TRANGIE NSW
THURSDAY 15
AUGUST 2024

GRAINS RESEARCH UPDATE

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GRDC 2024 Grains Research Update Welcome

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Graeme Sandral
Grower Relations Manager – North

Trangie

GRDC Grains Research Update

Thursday 15 August 2024

Trangie Agricultural Research Centre, 7878 Mitchell Hwy, Trangie NSW 2823

Registration: 8:30 AM for a 9:00 AM start, finish 2:50 PM

AGENDA

Time	Topic	Speaker(s)
9:00 AM	**GRDC welcome**	*GRDC*
9:10 AM	**Benefits of aeration, retro fitting aeration into existing silos & issues to consider when purchasing new. Venting of phosphine – avoid rejection at port by venting correctly.**	*Chris Warrick (GRDC Stored Grain Extension Team)*
9:45 AM	**Cereal rust & disease management update looming issues with fungicide resistance**	*Steve Simpfendorfer (NSW DPI)*
10:20 AM	**MORNING TEA**	
10:50 AM	**Soil constraints – the economic response of long term soil amelioration strategies. A planned approach to economically Identify and ameliorate sodicity**	*Chris Guppy (UNE)*
11:20 AM	**Pulse agronomy and performance in different environments**	*Maurie Street (GOA) & Rohan Brill (Brill Ag)*
11:55 AM	**Strategies to manage losses from fusarium crown rot**	*Steve Simpfendorfer (NSW DPI)*
12:20 PM	**LUNCH**	
1:10 PM	**AFTERNOON FIELD WALK looking at trials at the research station. Below is the wet weather presentation option**	
1:10 PM	**Farming systems – profit over time, crop legacy issues and risk**	*Jon Baird (NSW DPI), Branko Duric (NSW DPI) & Steven Simpfendorfer (NSW DPI)*
2:05 PM	**Sclerotinia impacts on chickpea yield and the role of Predicta®B to differentiate between species and inoculum load of sclerotonia.**	*Sean Bithell (NSW DPI)*
2:40 PM	**Unlocking soil potential by unlocking access to water and nutrients in NSW cropping soils with multiple constraints – a new R&D investment**	*Leigh Jenkins (NSW DPI)*
2:50 PM	**CLOSE**	

Contents

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Grain silo considerations and aeration performance

Chris Warrick[1]

[1] Primary Business (in capacity as the national lead for the GRDC Grain Storage Extension Team)

Key words

grain storage, silo, weevil, aeration, fan, backpressure

GRDC code

PRB2011-001SAX

Take home messages

- Once installed the decision to modify or upgrade silos is problematic. Consequently, the initial selection of silos in particularly important as they may provide significant advantages or headaches for the next 30+ years.
- Aeration cooling provides many benefits including maintaining high germinations rates, seedling vigour and grain colour, as well as reducing the impact of invasive grain insect pests and shortening fumigation venting time.
- Testing aeration in stored grain has highlighted the need for system designs that ensure ducting doesn't increase backpressure on fans, and that systems can provide adequate airflow for the types and depths of grain being stored.
- The fan performance provided by the manufacture, should were possible be cross referenced with industry data to ensure system airflows are verified with field testing (silo) results for the grain volume and types likely to be stored.

New silo considerations

Because silos cannot be traded in for a better model the decisions made at the time of purchase can determine if they are easy to use or a headache for the next 30+ years of their life. While transportable, cone-bottom silos may be sold and replaced, larger built-on-site silos are there for good, and some aspects are difficult or even impossible to improve later. Below is a list of considerations that growers often regret not giving more attention at the time of purchase.

Gas-tight sealable

Ignore any vague references to sealed or fumigatable and insist the silo is gas-tight sealable to the Australian Standard 2628-2010. Ensuring this standard is referenced in the purchase contract or invoice clarifies the manufacturer's obligation to demonstrate the silo performs a five-minute, half-life pressure test. While retro-sealing can be an option, it is a significant cost, with varying success and often a short lifespan. Insect resistance is still increasing in Australia and gas-tight storage is the only knock-down option.

Easy to clean

Insects only require a small amount of grain in a sheltered environment to survive. Silos that are difficult or impossible to remove all grain residue from are likely to harbour insects through the off-season, ready to infest fresh grain as it's in-loaded. Poorly designed wall-to-roof joints, lid or hatch joints, and aeration ducting that can't be removed for cleaning will accumulate grain residue, which harbours insects.

Easy and safe to operate

As already stated, built-on-site silos can't be traded in, so any aspects that make them difficult or dangerous to operate, will be a nuisance and potential hazard for the next 30+ years.

Safe ladder

Too often, ladders are left off new silo purchases to save money or remove the potential risk of falling from heights. Reality is, access to the top of silos is required to check for insects, monitor grain quality, test fumigation clearance and maintain lids and seals. Safe access via a compliant ladder, staircase, elevated walkway or work platform is required.

Aeration cooling

While aeration can be retrofitted to cone bottom silos, adding it to flat bottom silos after constructed is difficult and compromising. See further explanation below.

Roof vents

Manufacturers of large flat bottom silos generally insist on roof vents if aeration is included, but vents are often overlooked on cone bottom silos. The compromise is leaving the lid partly open, which runs the risk of rain or birds entering the silo. Ensure fan performance is not inhibited by inadequate vent space out the top of the silo, and that vents are gas-tight sealable when fumigation is required.

Outload speed

Occasionally I hear of growers surprised that the silo outlet or unloader can't supply their truck-loading auger to its operating capacity. I'm yet to hear a grower say they want to load trucks slower in the future, so to cater for the demands of the next 30+ years, outload speeds should arguably exceed current expectations.

Recirculation for fumigation

If silos are fitted with ground level application for phosphine, a recirculation system is required to facilitate gas liberation and distribution. On silos larger than 300t, powered recirculation achieves more uniform gas concentration throughout the silo and reduces the exposure period from 20 days, down to 7–10 days. Powered recirculation can be in the form of a portable box with an inbuilt fan, phosphine is placed in the box and recirculation is achieved by connecting it to the silo's aeration duct and headspace. An alternative is to plumb a small fan between the silo's aeration duct and headspace and place the phosphine in the silo headspace as directed on the label.

Aeration cooling – why bother

The benefits of aeration cooling are numerous and emerging research and experience has highlighted some helpful uses not previously considered priority.

Grain quality

Recent research by Agriculture Victoria has confirmed that grain quality in terms of germination, vigour and colour deteriorate rapidly when stored warm, but can be maintained at cool storage temperatures. Research currently underway is also investigating the potential for improving grain quality through manipulation of temperature during storage.

Insect prevention

Thanks to research by the Queensland Department of Agriculture and Fisheries, (QDAF) we know that insects of stored grain can't reproduce at temperatures below 15 °C and are not attracted to infest cool grain as it is not conducive to breeding.

Moisture management

Growers are more commonly using aeration cooling to manage high moisture grain during a wet harvest. While aeration cooling can't dry grain, it has been proven successful in blending moisture throughout a silo, preventing green grains and the occasional truckload from going mouldy, and holding slightly over moisture grain until it can be dried or blended with dry grain.

Phosphine venting

Recent research by QDAF has also proven that aeration cooling fans significantly reduce venting periods after fumigation, an issue when delivery sites are spear testing to a clearance level of 0.3 parts per million. Of particular concern, Workplace Health and Safety Ministers have announced this limit will reduce to 0.05ppm as of December 2026.

Airflow system design

Once the purposes of aeration cooling are determined, the system must be designed to handle the backpressure of the quantity and type of grain being stored. For cooling, the target airflow is 2–3 litres of air per second per tonne (L/s/t) and drying requires airflow of at least 15 L/s/t.

The GRDC Grain Storage Extension Team have been testing aeration system performance to provide manufacturers with current design parameters, rather than relying on modelling and calculated performance based on primitive research done in the USA, 70 years ago.

Grain type and settling

The recent aeration testing revealed that the type of grain being stored has a significant impact on fan performance. Canola for example, inflicts 2.4 times the backpressure on fans than wheat, and conversely, chick peas only create one quarter of the backpressure of wheat.

In addition to the type of grain, the size of the grain and how much it settles in the silo can increase the backpressure even further. During test rig experiments, grain settled vs loose filled increased bulk density by around 8% but increased the back pressure by up to 60%.

Field testing

Test rig results were verified against 48 aeration systems operating on silos, which revealed more variables and anomalies. The shape of the grain surface determines the route of most of the airflow as it takes the path of least resistance – the shortest path, or the shallowest depth out of the grain stack.

Duct restriction

The aeration duct style and perforation design has more of an impact on fan backpressure than previously understood. In two instances, inadequate ducting meant that fan performance was inhibited more from the duct, than from the grain in the silo. Evidenced by similar backpressure readings in silos that were full, compared to the same silo and fan that had only a shallow depth of the same grain. To put it into perspective, a silo that was supplied with a fan said to be able to deliver >5 L/s/t and recommended to be fitted with restrictor plates, was in fact only delivering 1.2 L/s/t.

Fan performance

On several occasions during field testing, fans were found to be significantly underperforming, compared to the manufacturer's calculated, claimed output. This led to performance testing 13 commonly used aeration fans for manufacturers who were willing to participate. Intended to be a learning exercise rather than a policing attempt, those manufacturers have been provided with their results. Where the tested fan performance was less than the claimed output, (in one instance only 65% of the claimed output), manufacturers have been put on notice to correct their claimed performance figures or redesign their fan.

Multiple fans

As a side experiment, where silos were fitted with multiple fans, measurements were taken with one, two, three and four fans operating to quantify the airflow increase with each additional fan. Turning on the second fan increased total airflow by 1.8 times rather than doubling, due to the increased backpressure. Similarly, running all four fans did not quadruple total airflow of the single fan, rather increased it by a factor of 2.5 due to the increased back pressure.

Detailed results of the aeration back pressure and performance testing will be available from storedgrain.com.au once published in the coming few weeks.

Acknowledgements

The research undertaken as part of this project and complementary projects by Queensland Department of Agriculture and Fisheries, (QDAF) and Agriculture Victoria are made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC. The author would like to thank the research partners and growers for their continued support.

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Cereal disease update for 2024: where do we sit in central NSW?

Steven Simpfendorfer[1], Brad Baxter[2]

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[2] NSW DPI, Wagga Wagga

Keywords

leaf diseases, Fusarium head blight, stripe rust, septoria tritici blotch, fungicide, climatic conditions

GRDC codes

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

Take home messages

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

Introduction

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

The contrast between leaf and head disease issues across central NSW in 2023 and 2022 was obviously stark. However, our memories of 2022 are fresh enough to have us nervous of cereal diseases in 2024, with the expectation of wetter spring conditions. What did we learn from the past two seasons and how can we use this to optimise management in 2024?

2022 – an exceptional season

The 2022 season was wet! Records were broken and flooding was widespread in some areas. Spring rainfall (Sep–Nov) in 2022 was generally very much above average across central and southern NSW compared with average spring rainfall in 2023 (Figure 1). Frequent rainfall is very conducive to the development of leaf diseases such as stripe rust, as causal pathogens require periods of leaf wetness or high humidity for spore germination and initial infection. However, just as significant a contributing factor to the prevalence of cereal leaf diseases was the spring (Sep–Nov) temperatures in 2022 which remained mild, compared with 2023 (Figure 1).

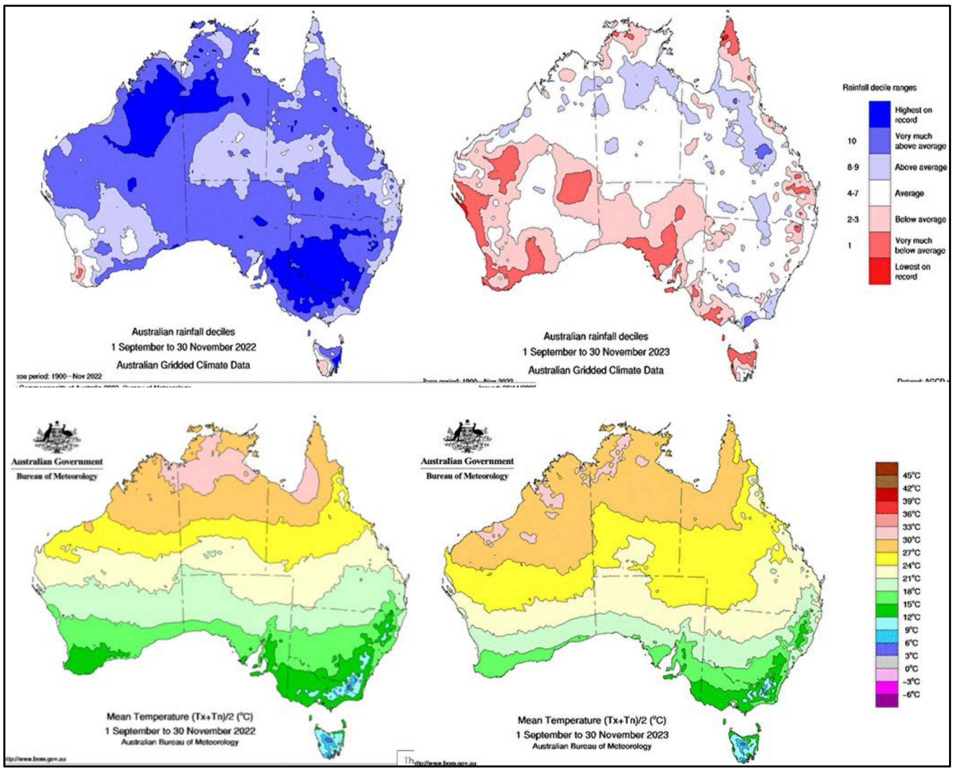

Figure 1. Rainfall decile (top) and mean daily temperature (bottom) for spring (Sep–Nov) in 2022 (left) compared with 2023 (right). Source: Bureau of Meteorology (www.bom.gov.au).

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

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

Disease	Optimum temperature range (°C)	Latent period (opt. temp)
Stripe rust	12–20	10–14 days
Septoria tritici blotch	15–20	21–28 days
Wheat powdery mildew	15–22	7 days
Leaf rust	15–25	7–10 days
Yellow leaf spot	15–28	4–7 days
Fusarium head blight	20–30	4–10 days

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

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

Main leaf diseases in 2022 and 2023

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

In collaboration with a range of locally based agronomists, random surveys of cereal crops across NSW were conducted annually with a total of 283 cereal crops surveyed in 2022 and 338 in 2023. This was composed of 468 bread wheat, 102 barley and 51 durum wheat crops (data not shown).

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

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

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

***Puccinia* spp. (cereal rusts, stripe rust)**

A general qPCR test exists for the detection of the three wheat cereal rusts (stripe, leaf and stem) but cannot distinguish between species, and also detects barley and oat rust species. Fortunately, these rust species are easy to distinguish on visual assessments of collected random cereal samples. Hence, the *Puccinia* spp. maps over seasons predominantly (around 95%) relate to the detection of *Puccinia striiformis* (stripe rust) in wheat crops (Figure 2). The only other cereal rusts recorded within the surveys have been a low prevalence of *Puccinia triticina* (wheat leaf rust) and *Puccinia hordei* (barley leaf rust) in 2022.

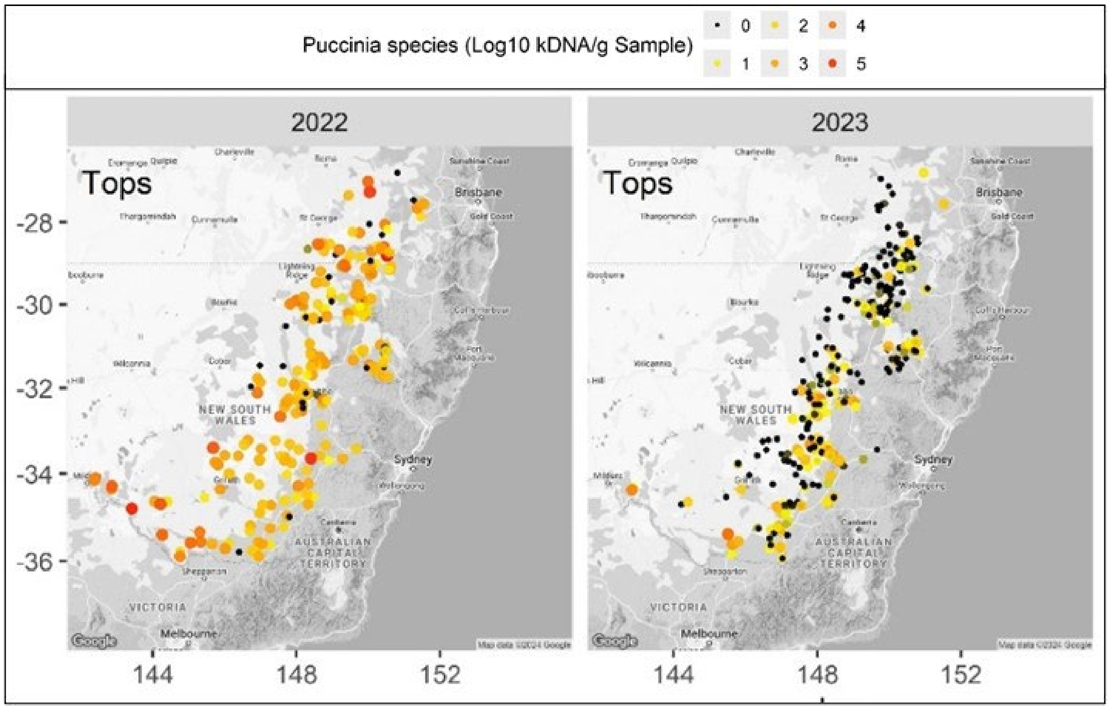

Figure 2. Quantification of *Puccinia* spp. (cereal rust) levels within plant tops of randomly surveyed cereal crops across NSW – 2022 and 2023.

The prolonged wet and mild conditions during grain filling in 2022 was favourable for continued stripe rust development in upper canopies and even resulted in head infections in some crops despite fungicide applications. *Puccinia* spp. levels were noticeably higher in 2022 (Figure 2) where continued rainfall across much of NSW often prevented access to paddocks to apply fungicides by ground rigs or delayed application. This was further exacerbated by a shortage of aerial applicators. Drier and warmer spring conditions in 2023 markedly reduced the prevalence and levels of stripe rust infection in wheat crops across northern NSW and southern Qld (Figure 2). Arguably, difficulties with stripe rust management in more susceptible wheat varieties in 2022 also saw many of these dumped and/or a significant reduction in area planted to these varieties in 2023 in central NSW. Hopefully, the memory was still fresh enough from 2022 for growers not to venture back into these harder to manage varieties in 2024.

Zymoseptoria tritici (septoria tritici blotch)

Septoria tritici blotch (STB) can be a significant leaf disease of wheat (up to 40% yield loss) which is favoured by prolonged wet conditions and successive wet seasonal conditions. The causal fungus *Zymoseptoria tritici* (*Zt*) is stubble-borne with the initial spores having moderate distance wind dispersal. STB leaf infections appear as pale grey to tan blotches which are characterised by black fruiting bodies (pycnidia) within the blotches which gives STB lesions a speckled appearance. These pycnidia are the source of secondary infections within crops which spread through rain splash having short distance dispersal. STB has a long leaf wetness requirement for infection (48 h) and a long latent period (21–28 days) which can complicate management especially compared to other pathogens (e.g. stripe rust and yellow leaf spot both 6 h leaf wetness and 10–14 day or 4–7 day latent period, respectively).

In 2019 *Zt* was largely confined to southern NSW but has progressively spread north into central NSW, northern NSW and even southern Qld with successive wetter seasons from 2020 to 2022 (data not shown). *Zt* levels were highest across NSW in 2022 with a general trend of increased levels in eastern compared with western subregions, especially in southern NSW. A return to drier conditions in northern NSW/southern Qld in 2023 resulted in the retraction of *Zt* largely into central and southern NSW (Figure 3).

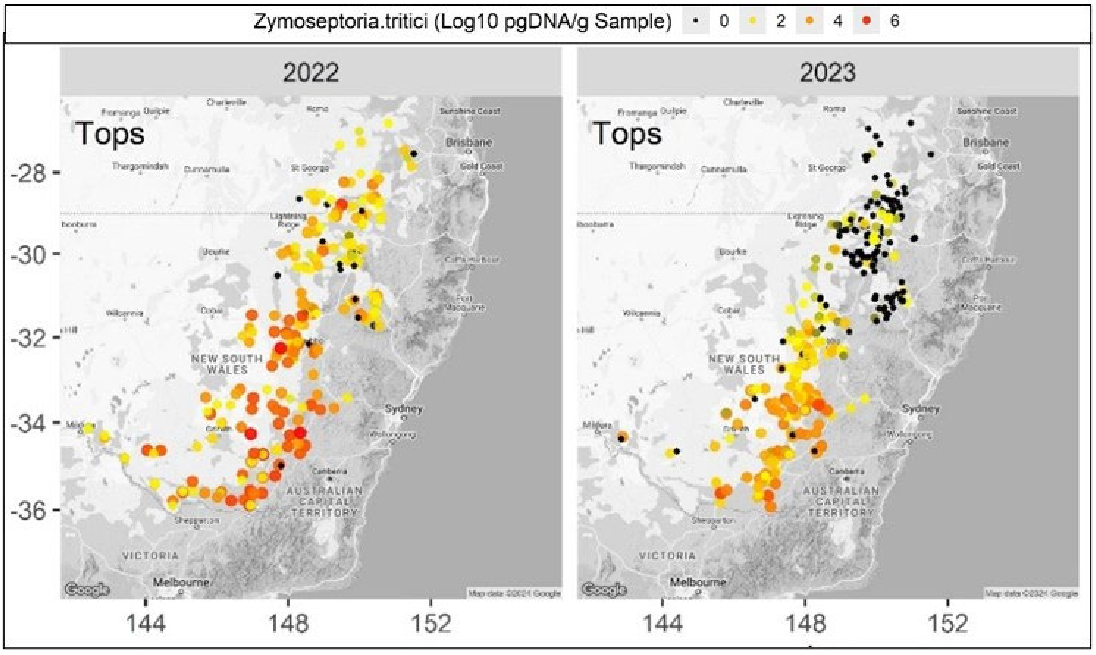

Figure 3. Quantification of *zymoseptoria tritici* (Septoria tritici blotch) levels within plant tops of randomly surveyed cereal crops across NSW – 2022 and 2023

Reduced sensitivity to some triazole (Group 3, DMIs) fungicide actives in *Zt* populations, especially in south-east NSW further complicates in-crop management.

Fungicide resistance in NSW Septoria tritici populations

A collaboration with Dr Fran Lopez-Ruiz at CCDM (Curtin University) was established to determine the frequency of DMI (triazole) and QoI (strobilurin) resistance in STB populations across NSW in 2021 to 2023. Information around location, variety and fungicide application history was collected from the collaborating agronomists for each STB infected leaf sample sent to Wagga Wagga. Leaves were also sent from random crop survey samples with visual STB infection. Leaf samples dried and sent to CCDM in WA to conduct specialised molecular testing of the frequency of mutations for DMI (Cyp51 mutation, triazoles) and QoI (G143A mutation, strobilurins) resistance within the STB population in each sample to inform NSW growers. In total 22 wheat leaf samples were submitted to CCDM for fungicide resistance testing from primarily central and southern NSW in 2023, 35 samples in 2022 and 4 samples from 2021 (Figure 4).

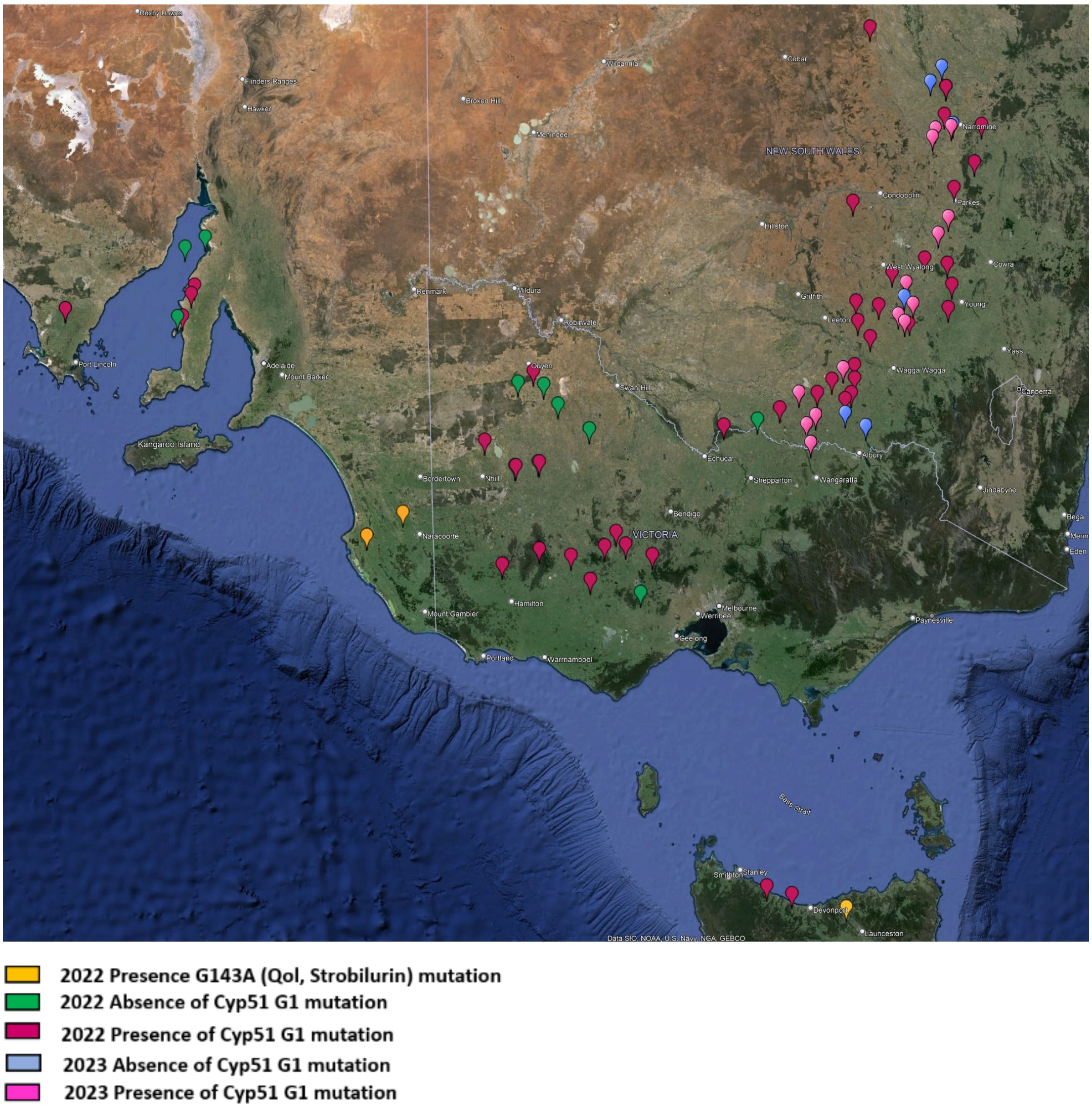

Figure 4. Septoria tritici blotch (STB) fungicide resistance screening results across south-eastern Australia in 2022 and 2023. Data courtesy of Dr Fran Lopez-Ruiz and at team Curtin University.

The G143A mutation, which confers resistance to Group 11 (QoI, strobilurins) fungicides such as azoxystrobin, was not detected in any of the samples submitted from NSW over the three years (Table 2). However, the G143A mutation was detected in an STB sample from Tasmania in 2022 (not shown), marking the first detection outside of South Australia. It is unclear if this is the result of gene flow (wind dispersion) or an independent mutation event. This detection should act as a warning for NSW growers to use fungicide resistance management strategies to prolong the effectiveness of Group 11 (QoI, strobilurin) chemistry against STB.

Table 2. Location of Septoria tritici blotch samples collected across NSW in 2021 to 2023 and frequency of DMI (triazole) Cyp51 deletion and QoI (strobilurin) G143A mutations. Data courtesy of Dr Fran Lopez-Ruiz and team at Curtin University.

Location	Year	Region	Variety	DMI Cyp51	QoI G143A	Location	Year	Region	Variety	DMI Cyp51	QoI G143A
Eugowra	2021	CE NSW	Illabo	63%	0%	Temora	2022	SE NSW	Illabo	92%	0%
Narromine	2021	CW NSW	Flanker	0%	0%	Jugiong	2022	SE NSW	Raider	95%	0%
Narromine	2021	CW NSW	Sunmax	0%	0%	Harden	2022	SE NSW	Illabo	99%	0%
North Star	2021	NE NSW	Sunmax	0%	0%	Gerogery	2022	SE NSW	DS Bennett	100%	0%
Tomingley	2022	CE NSW	Lancer	11%	0%	Walmer	2022	Vic	Illabo	14%	0%
Gumble	2022	CE NSW	Illabo	29%	0%	Undera	2022	Vic	Naparoo	38%	0%
Young	2022	CE NSW	Lancer / Raider	79%	0%	Forbes	2023	CE NSW	Beckom	50%	0%
Narromine	2022	CW NSW	Lancer	0%	0%	Caragabal	2023	CE NSW	Beckom	71%	0%
Narromine	2022	CW NSW	Lancer	0%	0%	Narromine	2023	CW NSW	Lancer	1%	0%
Narromine	2022	CW NSW	Sunmax	2%	0%	Warren	2023	CW NSW	Sunmaster	1%	0%
Narromine	2022	CW NSW	Lancer	5%	0%	Trangie	2023	CW NSW	Lancer	2%	0%
Narromine	2022	CW NSW	Beckom	10%	0%	Mungery	2023	CW NSW	Hellfire	16%	0%
Narromine	2022	CW NSW	Lancer	19%	0%	Narromine	2023	CW NSW	Illabo	17%	0%
Nyngan	2022	CW NSW	Spitfire	26%	0%	Peak Hill	2023	CW NSW	Beckom	44%	0%
Ungarie	2022	CW NSW	Beckom	45%	0%	Burrum-buttock	2023	SE NSW	Scepter	0%	0%
Narromine	2022	CW NSW	Illabo	67%	0%	Albury	2023	SE NSW	DS Bennett	0%	0%
Marrar	2022	SE NSW	Breeding line	7%	0%	Temora	2023	SE NSW	Illabo	0%	0%
Uranquinty	2022	SE NSW	Illabo	10%	0%	Trungley Hall	2023	SE NSW	Illabo	33%	0%
Balldale	2022	SE NSW	Scepter	17%	0%	Combanning	2023	SE NSW	Illabo	36%	0%
Tubbul	2022	SE NSW	Lancer	24%	0%	Oaklands	2023	SE NSW	Scepter	46%	0%
Henty	2022	SE NSW	Coota	29%	0%	Lockhart	2023	SE NSW	Scepter	53%	0%
Eurongilly	2022	SE NSW	Illabo	55%	0%	Junee	2023	SE NSW	Illabo	55%	0%
Ganmain	2022	SE NSW	Beckom	56%	0%	Trungley Hall	2023	SE NSW	Kittyhawk	56%	0%
Temora	2022	SE NSW	Scepter	72%	0%	Trungley Hall	2023	SE NSW	Illabo	67%	0%
Currawarna	2022	SE NSW	Beckom	73%	0%	Collendina	2023	SE NSW	Scepter	87%	0%
Glenellen	2022	SE NSW	DS Bennett	75%	0%	Lowesdale	2023	SE NSW	Scepter	90%	0%
Temora	2022	SE NSW	Illabo	76%	0%	Junee	2023	SE NSW	Beckom	99%	0%
Culcairn	2022	SE NSW	Whistler	80%	0%	Peechelba East	2023	Vic	Scepter	94%	0%
Walbundrie	2022	SE NSW	Scepter	88%	0%						

The Cyp51 G1 deletion (formerly identified as Cyp51 Isoform 11), associated with most resistant DMI (Group 3, triazole) genotypes in Australia so far, was detected in 49 of 57 (86%) STB leaf samples (Table 2). The frequency of the Cyp51 mutation within the STB population varied between locations and crops but appeared highest in central-east NSW (100% of sample), Victoria (100%), south-east NSW (90%) then central-west NSW (76%). The average Cyp51 frequency when present within the STB population ranged from 62% in SE NSW, 51% in CE NSW, 49% in Vic down to 20% in CW NSW. In CE NSW 4 of 6 samples (67%) had >50% frequency of this DMI mutation with this value being 19 of 30 (63%) in SE NSW, 1 of 3 (33%) in Vic and 1 of 17 (6%) in CW NSW (Table 2). This mutation is particularly significant because it leads to elevated levels of reduced sensitivity to some Group 3 fungicides such as tebuconazole, flutriafol and propiconazole.

Not all fungicide active ingredients are equal when it comes to controlling STB, and fungicide choice is becoming increasingly important for NSW growers. These results support the existing recommendation that Group 11 (QoI, strobilurin) fungicides are effective in preventing STB infection in NSW. If NSW growers are specifically targeting STB curatively with fungicides, it is best to avoid using cheaper Group 3 triazole actives like tebuconazole and propiconazole. Instead, opt for stronger Group 3 fungicides such as prothioconazole or epoxiconazole.

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

Fungicide management in 2024

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

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

1. Fungicides do not fix environmental, herbicide, physiological or nutritional issues within crops. Correct identification is the first critical step in disease management with around 15% of cereal diagnostics submitted each season not related to disease, so fungicide application is unnecessary.

2. Fungicides only protect leaves emerged at the time of application, they do not move into or protect leaves that emerge after application

3. The top three leaves (flag, flag-1 and flag-2) are the main contributors to yield in cereal crops so fungicide strategies need to focus on maximising green leaf retention (that is minimising infection) in these structures
4. All fungicides generally have much stronger protectant than curative activity, but this can vary between fungicide actives and pathogens (e.g. generally 1–2 days at best curative activity with yellow spot compared to 5–10 days with stripe rust)
5. Length of protection depends on how quickly each fungicide active moves through leaves (e.g. cyproconazole moves quickly so good rapid clean out of established stripe rust infections but more limited length of protection. Conversely, azoxystrobin much longer protectant but limited curative activity)
6. Coverage is critical with foliar applications so higher water volumes are better and ground rig generally improved efficacy over aerial applications
7. Fungicide resistance in fungal pathogens is real. Rotate and mix fungicide mode of action groups and actives within Group 3 (DMI, triazoles) between applications within a season (AFREN | Australian Fungicide Resistance Extension Networks).

Fusarium head blight risk in 2024

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

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

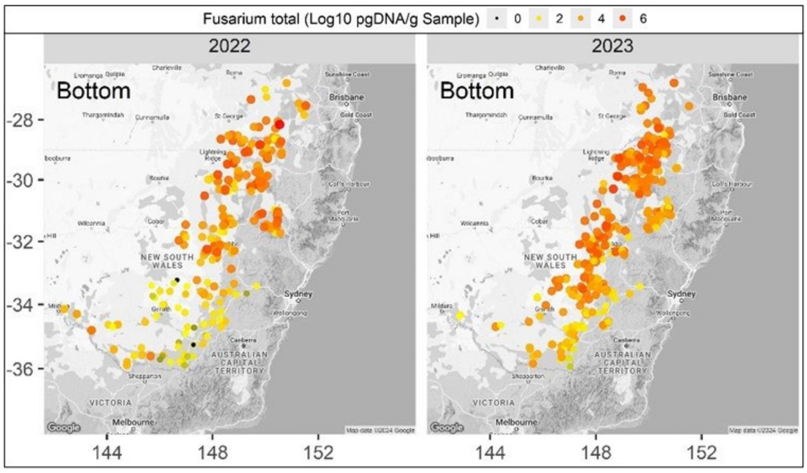

Figure 5. Levels of Fusarium crown rot within plant bases of randomly surveyed winter cereal crops across NSW – 2022 and 2023

Cause of FHB in 2022

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

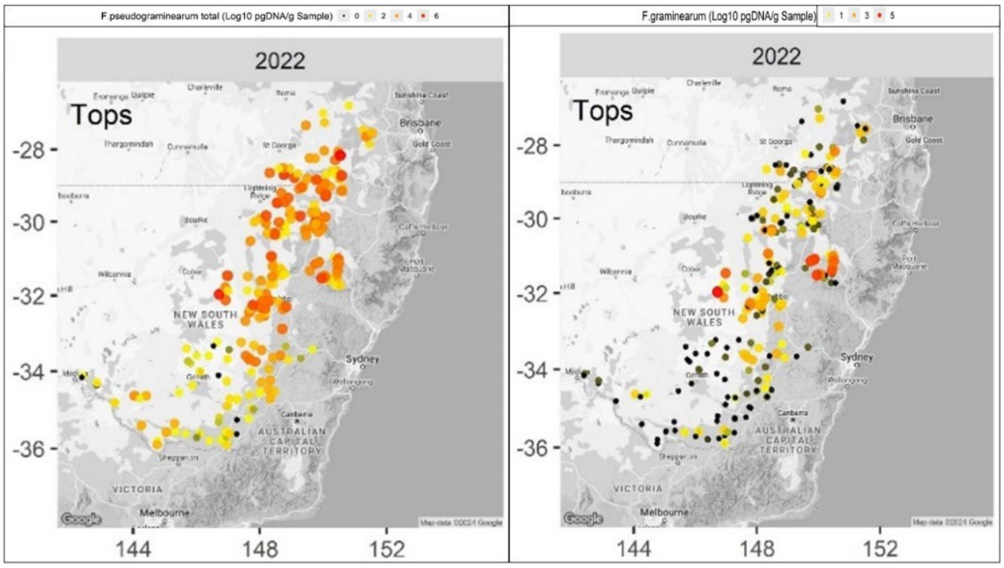

Figure 6. Levels of *Fusarium pseudograminearum* (left) and *F. graminarum* (right) within plant tops of randomly surveyed winter cereal crops across NSW – 2022

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

Managing FHB in-crop

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

Overseas research has demonstrated the importance of spray coverage in FHB control, with twin nozzles (forward and backward facing) angled to cover both sides of a wheat head and high volumes of water (≥100 L/ha) being critical to efficacy. However, at best this still provides ~80% control. Aerial application generally gives poorer coverage of heads and at best provides ~40 to

50% control. Some agronomists who used this application method in 2022 are questioning if the efficacy is even this high following their experience.

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

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

Summary

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

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

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

Further information

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

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

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

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

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Take home message

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

Background

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

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

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

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

Core site experiments

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

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

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

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

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

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

Results and discussion

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

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

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

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

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

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

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

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

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

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

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

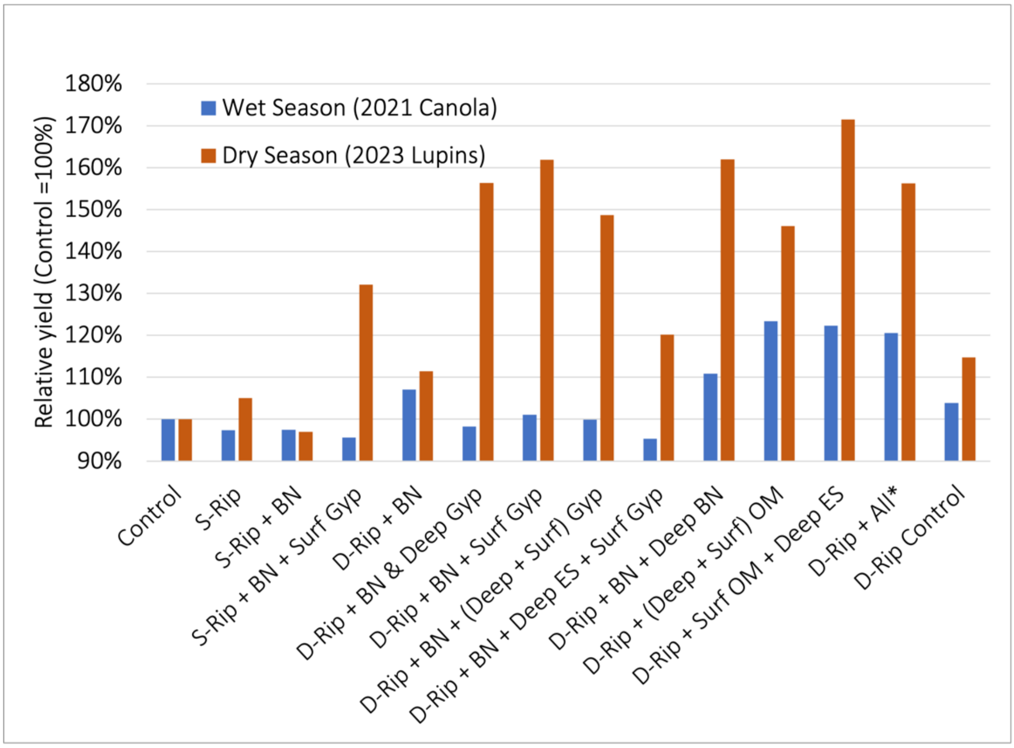

Figure 1. Relative yield (compared with control treatment) for a reference wet season (2021) growing canola at the Armatree core experimental site and a reference dry season (2023) growing lupins at the same site. Treatments were Shallow-rip (S-Rip), Deep-rip (D-Rip), Banded nutrients (BN), Surface and/or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

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

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

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

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

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

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

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

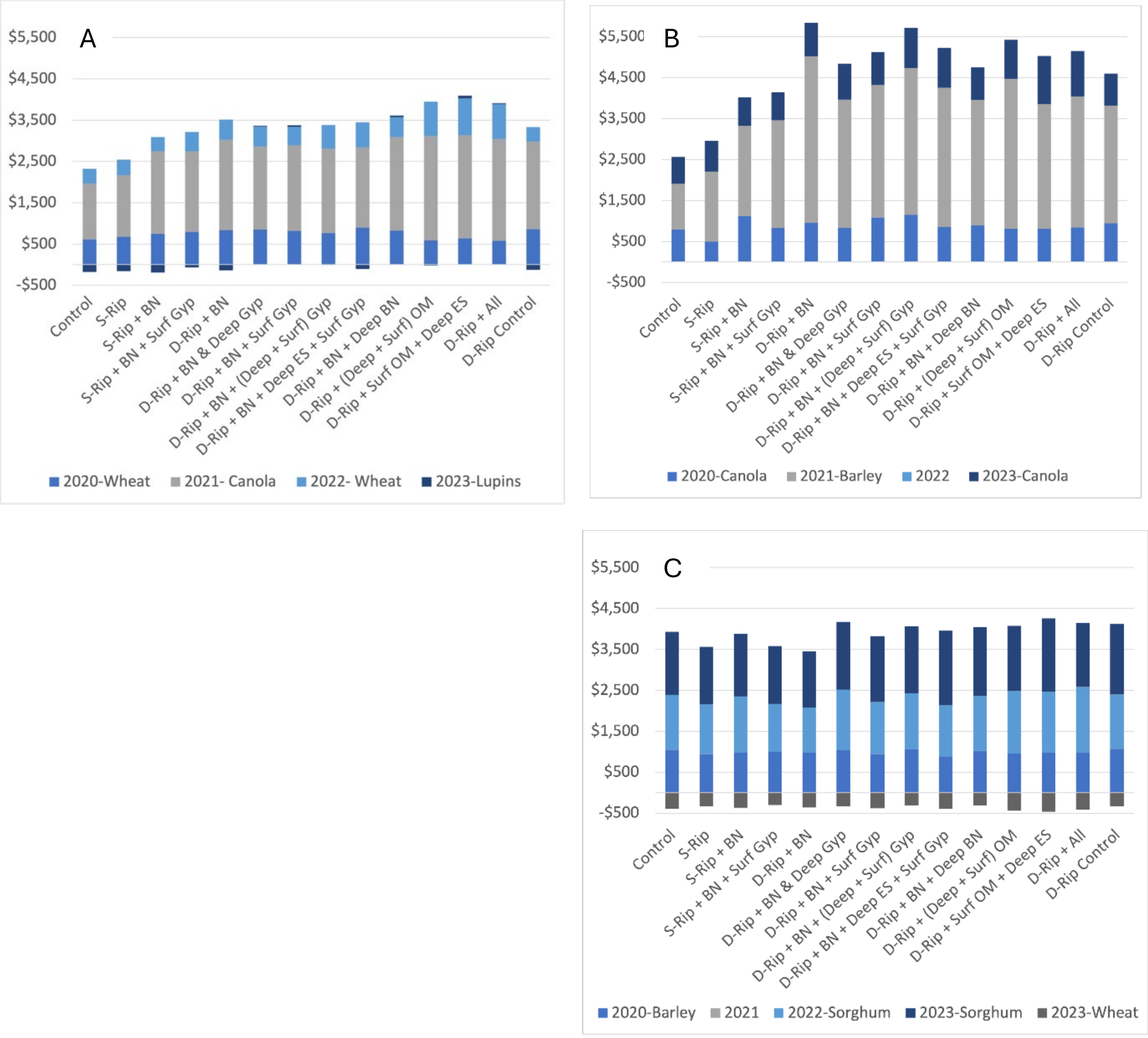

Figure 2. Cumulative net return from crops grown between 2020 and 2023 for subsoil amelioration treatments. Values presented are the mean for each treatment from the A) Armatree, B) Forbes and C) Spring Ridge experimental core sites. Legend captions indicate the year and crop planted each season. Years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

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

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

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

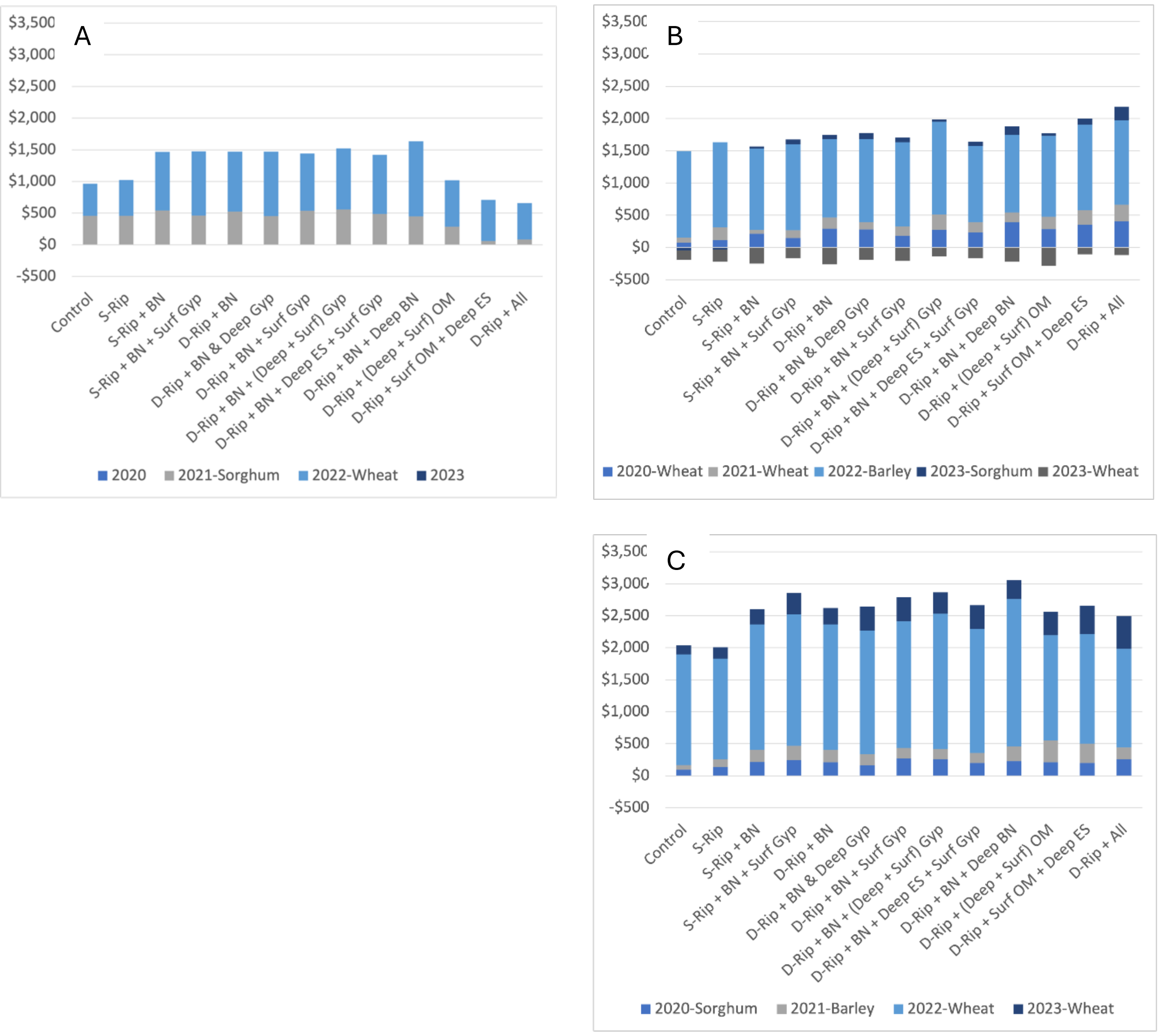

Figure 3. Cumulative net return from crops grown between 2020 and 2023 for subsoil amelioration treatments. Values presented are the mean for each treatment from A) the Talwood, B) Dulacca and C) Millmerran experimental core sites. Legend captions indicate the year and crop planted each season. Years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

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

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

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

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

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

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

On farm research (OFR) sites

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

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

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

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

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

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

Further reading

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

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Nitrogen balance of pulse species in central and southern NSW

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Key words

faba bean, chickpea, vetch, field pea, lupin, lentil, nitrogen fixation, grain nitrogen, pulse

GRDC code

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Take home message

- In 2021 and 2022 trials, for each tonne of above ground biomass (greater than ~1.2 t/ha), nitrogen fixation averaged 31 kg/ha
- Nitrogen fixation differences between species were largely driven by differences in biomass
- Faba beans and (where well drained) lupins had the highest biomass and hence the highest nitrogen fixation
- Grain nitrogen concentration ranged from about 6% in albus lupin, down to 3.2% in chickpea. Nitrogen removal per tonne of grain harvested (or hay cut for vetch) was ranked from albus lupin > narrow-leaf lupin > vetch > lentil = faba bean = field pea > chickpea > vetch hay.

Introduction

In 2021 GRDC initiated a project focused on 'Best Practice Pulse Agronomy' that brought together a unique group of organisations including Frontier Farming, Grain Orana Alliance, FAR Australia and AgGrow Agronomy. Led by Brill Ag it established two major themes of research activity:

8. Maximising economic yield and nitrogen (N) fixation in regional environments.
9. Developing locally relevant research knowledge on limitations to pulse production and productivity. Research to date has focused on plant density, disease management, nutrition management, inoculation strategy, phenological development, and herbicide tolerance.

This paper reports on the findings from Theme 1 above for the 2021 and 2022 seasons.

Materials and methods

Trials were conducted at seven sites across southern and central NSW in 2021 and five sites in 2022 (Table 1). Sites were selected to be regionally relevant with challenges (both perceived and real e.g., low pH, sodic and/or poorly drained soils) that may restrict the use and production of pulses in the rotation. The research is not designed to compare the performance of pulses in a benign situation but is focused more on determining the performance of pulse species for yield and N fixation performance in the local environment where adapted species may thrive, but less adapted species may struggle. This paper is reporting on ten of these twelve sites where N fixation analysis has been completed.

Table 1. Site description of ten pulse agronomy research sites from 2021 & 2022

Site	Sowing date	Rain (mm) Jan-Mar	Rain (mm) Apr-Nov	pH (Ca) 0-10 cm	Available N (kg/ha)	Site description
Barellan	13 May	270	435	4.5	63 (0–60 cm)	Acidic sandy loam soil with 3.3% Al.
Canowindra	3 May + 20 May[1]	290	490	4.8	192 (0–120 cm)	Moderately acidic, well drained red loam soil
Caragabal	29 April + 18 May[1]	280	480	5.0	53 (0–60 cm)	Slightly acidic loam (chromosol) with sub-soil sodicity
Buraja	7 May	180	450	4.6	54 (0–10 cm)	Moderately acidic silty loam soil
Ganmain	28 April + 18 May[1]	220	360	5.3	82 (0–60 cm)	Slightly acidic loam soil with sub-soil sodicity
Parkes	31 May	290	485	5.7	126 (0–90 cm)	Neutral pH, moderately heavy soil type with sub-soil sodicity
Barellan	6 May	255	537	5.2	76 (0–60 cm)	Well drained sandy loam soil
Ganmain	9 May	185	572	5.5	115 (0–80 cm)	Well drained loam soil (until flooded in late October from overland water)
Trundle	28 June	155	705	5.6	103 (0–90 cm)	Fairly well drained loam soil but site was very wet in 2022.
Wellington	23 May	235	780	5.4	120 (0–60 cm)	Grey basalt soil, wet in 2022.

[1] *Faba beans, vetch and lupins sown at earlier sowing date; field peas, lentils and chickpeas sown at later sowing date.*

N fixation was determined by collecting biomass samples at peak biomass (i.e., mid-podding stage and before leaf drop) and analysed using the ^{15}N natural abundance technique (Unkovich *et al*., 2008) to determine what proportion of the N in the biomass was derived from the atmosphere (NDFA). Once the quantity of NDFA in above ground biomass was calculated (peak biomass * N content of biomass * NDFA%), total N fixation (N-fix) was calculated by multiplying a co-efficient that estimates the root contribution which was 1.5 for faba beans, field peas, lentils, lupins and vetch; and by 2.0 for chickpeas. These figures (1.5 and 2.0) are known as 'root factors' and are described by Swan *et al.* (2022). The root factor calculation makes an allowance for below ground N (e.g. in roots and nodules) so an improved estimate of total N fixed can be provided. Finally, the N balance is calculated by subtracting the N removed in grain from total N fixed.

Results

Total nitrogen fixation

Total N fixed by the pulse species across the ten sites in 2021 and 2022 was closely related to crop biomass. For each tonne of biomass >1.2 t/ha, total N fixation was ~31 kg N/ha (Figure 1). Some crop biomass figures were very high in 2021 and 2022 due to high rainfall. The species most consistently able to achieve these very high biomass levels was faba bean as it handled intermittent waterlogging relatively well. Lupins had very high biomass in some trials (e.g. Canowindra 2021 & Barellan 2022) but had low biomass where waterlogging was an issue (e.g. Parkes 2021, Trundle 2022). Overall lentils had the lowest biomass and the lowest N fixation.

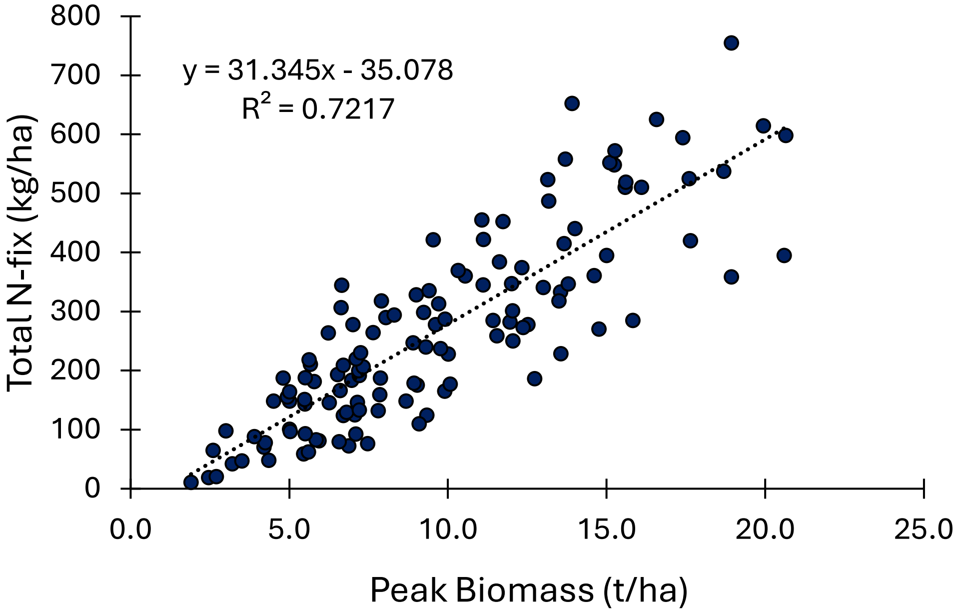

Figure 1. Relationship between peak biomass of pulses and total N fixed (N-fix) across 10 trials in 2021 and 2022.

Nitrogen removal

Nitrogen concentration in the grain was highest in albus lupin and lowest in chickpea, with albus lupins having approximately double the grain N concentration of chickpeas (60 kg N/tonne for albus lupins versus 33 kg N/tonne for chickpeas). Narrow-leaf lupins had the second highest grain N concentration (52 kg N/ tonne) with faba beans, field peas and lentils all within 40–45 kg N/tonne of grain (Figure 2). Vetch hay (from nearby trials) had an average N removal of 27 kg N/tonne of hay (data not shown). Site variation for grain N concentration was less significant than the differences between species.

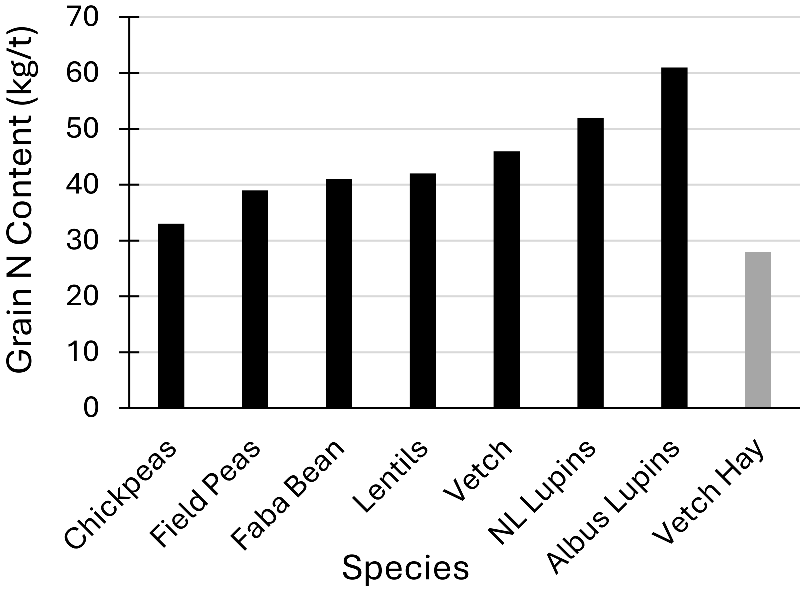

Figure 2. Average Grain (and hay) N concentration of pulse species in 2021 and 2022 in trials in southern and central NSW.

Nitrogen balance

N balance is simply a measure of how much N is harvested in grain (or removed in hay) subtracted from total N fixation. With >50 species*site combinations assessed in 2021 and 2022, the N balance was always positive ranging from 2 kg/ha to 402 kg/ha. Due to their low biomass production, the N balance of lentils was <100 kg N/ha in eight of nine trials where lentils were included. In contrast, faba beans had an N balance >100 kg N/ha in eight of ten trials where they were included (Tables 2 & 3). In general, higher biomass crops had higher grain yield and higher nitrogen balance. Pulse agronomy (for example sowing date, species selections, seeding rate) should focus on maximising biomass to increase both crop biomass (and N fixation) and grain yield.

Table 2. Peak biomass, total N fixed (N-fix), grain yield, N removed in grain and N balance of pulse species at research sites in NSW in 2021.

Site	Species	Cultivar	Peak biomass (t/ha)	N fix (kg/ha*)	Grain yield (t/ha)	N removed (kg/ha)	N balance (kg/ha)
Barellan	*Chickpea*	*CBA Captain*⦶	5.0	148	2.2	72	76
	Faba bean	*PBA Samira*⦶	9.4	335	4.4	171	164
	Field pea	*PBA Wharton*⦶	9.9	287	3.9	146	141
	Lentil	*PBA Hallmark XT*⦶	6.8	129	2.6	105	24
	Lupin	*Luxor*⦶	5.5	188	3.0	174	14
	Vetch	*Timok*⦶	9.3	240	3.5	162	78
Buraja	*Chickpea*	*CBA Captain*⦶	7.1	220	2.3	74	146
	Faba bean	*PBA Samira*⦶	6.7	209	2.9	123	86
	Vetch	*RM4*⦶	4.8	187	1	51	136
Canowindra	*Chickpea*	*CBA Captain*⦶	8.9	247	2.2	89	158
	Faba bean	*PBA Samira*⦶	15.0	395	5.8	230	165
	Lentil	*PBA Hallmark XT*⦶	6.7	124	1.4	58	66
	Lupin	*Murringo*⦶	17.6	525	4.3	263	262
	Lupin	*PBA Bateman*⦶	15.6	519	3.4	179	340
Caragabal	*Chickpea*	*CBA Captain*⦶	9.6	278	2.1	72	206
	Faba bean	*PBA Samira*⦶	17.4	594	5.7	251	343
	Field pea	*PBA Taylor*⦶	7.0	278	3.4	134	144
	Lentil	*PBA Hallmark XT*⦶	7.2	133	1.7	71	62
	Lupin	*PBA Bateman*⦶	9.7	313	2.1	112	201
	Vetch	*Timok*⦶	11.1	345	1.6	92	253
Ganmain	*Chickpea*	*CBA Captain*⦶	5.0	164	Not harvested due to hail		
	Faba bean	*PBA Samira*⦶	12.0	347	5.2	211	136
	Field pea	*PBA Wharton*⦶	8.3	294	2.7	104	190
	Lentil	*PBA Hallmark XT*⦶	5.5	93	2.1	91	2
	Vetch	*Timok*⦶	6.6	166	2.7	127	39
Parkes	*Chickpea*	*CBA Captain*⦶	9.0	328	2.6	89	239
	Faba bean	*PBA Samira*⦶	15.1	552	6.3	282	270
	Lentil	*PBA Hallmark XT*⦶	3.9	88	0.7	29	59
	Lupin	*Murringo*⦶	3.0	98	0.8	47	51

	Lupin	*PBA Bateman*⍦	7.9	318	2.6	132	186

Table 3. Peak biomass, total N fixed (N-fix), grain yield, N removed in grain and overall N balance of pulse species at research sites in NSW in 2022.

Site	Species	Cultivar	Peak biomass (t/ha)	N fix (kg/ha*)	Grain yield (t/ha)	N removed (kg/ha)	N balance (kg/ha)
Barellan	*Chickpea*	*CBA Captain*⍦	12.4	428	1.8	59	369
	Faba bean	*PBA Samira*⍦	13.0	195	4.6	185	10
	Field pea	*PBA Butler*⍦	11.3	268	2.3	96	172
	Lentil	*PBA Hallmark XT*⍦	7.7	175	2.6	105	70
	Lupin	*Luxor*⍦	15.0	425	5.3	312	113
	Lupin	*PBA Bateman*⍦	15.0	427	3.8	209	118
	Vetch	*Timok*⍦	10.7	307	4.7	220	87
Ganmain	*Chickpea*	*CBA Captain*⍦	9.5	282	0.5	18	264
	Faba bean	*PBA Samira*⍦	17.8	570	5.7	235	335
	Field pea	*PBA Butler*⍦	8.7	261	2.9	126	135
	Lentil	*PBA Hallmark XT*⍦	7.5	84	1.1	46	38
	Vetch	*Timok*⍦	12.1	251	2.4	120	131
Trundle	*Chickpea*	*CBA Captain*⍦	4.4	63	1.5	48	15
	Faba bean	*PBA Samira*⍦	15.3	595	4.1	192	402
	Field pea	*PBA Butler*⍦	5.4	63	1.6	52	11
	Lentil	*PBA Hallmark XT*⍦	3.0	31	0.4	17	14
	Lupin	*PBA Bateman*⍦	8.0	273	1.3	72	201
	Vetch	*Studenica*⍦	7.2	223	2.2	107	115
Wellington	*Chickpea*	*CBA Captain*⍦	5.9	111	1.1	37	74
	Faba bean	*PBA Samira*⍦	12.7	431	5.9	267	163
	Field pea	*PBA Butler*⍦	16.3	369	3.8	136	232
	Lentil	*PBA Hallmark XT*⍦	8.0	160	0.5	17	143
	Lupin	*Luxor*⍦	5.7	168	2.1	100	68
	Lupin	*PBA Bateman*⍦	7.1	243	2.7	138	105
	Vetch	*Studenica*⍦	7.6	241	1.7	80	161

Discussion and conclusion

The above average rainfall in 2021 and 2022 led to some very high biomass and grain yields being achieved across the project region, most consistently with faba bean. Other pulses such as lupin, lentil and chickpea had more variable yield responses. Field pea and vetch (for grain) performed consistently across sites and seasons, only occasionally being the best performer but also rarely being the poorest performer. This trait of lowish but stable yield may be appealing to some growers that wish to manage potential downside risks in pulse production. In addition to their excellent grain yield performance, faba bean had an average N balance of 180 kg N/ha.

The work from this project on pulse crop suitability to local environments and tactical agronomy couples well with GRDC Farming Systems research to gain a full understanding of the role of pulses in regional farming systems.

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Further reading

NSW Pulse Agronomy Development and Extension Project – 2021 summary of field trial results. https://grdc.com.au/resources-and-publications/all-publications/publications/2022/nsw-pulse-agronomy-development-and-extension-project

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

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Keywords

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

GRDC codes

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

Take home message

- Yield loss from Fusarium crown rot (FCR) is a function of the percentage of plants which get infected within a paddock
- The increased frequency of winter cereal crops within a rotation sequence elevated the probability of having much higher levels of FCR infection
- Rotation to non-host break crops such as canola and pulses does not fully eliminate FCR in all paddocks but considerably reduces the probability of having high levels of infection
- A two-year break may be required in paddocks with high FCR inoculum levels
- Rotation history remains a good indicator of likely FCR risk within individual paddocks but there is still some variability in actual levels of infection
- PreDicta®B or cereal stubble testing are useful tools to further refine crop rotation and other integrated disease management decisions to limit losses from FCR
- An integrated approach is required to reduce losses from FCR. There is no ‘magic bullet’.

Background

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

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

What did we do?

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

What did we find?

Seasonal effects

In total, 718 winter cereal stubble samples were processed from the 2022 and 2023 harvest which consisted of 598 bread wheat, 62 barley and 58 durum wheat crops (data not shown). There were 249 cereal crops sampled in 2022 and 469 in 2023 (Figure 1). The levels of FCR infection have risen from 2022 to 2023, with the proportion of paddocks with very high levels (≥51% FCR) rising from 18% to 30%. Over the same period the proportion of paddocks with high levels of infection (26–50% FCR) have also risen from 20% in 2022 up to 30% in 2023 (Figure 1).

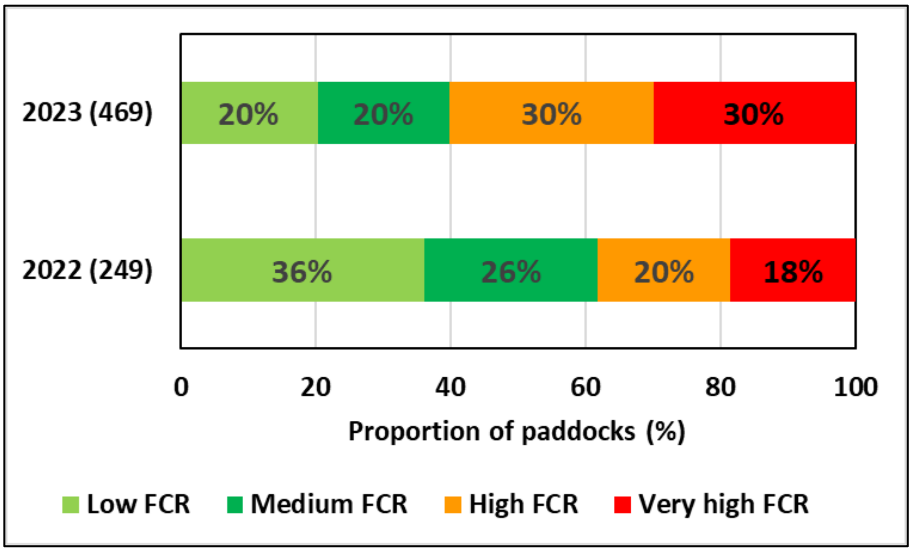

Figure 1. Proportion of winter cereal paddocks with varying levels of Fusarium crown rot (FCR) infection in 2022 and 2023.
Number in brackets (Y-axis) is the number of paddocks sampled in each year.
Low FCR = ≤10%, Medium FCR = 11–25%, High FCR = 26–50%, Very high FCR = ≥51%

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

Sub-region levels of FCR

In total, 14 samples were from South Australia (SA), 14 from Victoria (Vic), 30 from south-west NSW (SWNSW), 43 from south-east NSW (SENSW), 131 from central-west NSW (CWNSW), 57 from central-east NSW (CENSW), 163 from north-west NSW (NWNSW), 173 from north-east NSW (NENSW) and 93 from southern Qld (SQld). FCR infection levels in the last two cereal crops have been highest in SQld, NWNSW and NENSW with the proportion of paddocks with very high levels (≥51% FCR) at 38%, 33% and 32%, respectively (Figure 2). The proportion of paddocks in this highest category of FCR infection level was lower at 23% in SWNSW, 18% in CWNSW and 14% in CENSW. A lower proportion of paddocks with FCR in this highest category were measured at 7% in SA, 5% in SENSW and 0% in Vic. However, all regions had relatively high FCR levels (≥26% FCR in high or very high categories) ranging from 14% of paddocks in SA up to 62% in NENSW (Figure 2).

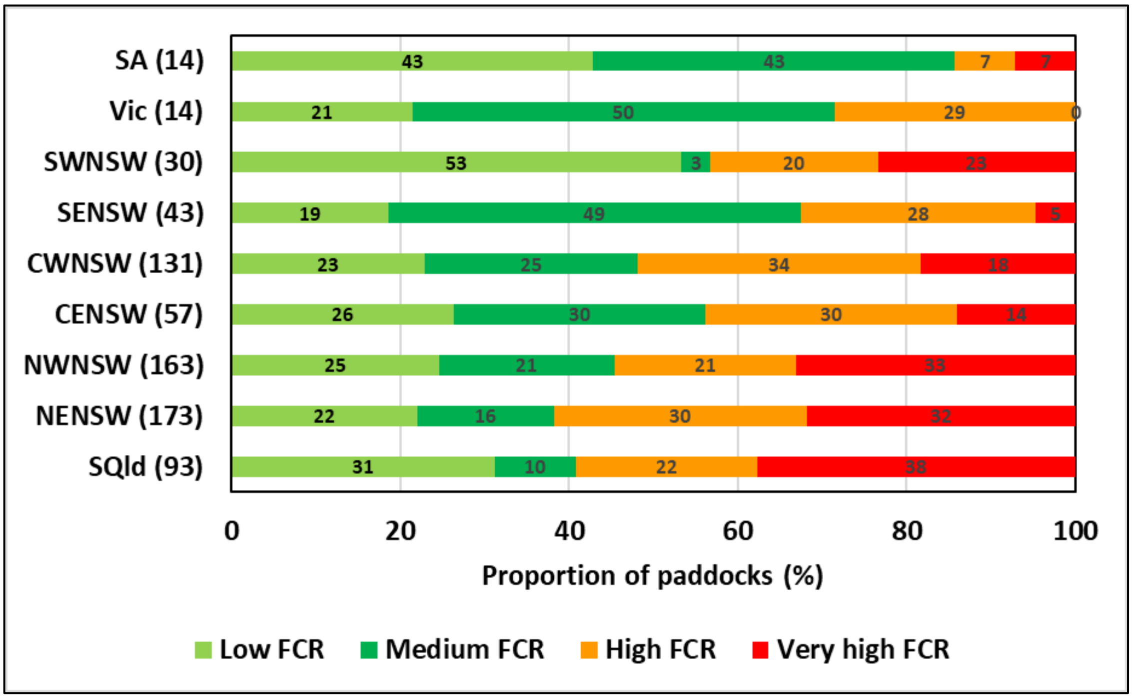

Figure 2. Proportion of winter cereal paddocks in 2022 and 2023 with varying levels of Fusarium crown rot (FCR) infection across sub-regions.
Number in brackets (Y-axis) is the number of paddocks sampled from each sub-region.
Low FCR = ≤10%, Medium FCR = 11–25%, High FCR = 26–50%, Very high FCR = ≥51%

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

Adopt a cereal-cereal-cereal ‘rotation’ and there is a 27% chance of having high (26 to 50%) and 50% chance of having very high (≥51%) FCR infection (Figure 3). If the preceding crop was a summer break crop, then cotton (22% high FCR and 39% very high FCR in 18 paddocks) was potentially slightly better than sorghum (40% high FCR and 34% very high FCR in 35 paddocks). Fallowing the paddock rather than growing a crop did not reduce FCR levels in the subsequent 32 winter cereal crops tested with 35% having high and 41% very high FCR infection. If the preceding crop was a winter pulse or canola break crop then this risk of very high FCR in the 2022 or 2023 cereal crop was reduced further to 14% (average of pulse species) and 12%, respectively (Figure 3). In terms of pulse break crops, faba bean (14% high FCR and 7% very high FCR in 29 paddocks) was more effective than chickpea (22% high FCR and 20% very high FCR in 51 paddocks) and lupin (50% high FCR and 0% very high FCR in 17 paddocks; Figure 3).

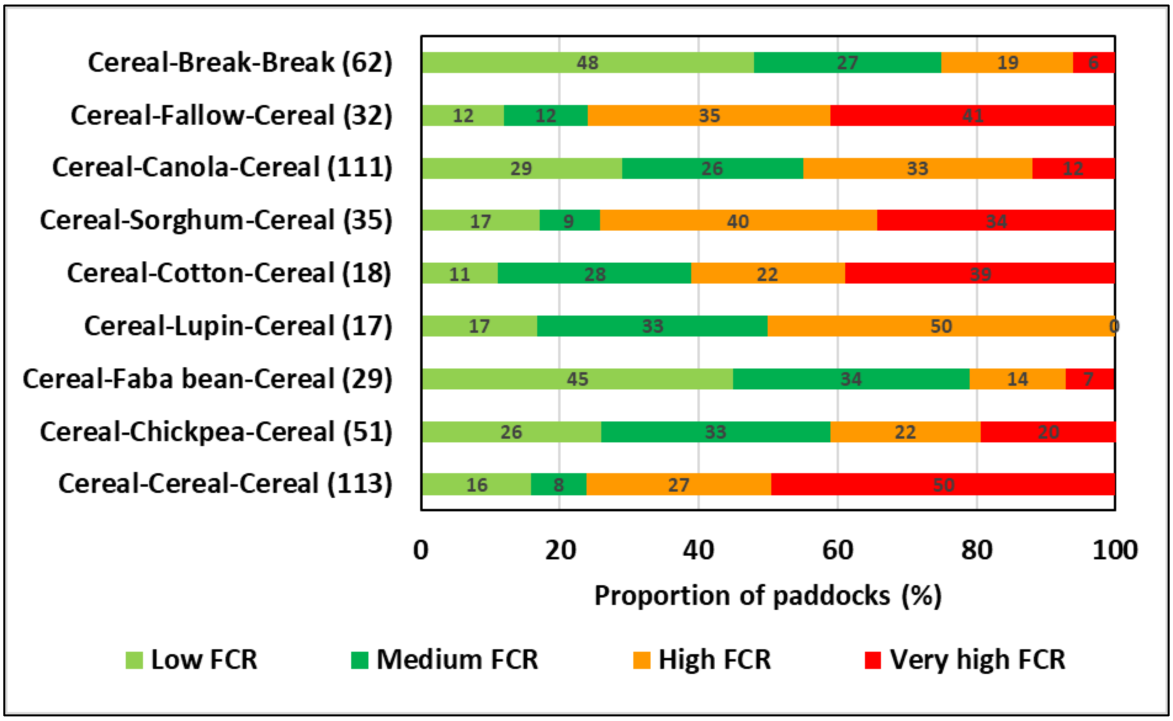

Figure 3. Proportion of winter cereal paddocks in 2022 and 2023 with varying levels of Fusarium crown rot (FCR) infection under different crop rotations.
Number in brackets (Y-axis) is the number of paddocks sampled from each rotation sequence.
Low FCR = ≤10%, Medium FCR = 11–25%, High FCR = 26–50%, Very high FCR = ≥51%

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

What is the effect of one break crop in three years?

Alright, let's try presenting differently and having a 'glass half full' approach. Assume low and medium FCR infection levels result in <25% whiteheads in a season conducive to disease expression, so does not trigger the 'I told you not to sow another cereal crop in that paddock' argument with your agronomist. In a three-year consecutive cereal situation (cereal-cereal-cereal), there is a 24% probability of this happening. This increased to 33% if the paddock was in fallow two years ago and 28% if it was a pulse crop two years ago. However, the likelihood of this outcome reduced to 23% if it was canola and 20% if it was a summer crop two years ago (Figure 4). Some may like these probabilities and continue to roll the dice whilst others may be swayed more by the probabilities around the second wheat crop having high or very high FCR infection levels (Figure 4).

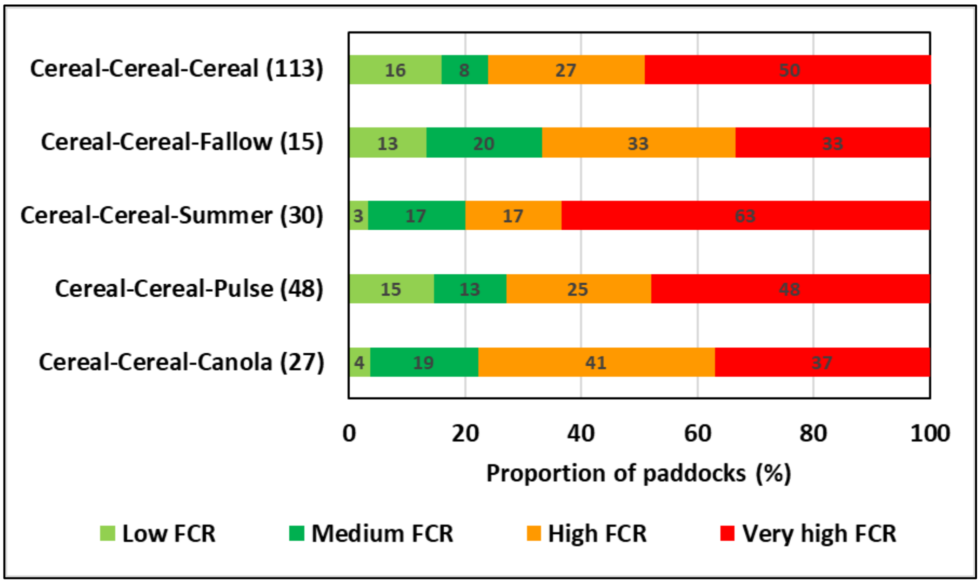

Figure 4. Proportion of winter cereal paddocks in 2022/23 with varying levels of Fusarium crown rot (FCR) infection under different crop rotations.
Number in brackets (Y-axis) is the number of paddocks sampled from each rotation sequence.
Low FCR = ≤10%, Medium FCR = 11–25%, High FCR = 26–50%, Very high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

Conclusions

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

Integrated management of FCR

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

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

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

If medium to high FCR risk, then:

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

If still considering sowing a winter cereal:

- Consider stubble management options in terms of both impacts on FCR inoculum but also fallow soil moisture storage.
  a. ***Cultivation*** accelerates stubble decomposition which can decrease FCR risk (as the causal pathogen is stubble-borne) BUT it takes moisture and time. Cultivation also increases the spread of Fusarium crown rot inoculum across a paddock in the short term and increases exposure of below ground infection points (coleoptile, crown and sub-crown internode) in cereal plants to contact stubble fragments infected with the FCR fungus. Cultivation close to sowing therefore increases the incidence of plants which get infected with FCR. Cultivation can also significantly reduce soil moisture storage during fallow periods.

  b. ***Stubble baling*** removes a proportion of the above ground inoculum from a paddock potentially reducing FCR risk. The pathogen will then be concentrated in the shorter stubble butts and below ground in the previous rows. Hence, baling in combination with inter-row sowing is more likely to reduce FCR risk. Reduced ground cover after baling and removal of cereal straw can reduce fallow efficiency.

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

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

- Select a cereal type and variety that has more tolerance to FCR ***and*** that is best suited to your region (see above results). Yield loss from FCR is generally durum>bread wheat>barley>oats. Recent research has shown that cereal type and varietal resistance has no impact on saprotrophic growth of the FCR fungus after harvest. Hence, cereal crop and variety choice does not have subsequent benefits for FCR risk with a paddock.

- Consider sowing a variety earlier within its recommended sowing window for your area. This will bring the grain filling period forward slightly and can reduce water and heat stress which exacerbates FCR expression and yield loss. However, this needs to be weighed against the risk of frost damage. Research across locations and seasons in NSW has shown that sowing at the start versus the end of a three-week recommended planting window can roughly halve the yield loss from FCR.

- If previous cereal rows are intact – consider inter-row sowing to increase the distance between the new and old plants, as most inoculum is in the stem bases of the previous cereal crop. Physical contact between an infected piece of stubble and the coleoptile, crown or sub-crown internode of the new cereal plants is required to initiate FCR infection. Research across locations and seasons in NSW (30–35 cm row spacings in stubble retained systems) has shown that inter-row sowing can roughly halve the number of wheat plants that become infected with FCR. Precision row placement can also provide greater benefits for FCR management when used in combination with rotation to non-host crops.

- Ensure nutrition is appropriate for the season. Excessive nitrogen will produce bulky crops that hastens moisture stress and makes the expression of FCR more severe. Whitehead expression can also be made more severe by zinc deficiency.

- Consider a seed fungicide treatment to suppress FCR. Fungicide seed treatments are not a stand-alone treatment and must be used as part of an integrated management approach.

References and further resources

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

Petronaitis LT, Forknall C, Simpfendorfer S, Backhouse D (2020) Stubble Olympics: the cereal pathogen 10cm sprint - GRDC. GRDC Update paper

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

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Economic performance of modified farming systems in Central West NSW

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system gross margin, pasture phase, legume frequency

GRDC code

CSA00050, DAQ00192

Take home message

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

Introduction

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

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

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

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

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

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

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

Trangie farming system modifications and descriptions

The key system modifications under examination involve changes to:

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

System gross margin analysis

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

The pasture margins were valued as cattle live weight gain, with 60% pasture utilisation and 10 to 1 as fed feed conversion for stocking rate calculations. Long-term Meat Livestock Australia (MLA) annual prices were used to determine income at $3.10 per kg cwt, a dressing percentage of 50% with variable production costs equal to $75 per beast for animal health. No cattle overhead costs were included, e.g. transport, fencing or water infrastructure. Pasture costs (sowing, fertiliser etc) were applied at standardised prices when required.

Site characteristics

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

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

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

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

System cropping sequence

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

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

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

Results

System performance

Of the five systems containing only a cropping sequence, the *Baseline, Higher nutrient* and *Higher legume* systems recorded the highest yield and gross margin across the seven years of research (Table 3). While there are benefits to selecting systems based on cropping diversity, smaller breeding programs may limit yield potential when directly compared to mainstream crop choices. As the project continues and disease and weed legacies develop, the *Higher diversity* system goal is to have greater sustainability and higher yield potential than low-diversity (monoculture) farming systems.

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

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

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

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

Economic evaluation

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

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

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

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

System performance in wet and dry seasons

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

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

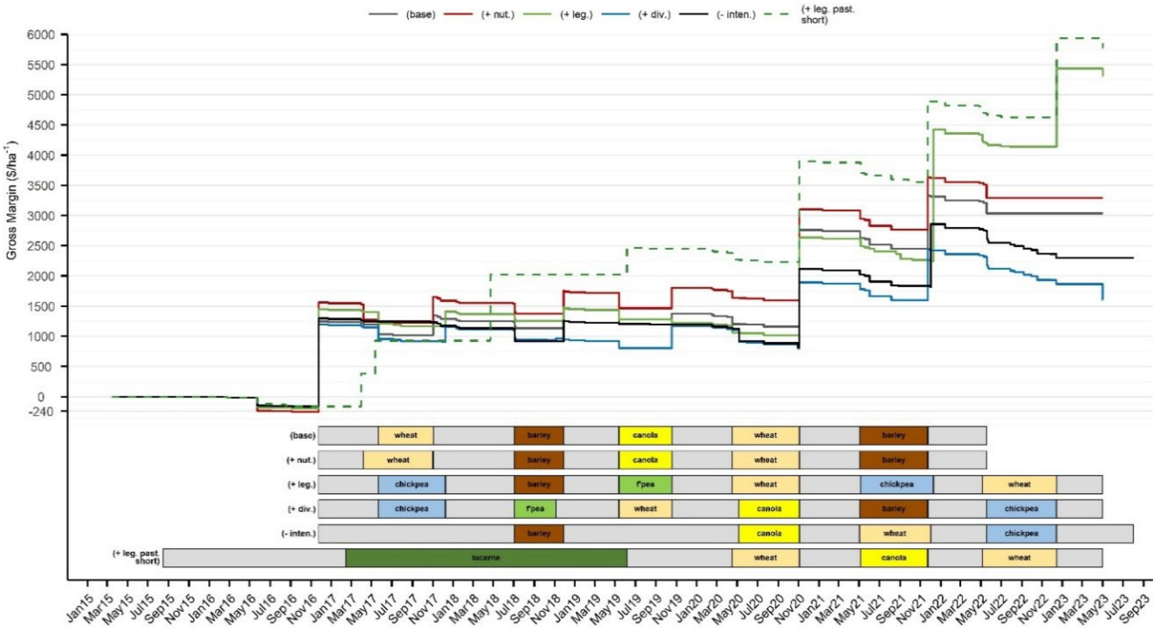

Figure 1. Trangie Red soil site time course system gross margin.
Base = Baseline, + nut = Higher nutrient, + leg = Higher legume, + div = Higher diversity, - inten = Lower intensity and + leg. Past. Short = Ley pasture.

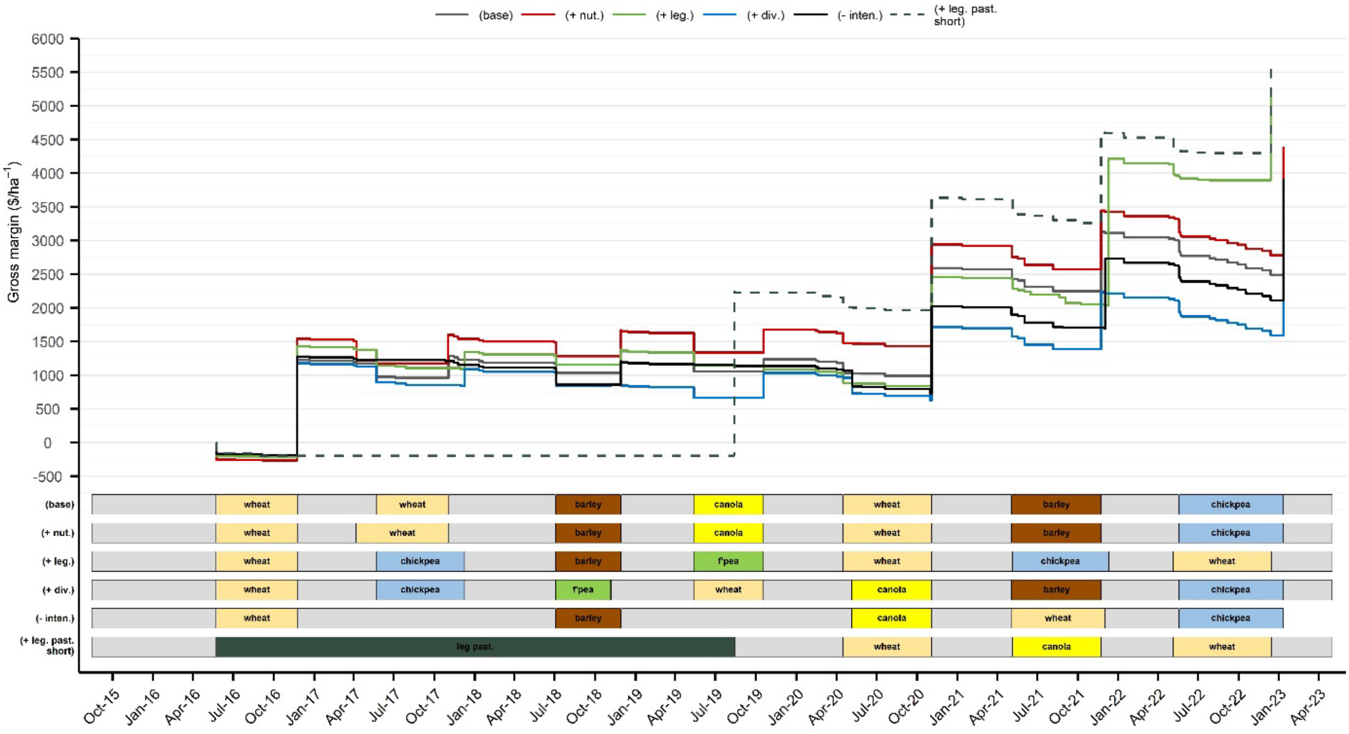

Figure 2. Trangie Grey soil site time course system gross margin.
Base = Baseline, + nut = Higher nutrient, + leg = Higher legume, + div = Higher diversity, - inten = Lower intensity, and + leg. past. short = Ley pasture.

Conclusion

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

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Sclerotinia impacts on chickpea yield and the role of Predicta®B to differentiate between species and inoculum load of sclerotinia

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Sclerotinia stem rot, chickpea, yield-loss, inoculum quantification

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Take home message

- There are three species of *Sclerotinia* present in chickpea crops in the northern cropping region. Sclerotinia populations may increase under susceptible crops including canola and chickpeas
- Of the three species, in two years of chickpea yield loss experiments *Sclerotinia minor* consistently caused higher grain yield loss (34–54%) than *Sclerotinia sclerotiorum* (10–26%) or *Sclerotinia trifoliorum* (7–15%)
- A new Predicta® B soil test can be used to identify which Sclerotinia species are present in paddocks. Predicta B results may allow paddocks to be monitored over time to gauge *Sclerotinia* inoculum concentration responses to changes in crop rotations.

Background

Infection of the stem base by *Sclerotinia* causes stem rot of chickpea, whilst a second infection route occurs from aerially dispersed ascospores infecting chickpea foliage. Analysis of over 100 Sclerotinia disease records for northern NSW chickpea crops showed that 48% were *Sclerotinia minor*, 32% were *Sclerotinia sclerotiorum* and 24% were *Sclerotinia trifoliorum* (Bithell *et al.*, 2023). It was unknown what scale of yield loss Sclerotinia disease of chickpea can cause and which *Sclerotinia* species has the most effect on chickpea production.

In addition, the monitoring of soil pathogen populations with the Predicta® B based method did not previously individually identify the three *Sclerotinia* species and distinguishing between *Sclerotinia sclerotiorum* and *Sclerotinia trifoliorum* is time consuming and requires specialist mycological techniques. Therefore, we sought to develop species specific molecular detection and quantification methods to provide Predicta B based monitoring of *Sclerotinia* species and inoculum concentrations in paddocks.

Methods

Four yield loss experiments were carried out on chickpea, PBA Seamerⓓ, at the Trangie Agricultural Research Centre. Each experiment was a randomised complete block design, using five-row 15 m^2 plots, with 4 replicates. Treatments were: three *Sclerotinia* species, *Sclerotinia* *minor*, *S. sclerotiorum* and *S. trifoliorum* applied as sterilised barley and millet grain infected with the *Sclerotinia* species and included in the chickpea seed packets at sowing; and five inoculum concentrations (0, 0.8, 1.7, 3.4, 6.7 g inoculum/m^2). The two 2022 experiments were not irrigated and there was 398 mm of in-crop rain. The 2023 experiments received 106 mm of in-crop rain. One 2023 experiment was managed with supplementary irrigation using a lateral irrigator and had 18.0, 17.5 and 20.0 mm applied at 55, 76 and 105 days after sowing (DAS), respectively. The second 2023 experiment received salvage irrigation to ensure ongoing survival of the experiment, with applications of 9.0 and 12.5 mm at 76 and 105 DAS, respectively.

Results

Emergence

Emergence counts were made in fixed quadrat areas of each plot. In the wet conditions of the 2022 season emergence of control plots at 21 plants/m^2 was lower than the 35 plants/m^2 target. Combined results for the two 2022 experiments are presented in this report as these experiments did not differ in irrigation management. In 2022 increasing *Sclerotinia* inoculum concentration significantly reduced emergence by 7 to 16 plants/m^2, $P<0.001$, LSD 2.4 plants/m^2, Table 1) although there was no significant effect of *Sclerotinia* species ($P>0.05$, LSD 1.9 plants/m^2).

Table 1. Percentage reduction of a) emergence and b) seedling PBA Seamer population of *Sclerotinia minor*, *S. sclerotiorum,* or *S. trifoliorum* inoculated plots relative to nil inoculum control plots across three experiments: 2022 combined, 2023 supplementary irrigation (SUI) and salvage irrigation (SAI).

a) Emergence reduction (%)

Species/Exp.	2022 combined	2023 SUI	2023 SAI	Average
S. minor	46	61	60	55.7
S. sclerotiorum	46	30	33	36.3
S. trifoliorum	40	23	25	29.3
Average	44	38	39.3	40.4

b) Seedling population reduction (%)

Species/Exp.	2022 combined	2023 SUI	2023 SAI	Average
S. minor	10	7	6	7.7
S. sclerotiorum	6	4	0	3.3
S. trifoliorum	3	0	1	1.3
Average	6.3	3.7	2.3	4.1

In the dry conditions of 2023, the population density of seedlings in control plots met the 35 plants/m^2 target. In both 2023 experiments for species effects across all inoculum concentrations, *S. minor* (19 plants/m^2) had significantly ($P<0.001$, LSD 2.33 plants/m^2) less emerged seedlings than both *S. sclerotiorum* and *S. trifoliorum* (26 and 28 plants/m^2, respectively). There was also a significant species by inoculum concentration interaction ($P<0.01$), whereby for all four *Sclerotinia* inoculum concentrations (0.8 to 6.7 g/m^2) there was a significant reduction in emergence for *S. minor* inoculated plots relative to *S. sclerotiorum* and *S. trifoliorum* emergence at the same inoculum concentrations. For the supplementary irrigation experiment at the highest inoculum concentration *S. sclerotiorum* had less plants that *S. trifoliorum*.

The effects of *Sclerotinia* on the establishment of chickpea are summarised by comparing the average counts of all Sclerotinia-inoculated treatments relative to the nil inoculum control plots for each species to determine the percentage of emergence reduction from Sclerotinia disease (Table 1a). The overall average percentage of emergence reduction across all experiments from *S. minor* was highest (56%), although substantial reductions also occurred for *S. sclerotiorum* (36%) and *S. trifoliorum* (29%).

Plant population and disease symptoms

Repeat counts of seedlings at approximately one month after the emergence counts (9 August in 2022, 17 July in 2023) were made in the same fixed quadrat areas of each plot each year. Symptomatic or dead seedlings were observed in marked quadrat areas at these times for each of the three *Sclerotinia* species; only plants with stem base infection were observed. Seedlings with stem base symptoms were collected and analysed. Samples of mycelium from the stem base of dying plants provided cultures with typical Sclerotinia characteristics. DNA analysis using SARDI's Predicta B test of stem base tissue from dead seedlings confirmed infection by each of the three *Sclerotinia* species.

The effect of Sclerotinia disease on seedling death of chickpea were also summarised on a percentage of seedling loss basis (Table 1b). The overall average percentage of emergence reduction across all experiments from *S. minor* was highest at 8% whereas the overall values for the other two *Sclerotinia* species were less than 5% on average.

Effects on yield

In 2022 there was a significant (*P*=0.006, LSD 412.2 kg/ha) interaction between the *Sclerotinia* species and inoculum concentration where *S. minor* at the second (2011 kg/ha) and third (1366 kg/ha) inoculum concentration treatments had a significantly lower grain yield than *S. trifoliorum* (2424 and 228 kg/ha) only, but at the fourth and highest inoculum concentration treatment *S. minor* (780 kg/ha) had a significantly lower grain yield than both *S. trifoliorum* (1704 kg/ha) and *S. sclerotiorum* (1352 kg/ha).

In 2023 for the supplementary irrigation experiment *S. minor* had significantly ($P<0.001$) lower grain yields (range 173 to 1126 kg/ha) than *S. sclerotiorum* and *S. trifoliorum* at all inoculum concentrations, whereas *S. sclerotiorum* (919 kg/ha) had a lower grain yield than *S. trifoliorum* (1064 kg/ha) only at the highest inoculum concentration. For the salvage irrigation experiment *S. minor* also had significantly ($P = 0.005$) lower grain yields (range 389 to 1073 kg/ha) than *S. sclerotiorum* (range 1080 to 1392 kg/ha) and *S. trifoliorum* (range 1025 to 1433 kg/ha) at all inoculum concentrations, but the grain yields of *S. sclerotiorum* and *S. trifoliorum* did not differ at any common level of inoculum concentration.

The effects of *Sclerotinia* on chickpea grain yield is summarised on a *percentage of grain yield lost to Sclerotinia disease* basis (Table 2). The percentage yield loss to *S. minor* was highest across all three experiments. In two of three experiments *S. sclerotiorum* had a higher percentage loss (18–26%) than *S. trifoliorum* (7–12%), but in one 2023 experiment *S. trifoliorum* had a 5% greater yield loss than *S. sclerotiorum*. Overall the results from two seasons of experiments indicate that *S. minor* can cause proportionally large (>30%) yield loss in both wet and dry seasons, but the largest losses are likely to occur in dry seasons.

Table 2. Percentage grain yield loss of PBA Seamerⓓ in *Sclerotinia minor*, *S. sclerotiorum,* and *S. trifoliorum* inoculated plots across three experiments: 2022 combined, 2023 supplementary irrigation (SUI) and salvage irrigation (SAI). Untreated controls in 2022 yielded 2498 k/ha, untreated controls in 2023 the SUI in yielded 1493 kg/ha and in the SAI yielded 1439 kg/ha.

Species/Exp.	2022 combined	2023 SUI	2023 SAI	Average
S. minor	34	54	48	45.3
S. sclerotiorum	26	18	10	18.0
S. trifoliorum	7	12	15	11.3
Average	22.3	28.0	24.3	24.9

Sclerotinia inoculum measurement

The new Sclerotinia Predicta B species tests successfully detected inoculum of the three Sclerotinia species. Table 3 presents results for one of the 2023 experiments which showed that, at planting, the inoculum concentrations of the three *Sclerotinia* species treatments did not differ significantly. However, following harvest of the 2023 chickpea experiment *S. minor* and had significantly higher values than *S. sclerotiorum* and *S. trifoliorum*.

In addition, the Sclerotinia Predicta B species tests were able to detect inoculum in the roots of chickpeas and other pulse crops from paddocks where isolates of these pathogens had been collected. This new capability may allow paddocks to be monitored over time to gauge Sclerotinia inoculum concentration responses to changes in crop rotations.

Table 3. *Sclerotinia minor, S. sclerotiorum,* or *S. trifoliorum* soil DNA extraction results (kilo copies DNA/g soil) post planting or postharvest in the Trangie 2023 supplementary irrigation experiment of PBA Seamer ⓓ, residual df = 42, *P* value and least significant difference (LSD) values presented.

Species	*S. minor*	*S. sclerotiorum*	*S. trifoliorum*	*P*	LSD
Post planting kDNA copies	1094	648	978	0.32	609.9
Postharvest kDNA copies	2712	1181	177	<0.001	1111.7

References

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