa colona*) | Glyphosate | 50 |
| | Paraquat | 0 |
| | Haloxyfop | 0 |
| | Clethodim | 0 |
| Sweet summer grass (*Brachiaria eruciformis*) | Glyphosate | 58 |
| | Haloxyfop | 0 |
| Flaxleaf fleabane (*Conyza bonariensis*) | Glyphosate | 100 |
| | Paraquat + diquat | 2 |
| | 2,4-D | 0 |
| Common sowthistle* (*Sonchus oleraceus*) | Glyphosate | 0 |
| | Chlorsulfuron | 68 |
| | 2,4-D | 9 |
| Wild oat* (*Avena* spp.) | Clodinafop | 20 |
| | Clethodim | 0 |
| | Pinoxaden | 7 |
| | Flamprop-M-methyl | 3 |
| | Mesosulfuron-methyl | 0 |
| | | |

* Queensland data only

## Discussion

The 2020/21 resistance survey has identified Group 22 (paraquat/diquat) resistance in both feathertop Rhodes grass and flaxleaf fleabane. This is the first detection of these resistances as part of a random survey of grain production systems. The result is likely due to selection with paraquat and paraquat+diquat applied for the double knock control of glyphosate resistant feathertop Rhodes grass and flaxleaf fleabane, respectively. Growers need to be looking at other chemical and non-chemical tactics to use in place of Group 22 herbicides.

Group 1 herbicides are an effective alternative for the knockdown control of grasses. This group of herbicides remains an effective option for summer grass weeds, but they are at high risk of resistance selection. Therefore, any survivors of Group 1 herbicides need to be controlled to stop seed set. For wild oats, Group 1 resistance is becoming more common. Alternative options are required for wild oat control which may be best facilitated by changes in crop rotation. For example, moving to a summer crop for a few years and achieving knockdown control in a winter fallow to reduce seed set and the wild oat seed bank.

Resistance to 2,4-D has been identified in common sowthistle for the first time in the northern region as part of this survey. Previous cases have been identified in farming systems of southern Australia.

Glyphosate resistance continues to be the most common resistance in the northern grains region. For the summer grasses and flaxleaf fleabane, glyphosate will rarely provide control in isolation. Alternative chemical and non-chemical tactics will be required.

The survey for resistance has highlighted an increase in resistances across the northern grain region. It is important for industry to manage weed populations with a range of diverse control tactics to minimise the spread of resistance and to preserve important and effective herbicides.

## Acknowledgements

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

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# Managing feathertop Rhodes grass in sorghum with sequential residual programs

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**Key words**

feathertop Rhodes grass, *Chloris virgata*, residual, management

**GRDC code**

NGA2009-001RTX

**Take home messages**

- Feathertop Rhodes grass (FTR) is a major management challenge due to the lack of low cost, effective knockdown herbicide options and frequent emergence prior to or at sorghum planting
- Sequential residual herbicide application is the best current strategy for FTR control in sorghum
- Fallow applications in July or August may need to be considered and followed by a top up of Dual Gold® at 1 L/ha at planting
- Initial herbicide choice is influenced by rainfall forecast, timing of first application, other weed spectrum and cost
- Under wet conditions or applications more than 6 weeks prior to planting date, Valor® 500 WG appears a more robust option than Dual Gold for extended FTR management

## Background

Management of feathertop Rhodes grass (FTR) has become a significant economic cost and major agronomic challenge in many areas of the northern grains region. Part of the challenge is that FTR is generally poorly controlled with either glyphosate or paraquat, even at seedling stage. In addition, although FTR is classed as a summer grass, it appears less temperature sensitive than other summer grasses and new seedlings can often be found in winter. Periods of soil wetness are more important than temperature for FTR germination and emergence. Consequently, in seasons with wet periods in late winter or early spring, FTR may emerge weeks prior to sorghum planting. In seasons with prolonged dry periods in late winter and early spring, FTR is likely to germinate on the sorghum 'planting rainfall event' and emerge at a similar time to crop planting (and at-planting herbicide application).

The combination of FTR resistance/tolerance to the key fallow knockdown herbicides (glyphosate and paraquat) and the likelihood of FTR emergence prior to or at sorghum planting means the focus needs to be on residual management of FTR in the fallow prior to sorghum planting, in addition to providing in-crop control.

### *Approach*

The intent of these trials was to evaluate the benefit of sequential applications for providing extended control of FTR. There is a 1-month plantback to sorghum following applications of Valor at rates used for residual control of FTR, so Valor is not an option for at-planting use in sorghum. The Dual Gold label allows up to a total of 2 L/ha to be used in the combination of the preceding fallow, during planting or early post-emergence in sorghum. For this series of trials, all early fallow treatments were followed by a 1 L/ha rate of Dual Gold at planting. This limits the rate of Dual Gold in the early fallow use to 1 L/ha. It is allowable to apply the maximum label rate of 2 L/ha of Dual Gold in early fallow, and this would be expected to provide longer residual control than the 1 L/ha tested, especially in wetter seasons, however this means that no FTR treatment could be applied at sorghum planting to provide in-crop control. Other potential strategies which also may deliver even longer periods of control (not tested in these trials) are likely to be the full rate of Valor early in the fallow, followed by Dual Gold 2 L/ha, either at-planting or applied early post-emergence; or Valor applied early fallow followed by a split rate of Dual Gold applied at-planting and early post-emergence. Atrazine was also included as a benchmark treatment in 2021 but does NOT have a FTR registration.

**Table 1**. Core treatments included in all trials in 2021 and 2022

| **Treatment** | **Herbicide treatment and timing** | | |
|---|---|---|---|
| | **End of July** | **End of August** | **At planting** |
| Untreated | – | – | – |
| Dual Gold* 1 L/ha July | Dual Gold 1 L/ha | – | – |
| + DG 1 L/ha planting | Dual Gold 1 L/ha | – | Dual Gold 1 L/ha |
| Dual Gold 1 L/ha August | – | Dual Gold 1 L/ha | |
| + DG 1 L/ha planting | – | Dual Gold 1 L/ha | Dual Gold 1 L/ha |
| Valor 210 g/ha July | Valor 500 WG 210 g/ha | – | – |
| + DG 1 L/ha planting | Valor 500 WG 210 g/ha | | Dual Gold 1 L/ha |
| Valor 210 g/ha August | – | Valor 500 WG 210 g/ha | – |
| + DG 1 L/ha planting | | Valor 500 WG 210 g/ha | Dual Gold 1 L/ha |
| Dual Gold 1 L/ha planting | – | – | Dual Gold 1 L/ha |
| Dual Gold 2 L/ha planting | – | – | Dual Gold 2 L/ha |

*Note sorghum must be treated with a seed safener when using Dual Gold. Refer to label.

### Residual efficacy in a dry winter/spring – 2021

Data from a trial at Nandi in 2021 (~18 km SW of Dalby) highlights the benefit of sequential residual management for FTR. This was one of a series of four trials conducted in 2021. Treatments of Dual Gold at 1 L/ha or Valor 500 WG at 210 g/ha were applied at the end of July and end of August as single applications, and compared with the same timings ‘topped up’ with Dual Gold 1L/ha at planting (Table 1). All treatments were compared to Dual Gold at 1 L/ha or 2 L/ha applied at planting.

#### *Rainfall*

August and September were both dry with total rainfall <10 mm in each month. This represented ~30% of mean rainfall for the two-month period. Rainfall of <2 mm was received in the week following both the July and August applications. Two rain events occurred in October prior to planting; 17 mm over 2 days (~2 weeks pre-planting) and 32 mm over 3 days (3–5 days pre-planting).

#### *Results*

There was no emergence of FTR at this site prior to sorghum planting but a very large emergence just prior to planting. Figure 1 shows the number of FTR seedlings 4 days after planting, with >97% control of FTR from either the Dual Gold or Valor 500 WG treatments applied at the end of July or August. Atrazine did not provide commercially acceptable control of FTR from either application time. The Dual Gold at-planting treatments were applied immediately after this assessment.

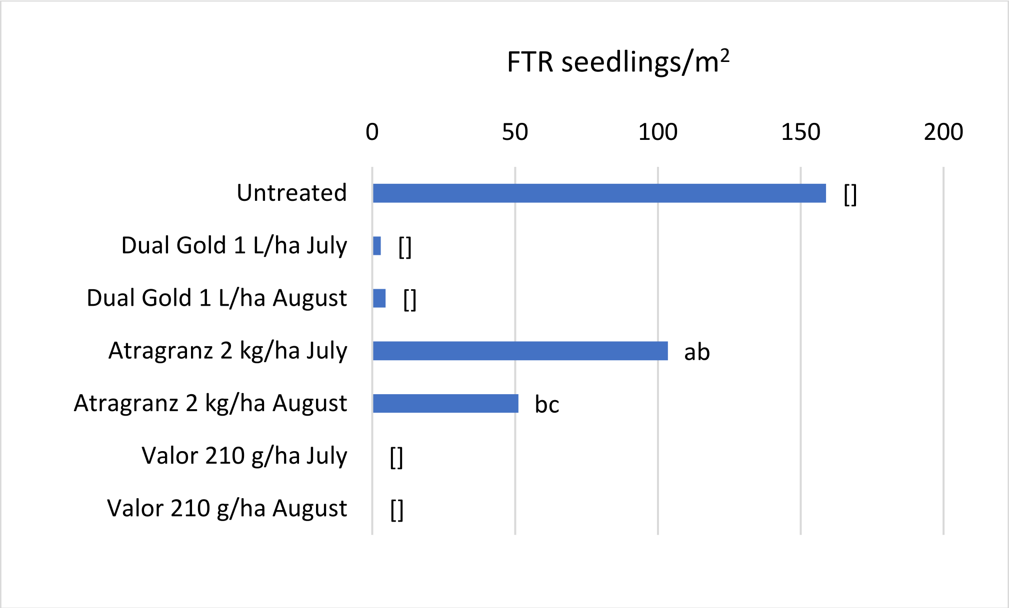

**Figure 1.** Feathertop Rhodes grass seedling numbers on 21/10/2021, 4 days after sorghum planting, 83 days after application 1 (83DAA1), 51 days after application 2 (51DAA2) at Nandi. Data with the same letters are not significantly different (*P* = 0.05).

Figure 2 presents the FTR plant population ~2 weeks later. It highlights that:

- Applications of Dual Gold at planting only reduced FTR counts from ~100 plants/m$^2$ (where no residual was applied) to ~30–50 plants/m$^2$
- Dual Gold 1 L/ha or Valor 210 g/ha applied alone in July or August, reduced FTR to ~1–10 plants/m$^2$
- When the July or August applications were 'topped up' with Dual Gold 1 L/ha at planting, FTR was reduced to 1–2 plants/m$^2$.

This trial was a clear example of the challenge of FTR management due to the lack of effective knockdown herbicides that can be used at sorghum planting.

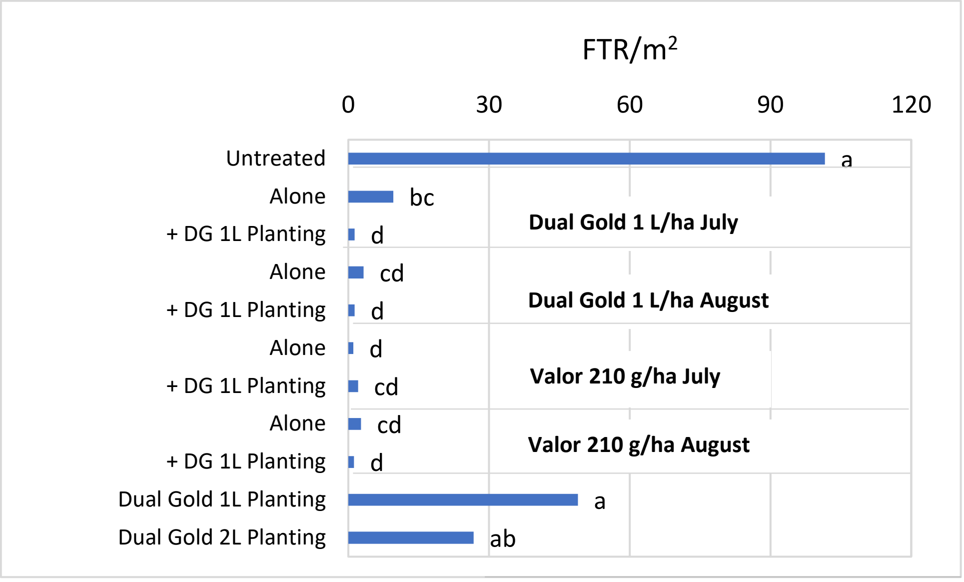

**Figure 2.** Feathertop Rhodes grass numbers on 5/11/2021, assessed 19 days after planting following July or August applications of either Dual Gold or Valor +/- 1L Dual Gold at planting.
Data with the same letters are not significantly different (*P* = 0.05).

Similar results to those shown occurred at a second site, but with untreated FTR densities of only 1–2 plants/m$^2$. Only trace levels of FTR (<0.2/plants m$^2$) emerged at the other two sites despite a history of FTR issues.

In 2021, under very dry conditions for the 2 months leading into sorghum planting, the most effective residual control strategies were:

1. Valor 210 g/ha in late July, alone ~99% control
2. Valor 210 g/ha in late August, topped up with Dual Gold 1 L/ha at planting ~99% control
3. Dual Gold 1 L/ha in late July or August, topped up with Dual Gold 1 L/ha at planting ~99% control

### Residual efficacy in a wet winter/spring – 2022

Data from a trial at Springvale in 2022 (~17 km SW of Dalby) highlights the performance of the residual approaches under wetter conditions. This was one of a series of two trials conducted in 2022. The same core treatments were applied as in 2021: Dual Gold at 1 L/ha or Valor 500 WG at 210 g/ha at the end of July and end of August as single applications, and compared with the same timings 'topped up' with Dual Gold at 1 L/ha at planting (Table 1). All treatments were compared to Dual Gold at 1 or 2 L/ha applied at planting on 8 October.

#### *Rainfall*

Rainfall of 25 mm was received one day after the July applications and 14 mm received 5 days after the August applications. July, August, September and October all received high rainfall. In the 3 'fallow' months leading into planting (July-September) a total of 182 mm was recorded compared to a mean of 82 mm. Rainfall totals in all months were close to or exceeded the 90th decile. October rainfall was 92 mm compared to a mean of 70 mm and a 90th decile of 93 mm.

#### *Results*

The first FTR emergence was assessed on 19 August, 29 days after the July application (29DAA1) with 63 mm of rain received during that period. The untreated population of FTR was ~10 plants/m$^2$. All treatments of Dual Gold 1 L/ha or Valor 210 g/ha provided complete control. An optical spot-sprayer was used to control FTR seedlings after the assessment.

Figure 3 shows the number of new FTR seedlings in late September, 68 days after the July application (68DAA1), 32 days after the August application (32DAA2) and 11 days prior to planting. The July application received 152 mm up to 5 days prior to this assessment, the August application had received 90 mm.

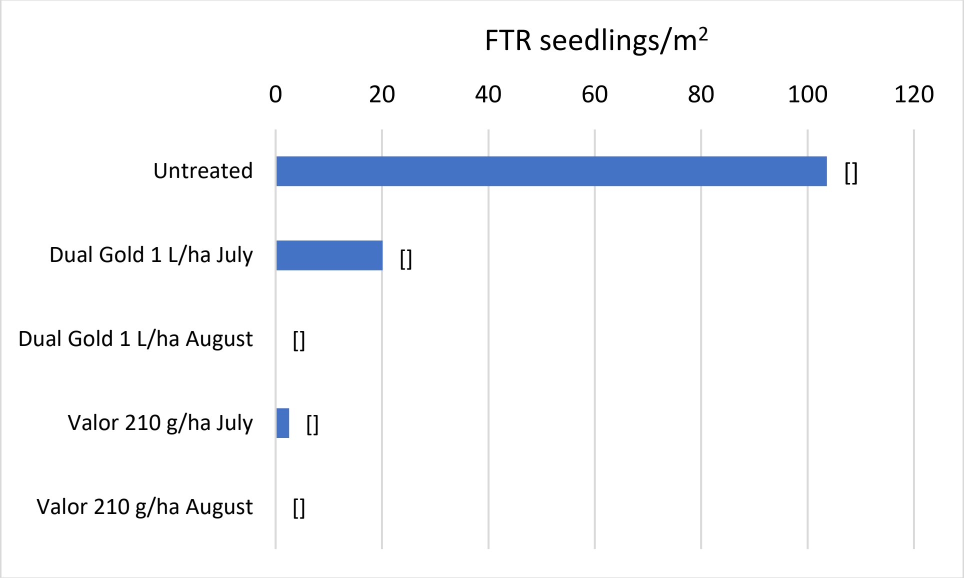

**Figure 3.** Feathertop Rhodes grass seedling numbers on 27/9/2022, 11 days pre-planting (68DAA1, 32DAA2). Data with the same letters are not significantly different (*P* = 0.05).

All treatments provided significant levels of control compared to the untreated control FTR population of ~104 plants/m$^2$. Although there was no significant difference, the July application of Dual Gold only provided ~80% control, 10 weeks after application and having received ~150 mm of rainfall since application. In contrast, the August application provided complete control after 4–5 weeks and ~90 mm of rain. An optical spot-sprayer was used to control FTR seedlings after the assessment.

Figure 4 shows the counts of FTR ~3 weeks after planting. It highlights that:

- All treatments with applications of Dual Gold at planting provided complete control of FTR emerging in the first 3 weeks after planting. Total rainfall of ~90 mm was received in this period.
- The July application of Dual Gold 1 L/ha alone reduced FTR emergence by ~61%, despite having received ~245 mm of rain since application 10–15 weeks earlier.
- The August application of Dual Gold 1 L/ha alone reduced FTR emergence by ~87%, despite having received ~180 mm of rain since application 5–9 weeks earlier.
- The July application of Valor 210 g/ha alone reduced FTR by ~90% with the August application alone reducing FTR counts by >99%.

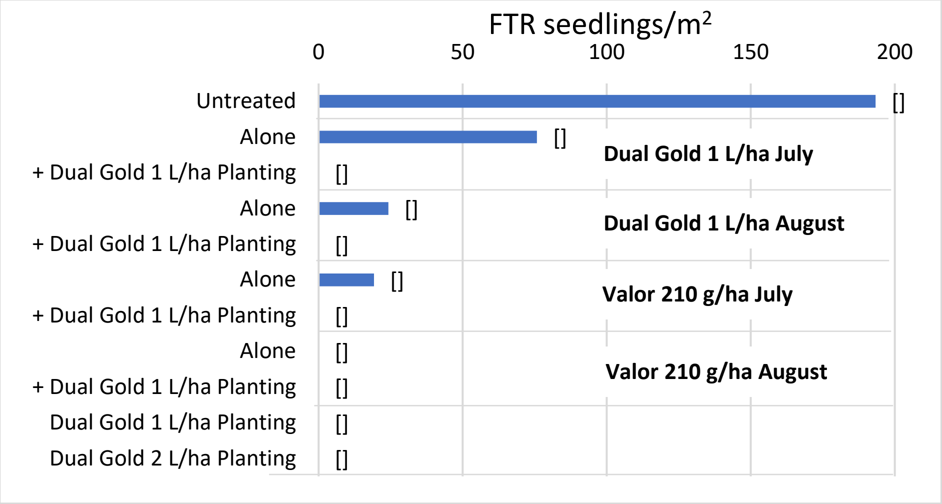

**Figure 4.** Feathertop Rhodes grass numbers on 31/10/2022, 23 days after planting (102DAA1, 66DAA2). Data with the same letters are not significantly different (*P* = 0.05).

The cumulative potential emergence counts of FTR over the 15 weeks from the July application is presented in Figure 5. It is described as 'potential' as experimentally, knockdown control of early FTR emergence was achieved with two optical spot-sprayer applications. The graph shows the potential FTR populations that would have been present without these spot-sprayer applications due to the lack of effective, economic knockdown herbicides for fallow FTR control.

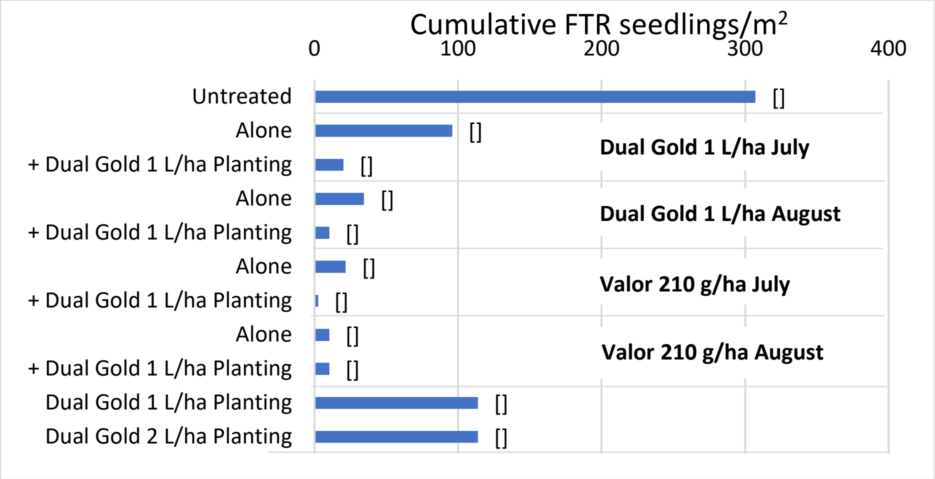

**Figure 5.** Cumulative potential feathertop Rhodes grass seedling numbers from 21/7/2022 to 31/10/2022, 23 days after sorghum planting (102DAA1, 66DAA2)
Note: + DG 1L Planting is a 'top up' of Dual Gold 1L at planting following the initial herbicide treatment in July or August. Data with the same letters are not significantly different (*P* = 0.05).

Figure 5 highlights the overall system impact from:

1. July application

- Dual Gold 1 L/ha alone was effective for ~6–10 weeks but only reduced overall FTR numbers under prolonged wet conditions by ~70%. When topped up with Dual Gold 1 L/ha at planting, the FTR population was reduced by ~93%.
- Valor 210 g/ha alone reduced overall FTR plant number by ~93%. When topped up with Dual Gold 1 L/ha at planting, it reduced overall FTR population by ~99%.

2. August application

- Dual Gold 1 L/ha alone reduced overall FTR plant number by ~89%. When topped up with Dual Gold 1 L/ha at planting, it reduced overall FTR population by ~97%.
- Valor 210 g/ha alone reduced overall FTR counts by ~97%. There was no benefit when topped up with Dual Gold 1 L/ha at planting as the Valor 210 g/ha treatment provided complete control in the first 3 weeks post planting.
- Planting application
- Dual Gold at 1 or 2 L/ha alone at planting provided complete FTR control in the first 3 weeks after planting. However, without an effective, economic knockdown approach, these applications only would have reduced overall FTR populations by ~63%. This approach was the poorest option overall.

Under decile 90 rainfall conditions in 2022, the most effective residual control strategies were:

1. Valor 210 g/ha in late July topped up with Dual Gold 1 L/ha at planting: ~99% control
2. Dual Gold 1 L/ha in late August topped up with Dual Gold 1 L/ha at planting: ~97% control
3. Valor 210 g/ha in late August alone or topped up with Dual Gold 1 L/ha at planting: ~97% control

### Conclusions

Until there is an effective, economic, non-residual knockdown option for FTR control, management prior to sorghum production will remain a challenge, particularly when FTR seedbanks are large.

The results obtained in these trials, together with feedback from commercial usage, strongly endorse the importance of a sequential residual herbicide program for FTR management prior to sorghum. The choice of herbicide is likely to be impacted by the type of fallow rainfall forecast (Dual Gold considered a poorer option under wetter conditions), timing of first application (Dual Gold generally provides a shorter residual length than Valor 500 WG), spectrum of other weeds, and product cost.

### Acknowledgements

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

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**Notes**