DUBBO
NSW

WEDNESDAY 22 &
THURSDAY 23
FEBRUARY 2023

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

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GRDC 2023 Grains Research Update Welcome

Welcome to the first of our northern GRDC Grains Research Updates for 2023.

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

One benefit of the COVID-19 pandemic is that it forced us to be more flexible with how we deliver this information to our key stakeholders, so while we're pleased to be able to facilitate plenty of face-to-face networking opportunities across this Updates Series, we have also committed to livestreaming and recording some of the events for anyone who is unable to attend in person.

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

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

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

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

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

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

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

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

If you have concerns, questions or feedback please contact our team directly (details on the back of these proceedings) or email northern@grdc.com.au.

Regards,
Gillian Meppem
Senior Regional Manager – North

Day 1 Program: Wednesday 22 February 2023

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

Time	Topic	Speaker(s)
9:00 am	Registration, morning tea & trade displays	
10:00 am	Welcome	***GRDC***
10:30 am	The short & long-term profitability of different farming systems	***Lindsay Bell*** *(CSIRO)*
11:00 am	Pulse & nitrogen strategies in farming systems - legacies, profit & risk	***Kathi Hertel*** *(NSW DPI) &* ***Jon Baird*** *(NSW DPI)*
11:35 am	Nitrogen - strategies for building the pool & reducing losses • Organic vs different fertiliser N sources • Spread urea or drill it in? • How much N do legumes add? • A systems approach to N	***Chris Dowling*** *(Back Paddock Co.)*
12:10 pm	Panel discussion	
12:30 pm	Lunch	
1:20 pm	Concurrent session 1 – *See concurrent sessions for details*	
3:05 pm	Afternoon tea	
3:35 pm	Concurrent session 2 – *See concurrent sessions for details*	
5:20 pm	Close	
7:00 pm	Networking dinner & drinks at the Devil's Hollow Brewery. 10 Commercial Ave, Blueridge Business Park, Dubbo (Supported by FMC & AGT)	

Day 2 Program: Thursday 23 February 2023

7:30–8:20am early risers session. Day sessions 8:30am start, finish by 3:10pm

Time	Topic	Speaker(s)
7:30 am	EARLY RISERS DISCUSSION SESSION. Soil acidity • pH stratification and how soils respond to lime in different environments	***Jason Condon*** *(CSU)* ***& Helen Burns*** *(NSW DPI)*
8:30 am	Concurrent session 3 – *See concurrent sessions for details*	
10:15 am	Morning tea	
10:45 am	Concurrent session 4 – *See concurrent sessions for details*	
12:30 pm	Lunch	
1:30 pm	Understanding the physiology of wheat yield & interactions between temperature, nitrogen & water	***Victor Sadras*** *(SARDI)*
2:00 pm	Optimising control of annual ryegrass • Optimising clethodim activity on resistant annual ryegrass • Updated herbicide resistance data for central NSW • Managing issues with pre-sowing knockdown of glyphosate resistant ryegrass • Are we selecting for later germinating biotypes of ryegrass? What is the impact on the performance of pre-emergent herbicides?	***Chris Preston*** *(Uni of Adelaide)*
2:40 pm	Companion cropping of high value cash crops (wheat & chickpeas) in central NSW - should it be considered?	***Colin McMaster*** *(NSW DPI)*
3:10 pm	Close	

Location & Timing of Concurrent Sessions

	Theatrette	Starlite 1 & 2	Starlite 3
Day 1 – Session 1	Canola	Pulses	Phenology
Day 1 – Session 2	Canola	Mental health & finding system profit	Pulses
Day 2 – Session 3	Weeds	Insects & other pests	Diseases
Day 2 – Session 4	Weeds	Diseases	Insects & other pests

(Agenda subject to change)

Concurrent Sessions DAY 1

Canola (Sessions 1 & 2)

Time session 1	Time session 2	Topic and Speaker(s)
1:20 pm	3:35 pm	Matching canola variety with environment & management • Time of sowing, flowering windows & drivers of phenology *Jeremy Whish (CSIRO)*
1:50 pm	4:05 pm	Predicting canola phenology using environment and genetics *Shannon Dillon (CSIRO)*
2:20 pm	4:35 pm	Effect of heat stress on canola yield & quality - what's the impact of genetics? *Rajneet Uppal (NSW DPI)*
2:50 pm	5:05 pm	Discussion session - planning for canola 2023, issues to consider.

Pulses (Sessions 1 & 2)

Time session 1	Time session 2	Topic and Speaker(s)
1:20 pm	3:35 pm	Pulse agronomy to maximise yield & farming system benefit • 2 years data on locally relevant soils *Maurie Street (GOA)*
1:50 pm	4:05 pm	Pulse manure crops for nitrogen banking *Peter McInerney (3D Ag)*
2:25 pm	4:40 pm	Aphids in faba beans - an update *Zorica Duric (NSW DPI)*
2:45 pm	5:00 pm	Discussion

Phenology (Session 1 only)

Time session 1	Topic and Speaker(s)
1:20 pm	An updated cereal phenology classification - finding the fit for new wheat and barley varieties *Rick Graham (NSW DPI)*
1:50 pm	Long coleoptile wheat - for a longer sowing window and deeper seeding option - how will they change how we grow wheat? *Greg Rebetzke (CSIRO)*
2:20 pm	Dual purpose wheat and canola research in northern New South Wales – varieties, agronomy, TOS and production performance *Rick Graham (NSW DPI)*
2:45 pm	Discussion

Mental health & finding farm profit (Session 2 only)

Time session 2	Topic and Speaker(s)
3:35 pm	Looking after yourself to look after your clients in challenging times *Camilla Kenny (RAMHP)*
4:40 pm	Finding profit in the face of increasing input costs, interest and land value *Simon Fritsch (Agripath)*

Concurrent Sessions DAY 2

Weeds (Sessions 3 & 4)

Time session 3	Time session 4	Topic and Speaker(s)
8:30 am	10:45 am	New pre-emergent herbicides - how are they performing? *Chris Preston (Uni of Adelaide)*
9:00 am	11:15 am	Advances in the biological control of flax leaf fleabane with a novel rust fungus *Ben Gooden (CSIRO)*
9:25 am	11:40 am	Weed mapping using drones for targeted weed spraying *John Single (Single Agriculture)*
9:50 am	12:05 pm	Practicalities of integrating alternate weed management strategies in regional farming systems *Greg Condon (Grassroots Agronomy)*

Insect & other pests (Sessions 3 & 4)

Time session 3	Time session 4	Topic and Speaker(s)
8:30 am	10:45 am	The impact of insecticides on beneficial insects in broadacre crops & how we can support them *Lizzy Lowe (Cesar Australia)*
9:05 am	11:20 am	How do new slug products perform in wet conditions & on other establishment pests? *Michael Nash (What Bugs You)*
9:40 am	11:55 am	Mice management strategies in the lead up to baiting. Optimising bait effectiveness with different levels of background food *Steve Henry (CSIRO)*

Diseases (Sessions 3 & 4)

Time session 3	Time session 4	Topic and Speaker(s)
8:30 am	10:45 am	Rust in 2023 & beyond • Pathotypes, varieties & strategies for durable deployment of new resistance genes *Robert Park (Uni of Syd PBI)*
9:00 am	11:15 am	Cereal diseases - an autopsy of 2022 & doing better in 2023 • Rusts, yellow leaf spot, mildew & blotches • Septoria • Crown-rot • Fungicide resistance *Steven Simpfendorfer (NSW DPI)*
9:40 am	11:55 am	Rust sentinel sites in Central NSW - what did we learn in 2022? *Maurie Street (GOA)*
9:55 am	12:10 pm	Discussion

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General Plenary Day 1

Short and long-term profitability of different farming systems - central west NSW

Lindsay Bell, Jeremy Whish & Heidi Horan, CSIRO

Key words

crop rotation, soil water, economics, costs, legumes, break crops

GRDC code

DAQ2007-004RMX

Take home message

- Farming system decisions – crop choice and soil water required for sowing can have a large influence on system profitability over the short and long-term; differences of >$100/ha/yr occur regularly
- Systems involving alternative crop types can not only help manage biotic threats (e.g. diseases and weeds) but also be profitable compared with conventional systems
- While the last 6 years have presented a diverse range of seasons, this period has influenced the potential rank of the systems in terms of potential profit of the farming system
- Simulated predictions of relative profitability of the systems generally correspond well with those calculated from experimental data over the same period.

Introduction

The northern farming systems project has been examining how different farming system strategies impact on various aspects of the farming system since 2015. Across a diverse range of production environments, we have tested the impacts of changing:

A. the mix of crops grown by increasing the frequency of legumes or diversifying crop choices to provide disease breaks, or

B. the intensity of the cropping system by either increasing it by reducing the soil water threshold to sow more crops or by reducing it and only growing higher profit crops once the soil profile is full; and

C. the supply of nutrients provided to crops.

Despite now collecting over 6 years of data on each of these different farming strategies, the full range of climatic conditions that are experienced across the region have not been captured. In particular, most sites have experienced extremely dry periods over the past 6 years, which is likely to bias or favour some particular farming systems. Simulation modelling can be useful to help explore how the different farming strategies might perform over the longer-term and under a range of climatic conditions. In this paper we compare APSIM predictions of system profitability over the long term with those for the period 2015-2020. This paper reports specifically on results from the two sites in central west New South Wales, located at Trangie, one on red soil and one on grey.

System simulations and estimates of profitability

The different farming systems were simulated from 1958 to 2020 using APSIM. Soils used in simulations were those characterised at each location, and long-term climate data was sourced from the closest meteorological station. For each farming system at each location, the simulation was provided a list of crops (prioritised), their sowing window, and minimum soil water required to allow them to be sown. An example of the rules dictating crop choices at the Pampas site are outlined in Table 1; other sites vary in the crop choices, their sowing dates and soil water thresholds but the general rules dictating crop choice were constant.

Table 1. Rules associated with crop choice, crops available and their plant-available water threshold required to be sown in the Baseline and 3 modified farming systems at Trangie red and grey soil sites.

System	**Crop choice rules**	**Crops**	**Soil water threshold (mm PAW)**	
			Red soil (PAWC = 90 mm)	**Grey soil** (PAWC = 150 mm)
Baseline	No more than 3 winter cereals or sorghum in a row ≥2 yrs between chickpea	Wheat Chickpea Barley Canola Faba bean Field pea	35 35 35 60 60 35	50 50 50 75 75 50
High legume frequency	*As above +* Legume every second crop	*As above +* Lupin	40	50
Higher crop diversity	*As in Baseline +* ≥1 yr break after any crop ≥50% crops nematode resistant	*As above +* Durum wheat Sorghum Mungbean	80 80 80	130 130 130
Lower crop intensity	*As in baseline*	Wheat Chickpea Canola	80 80 80	130 130 130

Revenue, costs and gross margin for each crop were calculated using predicted grain yields and estimates of crop protection, non-N fertilisers and operational costs for each crop (see Table 2). Fertiliser inputs were simulated dynamically based on a crop budget targeting a median yield (N fertiliser was costed at $1.30/kg N), and fallow herbicide applications ($15/ha/spray) were also predicted using the model based on the number of germination events that occurred.

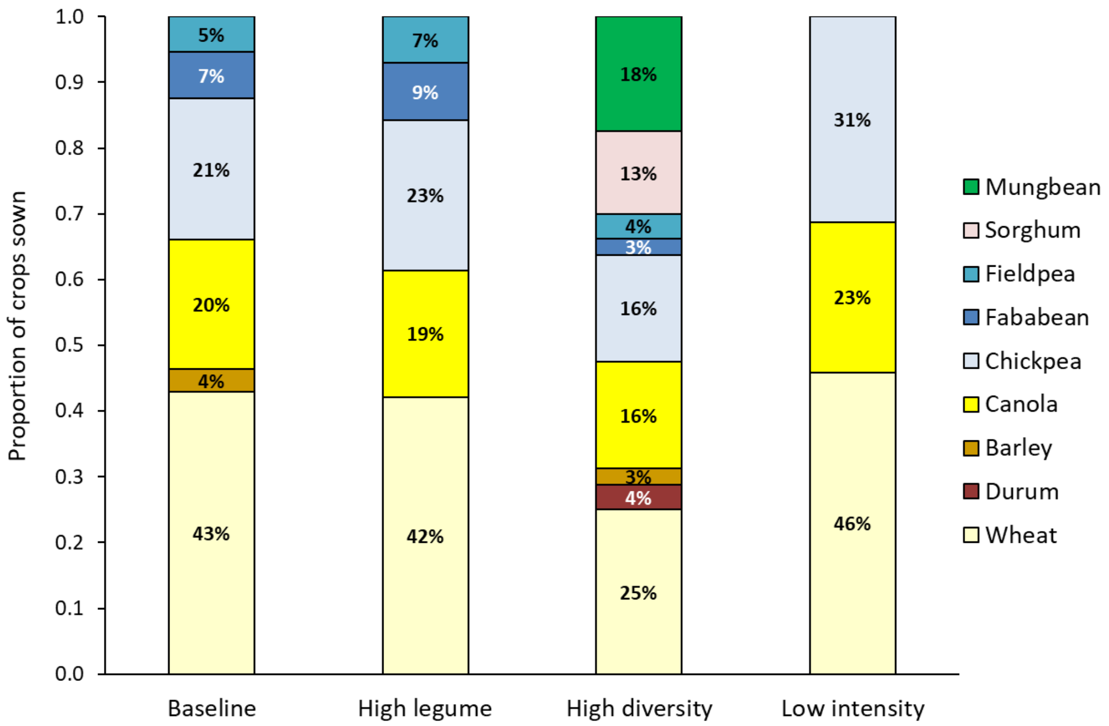
Table 2. Assumed prices (10-year average, farm gate after grading/bagging/drying) and variable costs for inputs and operations (e.g. seed, pesticides, starter fertilisers, sowing, spraying) and harvest costs (for viable yields only) for each crop simulated.

Crop	Price ($/t product)	Variable crop Costs ($/ha)	Harvest costs ($/ha)
Wheat	269	175	40
Durum	335	175	40
Barley	218	175	40
Chickpea	504	284	45
Sorghum	221	221	55
Mungbean	667	276	55
Faba bean	382	341	40
Field pea	382	341	40
Canola	503	351	70

Because of the dynamic nature and range of different crops across these simulations, we generated only a single crop sequence over the simulated period. To allow analysis of the climate-induced variability, we aggregated the system gross margins over sequential 5-year; for example, from 1958-1962, 1959-1963 and so on. Hence, we were able to compare what the simulations predicted would occur during the experimental period of 2016-2020 compared to 59 other 5-year periods, thus allowing us to examine how this period compared with longer-term conditions. We were also able to compare the relative performance of the different simulated systems over this period compared to their relative performance from our experimental data. Differences in how costs were calculated, with simulations assuming a set crop input cost, meant there was always a difference in the actual gross margins estimated from the model compared to the actual costs attributed in the experiments.

Crop sequences & frequencies amongst simulated systems

The simulation rules imposed (Table 1) resulted in a *Baseline* system consisting of about 50% winter cereals, 20% canola, 20% chickpea and 10% other grain legumes. The changes in the system rules/strategies saw some clear changes in the frequency and types of crops grown in the farming system. The *Higher legume* system resulted in some additional fababean and field pea crops, which mainly replaced barley in the crop sequence (Figure 1). The *Higher crop diversity* system, as summer crops were introduced, responded with around 70% winter crop and 30% summer crop. The summer crops were a combination of either sorghum or mungbean, which saw the cropping intensity at the site increase from 0.87 crops per year to around 1.2 crops per year. Durum wheat also replaced wheat in the system, but the ratios of the other winter crops remained fairly consistent. The *Lower intensity* system (i.e., a higher soil water threshold to sow crops) saw the crop frequency drop by only 0.15 crops per year (0.87 to 0.71 crops per year) – less than might be expected. The ratio of crops remained fairly stable except, chickpea was the only legume option allowed.



Crops/yr	**0.87**	**0.87**	**1.20**	**0.71**
% winter	100	100	70	100
% cereal	46	42	61	46
% legume	34	39	23	31
% oilseeds	20	19	16	23

Figure 1. Cropping intensity (crops/yr) and the proportion of different crops simulated under different farming system strategies at Trangie over the long-term.

Long-term predictions of system profitability

Figure 2 shows the range in average annual gross margin predicted over all the 5-year periods between 1958 and 2020 amongst the 4 different farming systems. These are arranged from the lowest to the highest to show the distribution of these predictions as a result of climate variability (note prices are held constant at 10-year average values).

The *Baseline* system (black circles) was predicted to generate the highest average gross margin on both soil types (Figure 2). On the red soil the *Higher legume* (white triangles) and *Higher diversity* (black triangles) systems generated very similar long-term average gross margins (within $20/ha/yr), and were more favourable under higher profitability periods, but on the other hand were less profitable during lower profit periods. In particular, the *High diversity* system, which also involved a higher crop intensity was much riskier, with much lower gross margin returns in the worst 20% of 5-year periods. On the grey soil, the *Higher legume* and *Higher diversity* systems were less profitable with gross margins frequently behind the *Baseline* system, though again they could be more profitable in favourable periods. On both soil types, the *Low intensity* system (white circles) performs worse over the long-term than the other systems.

The predicted profit achieved in the experimental period (2016-2020) relative to the wider range of seasons is shown with the horizontal lines in Figure 2. On the grey soil, all systems were found to generate gross margins around the 10-20th percentile of all 5-year periods. However, on the red soil there was a greater disparity in the rank of the systems; the *Lower intensity* system ranking around the 50th percentile of all 5-year periods, the *Baseline* and *Higher legume* systems ranked around the 33rd and 25th percentile, respectively. Meanwhile the *Higher diversity* system over this period was predicted to be in the lowest 15% of all 5-year periods.

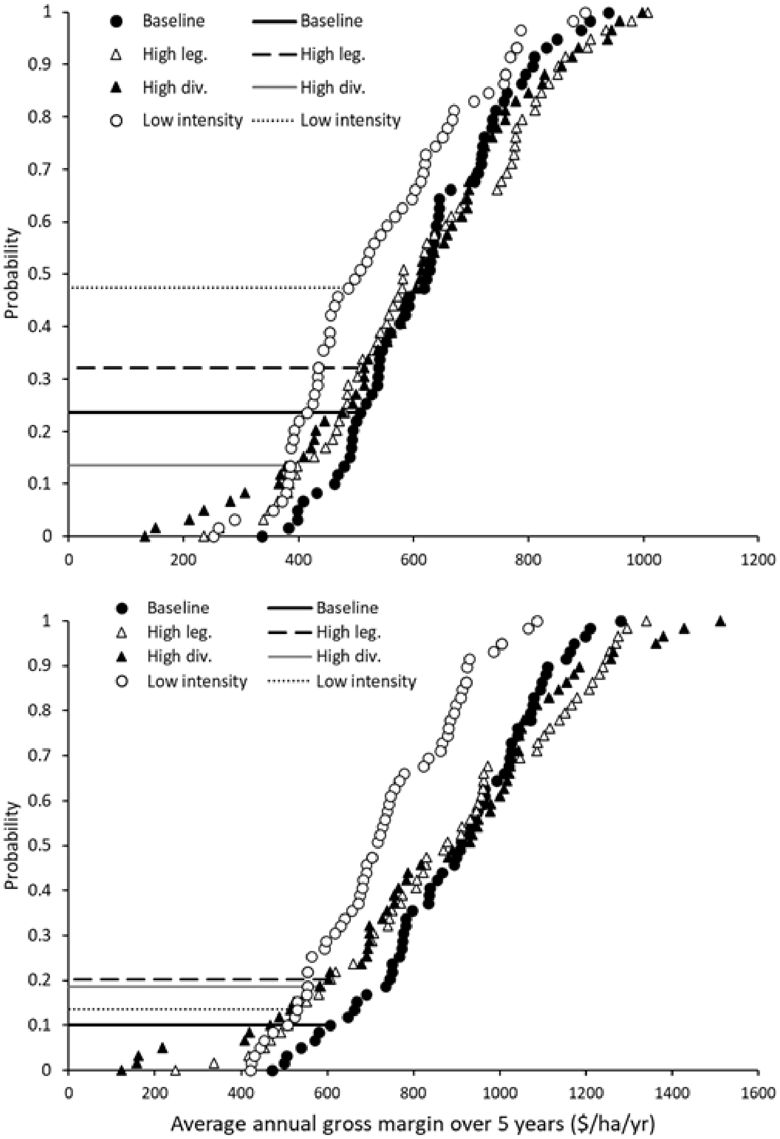


Figure 2. Distribution of simulated gross margins (average of 5-years) over 60 years period (1958-2020) of different farming systems strategies at Trangie, NSW on a red soil (top) and grey soil (bottom). Each dot indicates the outcome of a 5-year period and the lines indicate the predicted GM for the 2016-20 period.

Short-term (experimental period) relative to the long-term

When the relative returns achieved from the various systems over the same 5-year period are compared with the *Baseline* system, this shows that the modified farming systems can often produce higher average returns during certain periods (Figure 3). *Higher diversity* systems produced higher returns 50% of the time on the red soil and 40% of the time on the grey soil; *Higher legume* systems produced higher returns 50% of the time on both soils, and the *Lower intensity* systems produced higher returns about 30% of the time on the red soil and 10% of the time on a grey soil.

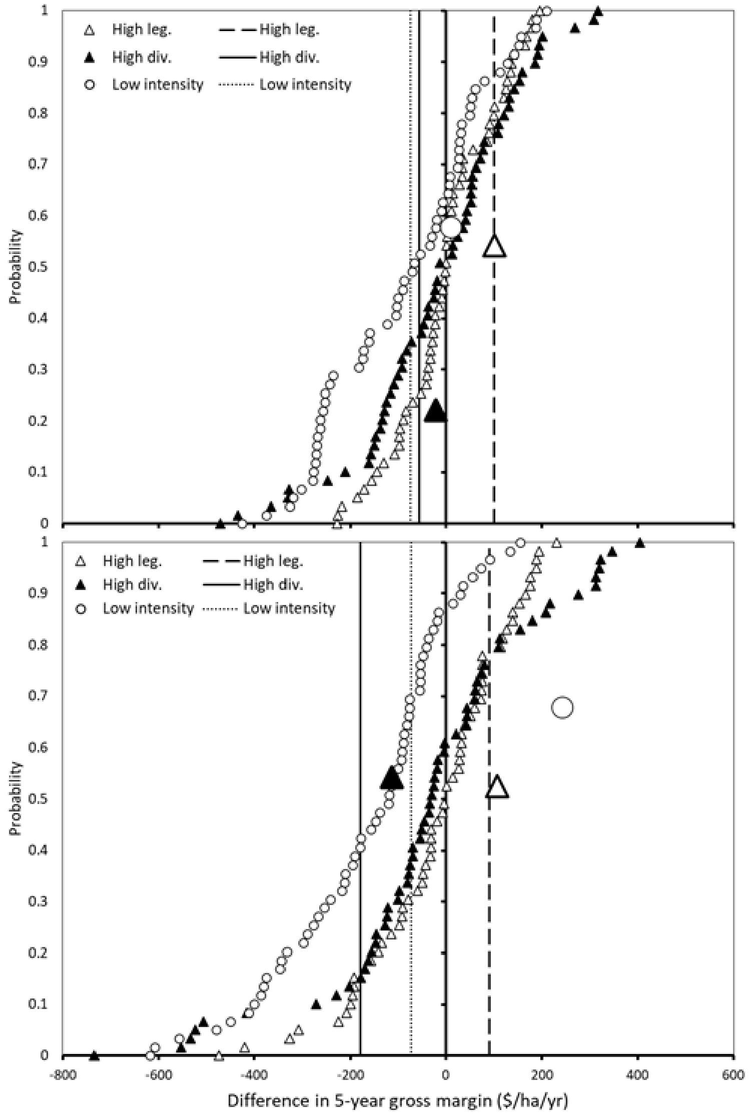


Figure 3. Difference in simulated 5-year gross margin between the Baseline and 3 modified farming systems at Trangie on a red soil (top) and grey soil (bottom) between 1957 and 2020. Small symbols show the difference in annual returns over the distribution of the 59 different 5-year periods, the large symbols indicate the difference for a simulation of just the period of 2016-2020, and the vertical lines indicate the differences measured in our experiments over this same period. Negative values indicate the alternative system has produced a lower GM than the *Baseline*, and vice versa.

When just comparing the modelled differences between the *Baseline* and the various other systems over the experimental period (indicated by the larger symbols in Figure 3), the *Higher legume* system was predicted to be $90-100/ha/yr ahead of the *Baseline.* This also corresponded very closely with the differences over the same period from our experimental data (indicated by the vertical lines). The *Higher diversity* system was predicted to generate lower gross margins than the *Baseline* system, and these differences were also reflected in the experimental data. Hence, this provides a good indication of where the recent experimental period is likely to sit amongst the range of possible predictions of profit differences amongst these farming systems.

However, the simulations predicted that the *Lower intensity* systems would have performed relatively better than the *Baseline* over the 2016-2020 period, particularly on the grey soil. The gross margins generated experimentally in our *Low intensity* systems were significantly lower than was predicted over this period. Experimentally, unprofitable barley crops were grown in 2018, which were not sown in our simulations as the soil water threshold was not satisfied, which goes someway to explaining this disparity.

Conclusions

Farming strategies or systems need to consider resilience and relative performance across the full range of likely climate variability. While our experimental work has captured a range of seasons, the modelling here adds further insight into how the various farming system strategies might perform over the long-term. The modelling predictions of the relative differences over the past 6 years correspond well with our experimental data over the same period. While some of the alternative systems have not proved to be advantageous over this experimental period, the analysis suggests there is potential to make use of a greater diversity of crops which could add significant upside under more favourable growing seasons. Further examination of the influence of price variability and risk on these findings is required to understand how robust different strategies are, and the key factors that might influence this.

Acknowledgements

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

We acknowledge the various collaborators involved with collecting the experimental data and farmer collaborators for hosting the farming systems experiments across the region.

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Modifying farming systems in northern grains region – legacies, profit and risk of pulse and nitrogen strategies

Jon Baird[1], Kathi Hertel[1], Lindsay Bell[2], Jayne Gentry[3], Andrew Erbacher[3], Darren Aisthorpe[3], David Lawrence[3], Branko Duric[1] & David Lester[3]

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Key words

farming systems, nitrogen, pulses, economics, fertiliser

GRDC code

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Take home message

- Applying N fertiliser rates targeting high yields boosted long-term system productivity at three of the research sites compared to fertilising for a median crop yield
- 'Banking' soil N via a robust fertiliser N strategy can maintain higher soil N levels and reduce reliance on tactical fertiliser applications
- Over the long term, the profitability of systems growing 50% legumes can be equal or higher than current district *Baseline* systems
- Farming systems containing a high frequency of legume crops do not necessarily reduce fertiliser N use
- While legumes can provide inputs of N via fixation from the atmosphere, they can extract soil mineral N if it is available, similar to non-legume crops
- High yielding legumes will export N at a far higher rate than similar yielding cereals, often negating any N they have fixed
- Long term, soil mineral N reserves and system N balances are declining regardless of different farming system strategies, except where high N replacement has been applied
- Crops are more efficient at sourcing N from soil sources than applied fertiliser, so soil monitoring is essential to determine fertility levels to match crop requirements, and adjust for possible losses and trends over time.

Introduction

Long-term sustainability and profitability of farming systems need to evolve to manage the challenges of climate variability, increasing soil-borne pathogens, herbicide resistance and problem weeds, and declining soil fertility and increasing reliance on costly fertiliser inputs. A major challenge for our farming systems is to match crop nutrient supply and demand under variable growing conditions and maintain our soil's underlying fertility in the long-term. The northern farming systems project is looking at the long-term implications of different fertiliser application strategies and using more legumes in the farming system.

Nationally, legume (pulse) crops represent just 10% of the total cropping area (Pulse Australia 2023), with winter species dominating the pulse crop area in the northern cropping region. Legume crops both fix nitrogen (N) (via rhizobia symbiosis) and remove N from the system (via plant residues and grain). This creates a different dynamic to the overall farming system compared to that of non-legume crops. Given that N is a major variable cost in most farming systems with heavy reliance on off-farm sources (primarily urea), the effect of legumes on subsequent crops' N requirements, performance, and soil N balance can be significant. Understanding these impacts together with the legume crop profitability and risk are key to improving the future sustainability and profitability of farming systems.

The northern farming systems research project commenced in 2015 with long-term experiments at seven locations: a core experimental site comparing 38 farming systems at Pampas near Toowoomba, and a further six regional sites that included 6−9 locally relevant farming systems at Emerald, Billa Billa and Mungindi in Queensland and Narrabri, Spring Ridge and Trangie covering red and grey soils in NSW.

This paper will focus on three core farming systems treatments implemented across the experimental sites: the local regional '*Baseline*' or current best management system, and systems with modified strategies which increase N fertiliser rates and legume crop frequency across the crop system.

1. *Baseline* – derived to represent local best management practice where the selection of crops and their management were designed in partnership with local grower panels and analysed as the control treatment. Crops were planted at or above soil moisture of 50% plant available water (PAW) and fertiliser N and phosphorus (P) rates were applied to meet the demand of a 50th percentile crop yield.
2. *Higher nutrient system* — contains identical crop sequence to *Baseline* but with higher N and P fertiliser rates applied to meet the demands of a 90th percentile crop yield.
3. *Higher legume* system where at least 50% of planted crops are legumes, crops were planted at or above 50% PAW. Legume crops did not have N fertiliser applied and P fertiliser rates were calculated to meet export rates, and fertiliser N and P rates were applied to meet the demand of a 50th percentile crop yield for non-leguminous crop.

Over the seven years of the project (2015 to 2021), seasonal conditions at regional experiment sites have varied, including extremes of drought and local flooding, as well as 'average' and 'favourable' seasons.

Results

Grain productivity

High nutrient strategy

Applying the higher fertiliser rates strategy across seasons maintained higher residual N levels in the soil. The legacy of this higher soil fertility within the system provided a strong foundation for future crops to optimise production especially in average or above average rainfall seasons. At three of the seven regional sites, applying additional fertiliser in the *Higher nutrient* system increased grain productivity compared to the *Baseline* system. At these sites grain production was increased on average by half a tonne per hectare over the seven seasons (Figure 1). At other sites there was no positive response to the additional N applied, because the drier than average seasonal conditions meant that crop demand did not exceed supply provided in the *Baseline*, and hence the additional N was not required.

At one site (Trangie grey soil), grain yield was lower in the *Higher nutrient* system compared to the *Baseline*. In this example a lower yield was obtained in one crop year and in other crop years seasonal conditions were not favourable to take advantage of the extra soil N.

High legume frequency

Recently there has been increased plantings of grain legumes in cropping systems, driven in part by the profitable prices for pulses but also goals to reduce N fertiliser use and potentially improve soil health/fertility. The addition of legumes to the farming system had little to no influence on productivity over the seven years at most sites. However, we identified variability and a higher risk with the adoption of legumes as two sites – Pampas and Billa Billa which had lower system grain yield than the *Baseline* system. Grain legumes often produce lower yields than cereals but many have higher prices per tonne and hence, the economic outcome may look quite different to non-leguminous crops (Figure 2).

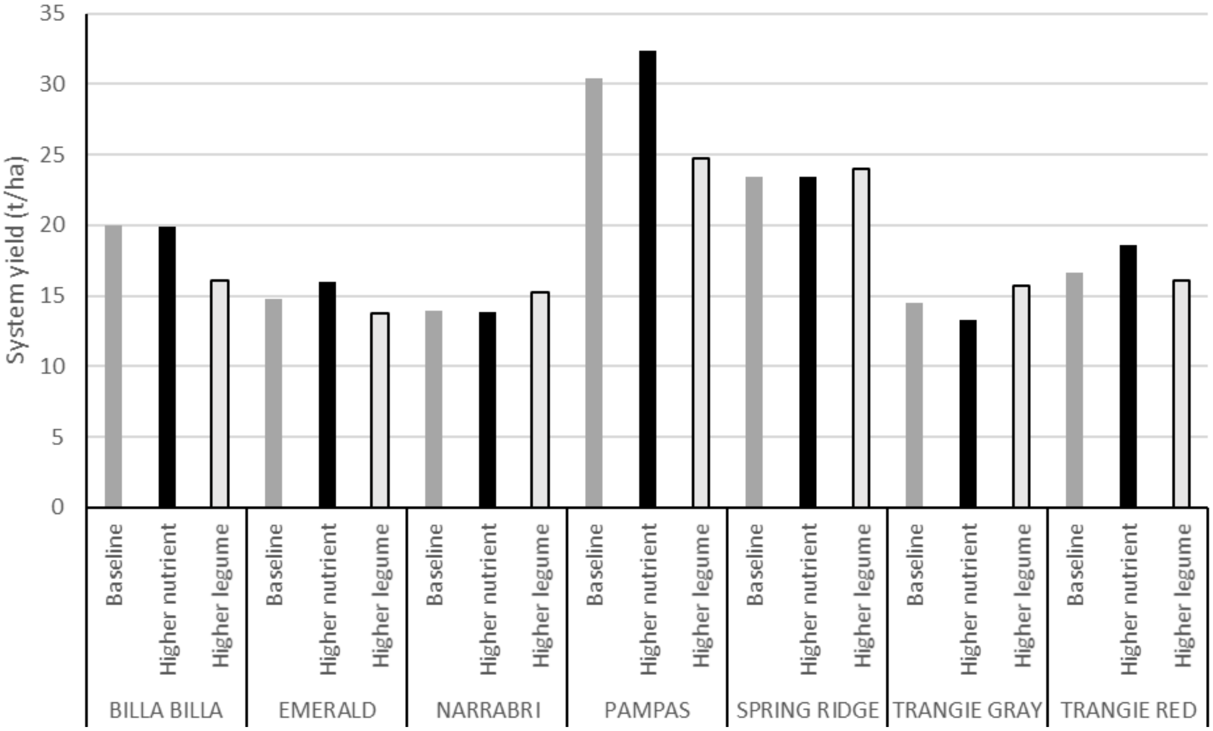

Figure 1. Grain production (t/ha) in the *Baseline*, *Higher nutrient*, and *Higher legume* systems over 7 years (2015−2021) at long-term farming systems experiments.

System Economics - profit/loss

Economic analysis of the farming systems was conducted using 10-year average grain prices (2011-2020) and general input/machinery/processing costs. System gross margins from the last six seasons show that while current growers' practices are performing well in their regions, several sites have improved returns by incorporating more legumes or applying more fertiliser for higher yield production (Figure 2).

High legume frequency

Over the 7 years, the *Higher legume* systems produced higher or equal returns at 5 of the 7 sites compared to the *Baseline*, while there was a small penalty ($500/ha) at 2 sites. For example, at the Spring Ridge and the Trangie red soil site, systems gross margins were >$1000/ha in the *Higher legume* system compared to the *Baseline* system (Figure 2). The higher gross margins are related to the higher grain value of legumes over this period. However, recently experience shows these high values can be variable; therefore, this advantage can disappear, reducing the profitability of growing legume crops. Growers should be aware of current grain prices and understand the often-higher input costs associated with high-yielding legumes.

High nutrient strategy

At only 3 of the 7 sites was there a benefit of growing higher grain yield with additional fertiliser application. Higher fertiliser input generated a greater cost to the *Higher nutrient* system, reducing long-term system profitability at the other sites where there was no grain yield response to the additional N applied. This analysis does not consider the value of N 'banked' in the soil. However, even with the added value, there were deficits to the gross margin compared to the *Baseline* system (Bell et al. 2022). Nonetheless, the cost of this high nutrient strategy is relatively small, equating to around $20/ha/yr. compared to the upside that can be achieved when seasonal conditions are positive.

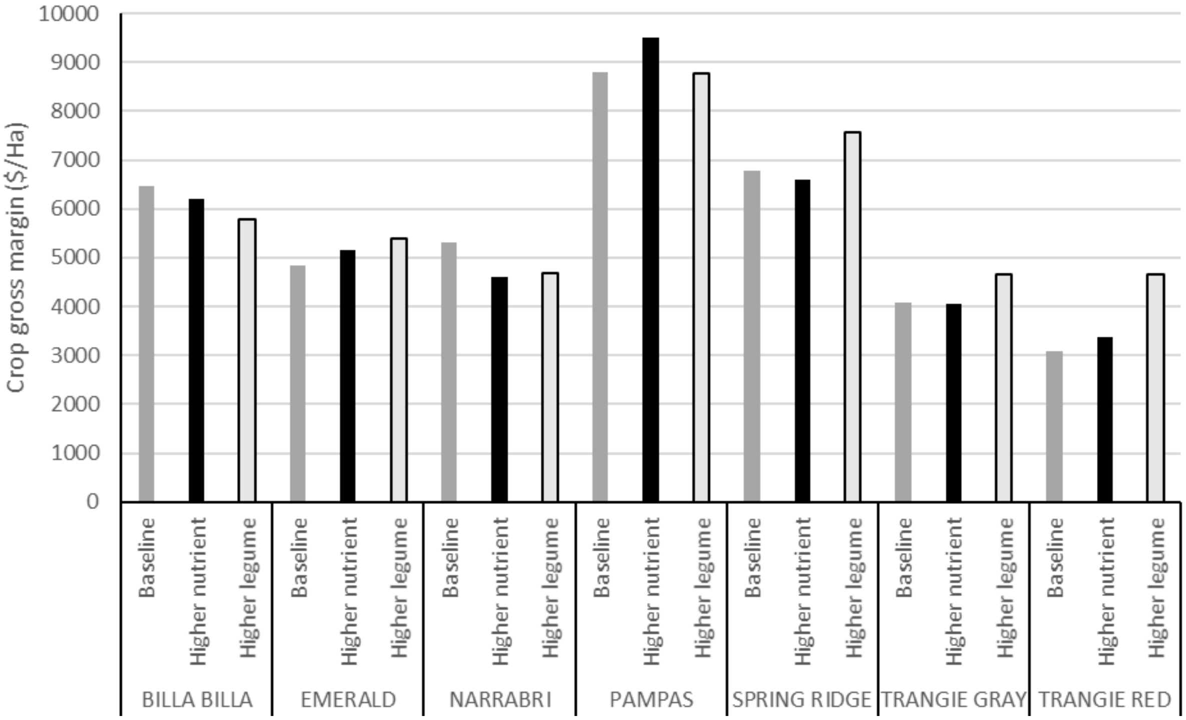

Figure 2. Cumulative crop gross margins over 7 years (excl. fallow costs) of the modified farming systems with additional fertiliser input and legume crops (2015−2021).

Legacy effects of legumes on crop yields and nitrogen use of following cereals

A closer investigation into the legacy of legumes in a farming system was conducted by examining particular crops and short-term sequences within the various systems across our experiments. Table 1 shows the grain yield and crop N use of subsequent crops grown after either a winter legume or non-legume crop. In addition, it highlights comparisons where the same crops were grown after a legume or cereal with similar moisture and fertiliser application rules.

Of the 7 comparisons, only 2 occasions saw an observable yield benefit following legumes compared to a non-legume crop. On all but one occasion the crop following the legumes also received a similar N application to meet the N budget predicted for that crop in that season. Typically crops grown after a legume crop had higher N use (i.e., the change in mineral N between sowing and harvesting plus applied fertiliser N). This was due to sourcing more N from the soil mineral pool and N derived from the legume's N fixation activity rather than applying higher fertiliser N rates.

Table 1. Legume crop influence on the following crop yield, N applied and used (applied fertiliser plus the change in soil mineral N) across various comparisons in farming systems experiments.

Site	Season	Crop	Previous crop	Grain yield (t/ha)	Applied N fertiliser (kg/ha)	Crop N use (kg N/ha)
Narrabri	2017	Wheat	Chickpea	2.4	76	129
			Fababean	2.2	76	112
			Canola	2.0	76	79
Spring Ridge	2017	Wheat	Chickpea	3.2	52	152
			Fababean	3.2	52	123
	2020	Wheat	Chickpea	4.8	27	139
			Canola	4.9	96	107
Trangie – grey soil	2018	Barley	Wheat	0.4	9	9
			Chickpea	0.1	9	9
	2020	Wheat	Canola	2.0	9	157
			Fababean	4.3	11	269
Emerald	2017	Wheat	Chickpea	1.8	26	93
			Wheat	1.6	26	43
	2020	Wheat	Chickpea	1.8	-	45
			Wheat	2.2	-	9

Farming system influence on fertiliser N input requirements

Current fertiliser prices are at record levels, so improving fertiliser recovery and efficiency is crucial to maximising growers' return on investment. Here we examine the degree that different farming systems have altered the N inputs required and the balance of N applied and exported over the 7 experimental years.

One aspect of the *Higher legume* system was to investigate whether additional legumes will maintain or improve soil fertility while at the same time reducing fertiliser input over the long term. At most sites, there was little if any change in the total fertiliser N required in the *Higher legume* system compared to the *Baseline* (Table 2). On average across all sites the *Higher legume* systems required 45 kg N/ha less over the 6 years than the *Baseline* (i.e. only 8kg N/ha/yr. less). This was because the legumes exported much more N from the system (Table 2), and this meant that there was little additional N cycled to offset subsequent N applications in non-legume crops. Spring Ridge is one site where the application of fertiliser input (N fertiliser) was significantly reduced under the *Higher legume* system compared to the *Baseline* system. This showed a potential saving in fertiliser use by growing more legumes in this region. However, soil N has also been extensively used during the same period (Figure 3), and therefore, growers need to monitor their soil nutrients to ensure native soil nitrogen use is not detrimental to long-term soil fertility.

A common theme across most farming system sites is that applying the higher fertiliser strategy clearly required additional N inputs (ranging from an additional 6 to 260 kg N/ha over the 6 years). However, the surplus N unused was retained in the soil and so maintained higher mineral N levels in the soil than the *Baseline* system – much of the additional N that was applied was retained and was available to offset N applications in subsequent crops (Figure 3). Maintaining a higher system N status via N banking is a potential management practice in northern farming systems to ensure greater yields can be achieved in high decile seasons. Lester et al (2021) found that fertiliser recovery can be improved when nitrogen is applied early in the fallow, and there is improved logistics for growers when they fertilise during lower labour demand period rather than at sowing or during the growing season. One implication growers need to be aware of when they apply fertiliser early in a fallow period, is the potential losses that may occur during the fallow, before the crop can utilise the N. For example, a severe weather event at Spring Ridge caused high mineral N loss in late 2019 when *Baseline* and *Higher nutrient* systems were in a fallow period and losses ranged between 203 and 152 kg N/ha (Figure 3).

Table 2. Fertiliser N applied and grain N exported from *Baseline*, *High nutrient* and *High legume* systems across 6 farming systems sites over 7 experimental years (2015-2021)

Location	**Fertiliser N applied (kg N/ha)**			**Exported N (kg N/ha)**		
	Baseline	Higher nutrient	Higher legume	Baseline	Higher nutrient	Higher legume
Billa Billa	18	77	23	417	451	430
Emerald	49	55	11	330	347	335
Narrabri	206	447	208	345	350	468
Pampas	155	337	80	498	538	556
Spring Ridge	307	446	146	482	496	450
Trangie Grey	63	169	89	235	287	322
Trangie Red	137	395	105	263	344	300

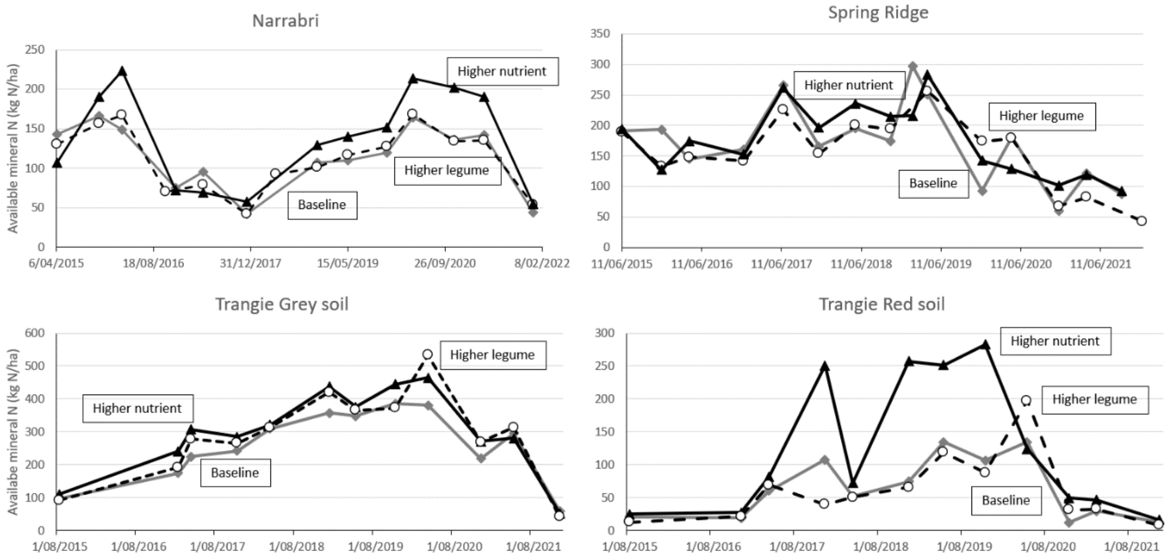

Figure 3. Mineral nitrogen long-term dynamics at Farming system sites in Northern NSW. The grey line and diamond marker are *Baseline* system, Black line and triangle is the *Higher nutrient* system, and the dashed line with open circle is the *Higher legume* system. Note y axis scale varies at each site.

Source of crop N use

For the three modified cropping systems across the seven experimental sites – *Baseline* (triangle), *Higher nutrient* (square) and *Higher legume* (circle), Figure 4 illustrates the source of N in terms of the percentage of the crop N used. The source of N is calculated over the experimental period (2015-2021) for the proportion that was derived from either the starting soil mineral pool (i.e., the change in soil mineral N between the start and end of our sequence), applied fertiliser or was mineralised from the soil (i.e., N accumulated during a fallow or the balance of crop uptake not from fertiliser or soil mineral pools).

The study highlights the importance of cropping systems' efficiency in utilising N from stored organic sources. Most systems and experimental sites sourced at least 40% N from mineralised organic or stored N (spared N) rather than drawing down from starting N levels. This data supports findings from Daniel et al. (2019) where the efficiency of N grain recovery from soil N sources was ≈4 times greater than that of applied fertiliser N.

As stated before, incorporating more legumes resulted in crops utilising more N from mineralised N, attributable to the faster breakdown of legume residues that can be used in subsequent crops. This meant there is generally a lower reliance on using background N (starting N) and synthetic fertilisers.

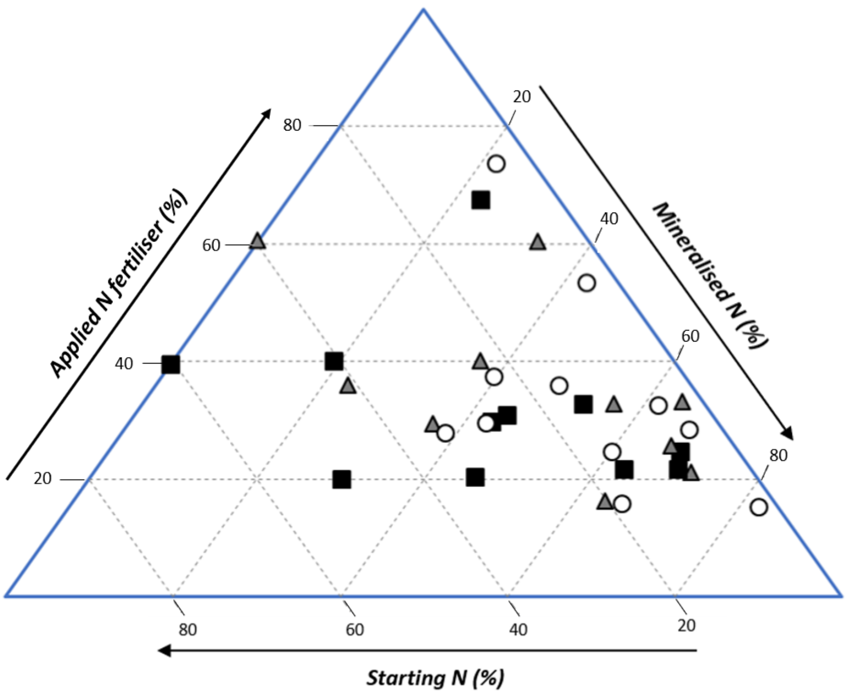

Figure 4. The source of N used by modified systems as a percentage of crop use. *Baseline* is grey triangles; *Higher nutrient* is black squares and *Higher legumes* is white circles. The dotted lines represent 20% levels of percentage for each N source.

Effect of crop choice on nitrogen export from a farming system

Previous reports from the Northern Farming Systems project have shown there is minor to no reduction in fertiliser application when legume crop frequencies were increased (Baird et al. 2019). This paper has shown that legumes increase cropping systems' N balance compared to cereals, with the majority of N sourced from increased cycling of N.

Crop N export rates help us understand the gap between system N balance and fertiliser input between legumes and cereals. High yielding legumes with a high harvest index will export N at a far higher rate than similar yielding cereals (Figure 5). The N export rate is significantly different for yields above 2.5 t/ha. For example, a legume crop yielding 5 t/ha will on average export 174 kg N/ha while wheat will export 110 kg N/ha.

Therefore, farming systems implementing more legumes should be mindful of the high use (and cycling) of N. It's recommended that growers monitor their soil N levels to ensure their systems won't be yield limited due to low soil N which may happen if a high loss event occurs. Knowing the current soil N status is always useful, rather than assuming that legumes will have left or contribute additional N to subsequent crops. The high N removal and potential to extract mineral N may in fact mean that legumes have little or no direct benefit or on occasion lower mineral N than following non-legume crops. The N balance outcome is largely dependent upon the grain yield (amount of N exported kg/ha) and peak biomass of the legume crop (directly related to the amount of N fixed kg/ha).

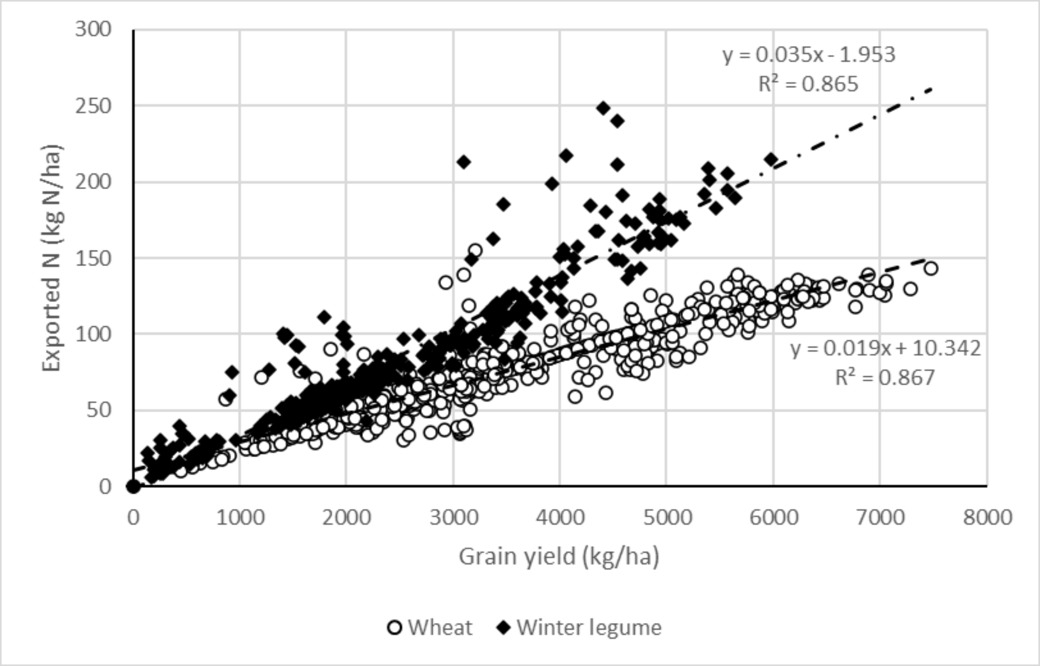

Figure 5. Crop export rates of wheat and winter legumes (including chickpea, fababean and field pea) from the farming system project (2015−2021).

Conclusion

Modifying farming systems can provide growers with potential improvements in yield and gross margins, but legacies need to be monitored as every system will have pros and cons. For example, adopting a system with a higher frequency of legumes will increase N cycling, but the system has higher export rates of N which ultimately result in no net benefit for N balance or a large offset of fertiliser N requirements.

Systems that include high application rates of N fertiliser maintain higher levels of background N, but this practice may not be economically viable at today's fertiliser prices and a positive return on investment is contingent on receiving favourable climatic conditions when the crop can convert the additional N supply into higher grain yields.

Acknowledgements

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Is it time to challenge current nitrogen strategies, tactics and rules of thumb?

Chris Dowling, Back Paddock Company

Key words

N pools, organic, efficiency, strategy, spread, drill

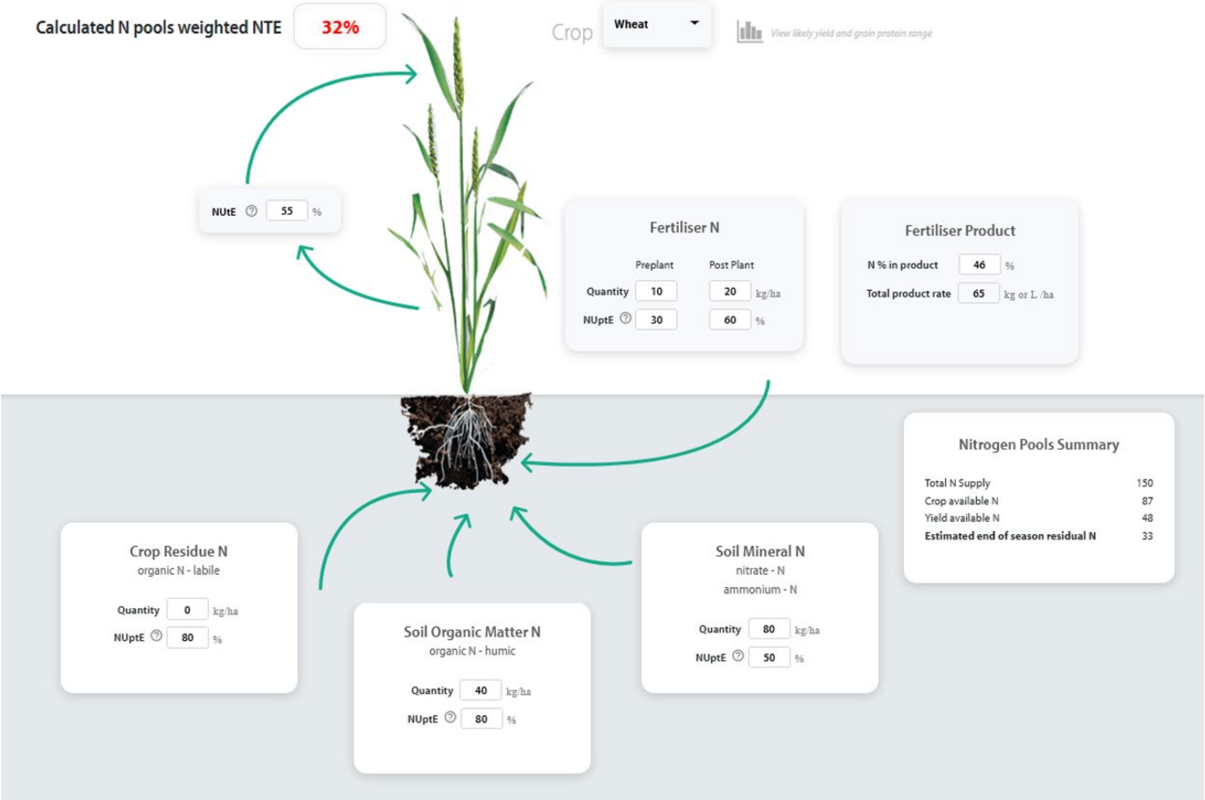
Take home message

- After a run of high-yielding years and wetter than normal soil conditions post-harvest for the coming season, we are likely to see soil mineral N reserves low, soil stored water at maximum capacity, crop residue levels higher than usual, recycling of nutrients from partially and unharvested crops, and minimal fertiliser nitrogen movement into the soil profile. These add up to a challenging situation in a cropping system that would typically expect greater than 50% of crop N to be sourced from mineralisation, some stored mineral N reserves distributed down the soil profile, and some movement of fertiliser N into the profile from the pre-sowing application
- In seasons and situations where there is a significant change in the balance of crop N sourced from organic, soil mineral and fertiliser N pools, caution is needed in determining seasonal N fertiliser requirements based on general rules of thumb, particularly as the crop N uptake efficiency is 50%
- Most current N management strategies are limiting the maintenance or growth of organic C and N reserves by not replacing the contribution from annual mineralisation in N budgets. A more strategic approach that concentrates on soil N management rather than crop N requirement may be more suitable to achieve both crop productivity and soil fertility goals
- With the seasonal conditions this year, the logistics of getting N applied will necessitate fertiliser N being applied in ways that would not usually be considered due to a higher risk of loss or lower efficiency. Even with the current high N fertiliser prices in highly N-responsive situations, insufficient N will likely cost more than losses and lower the efficiency of alternate application strategies.

Organic vs different fertiliser N sources

In managing crop N requirements for the last 30 years, there has been widespread reliance on simple N budgets that, in essence, treat all sources of N available to the crop, soil N depth distribution and fertiliser application strategies equally. But is accepting equality of N supply still the best approach , or is it computational expediency that, for the most part, has served its purpose and now it’s time for a closer look at a more informed approach?

At a gross functional level, plants acquire N from the soil dominantly via the mineral pool, which in turn is topped up by the plant residue (labile), the ‘old’ organic matter (humic), and fertiliser where the supply from other sources is adjudged to potentially limit yield and produce quality (Figure 1).



Calculated N pools weighted NTE 32%

Crop Wheat

NUtE 55 %

Fertiliser N

	Preplant	Post Plant	
Quantity	10	20	kg/ha
NUptE	30	60	%

Fertiliser Product

N % in product 46 %
Total product rate 65 kg or L /ha

Nitrogen Pools Summary

Total N Supply	150
Crop available N	87
Yield available N	48
Estimated end of season residual N	33

Crop Residue N
organic N - labile
Quantity 0 kg/ha
NUptE 80 %

Soil Organic Matter N
organic N - humic
Quantity 40 kg/ha
NUptE 80 %

Soil Mineral N
nitrate - N
ammonium - N
Quantity 80 kg/ha
NUptE 50 %

Figure 1. Representation of a soil N supply pool scenario with differing N quantity/N uptake efficiency contributions to plant N supply and potential grain yield and protein outcomes (image from Back Paddock Opterra N Pools Calculator).

The science says not all crop N supply pools are the same, differing in the quantity of N supplied and efficiency of crop uptake being impacted by characteristics of the N forms that make up the source pool (Table 1). Significant N supply pool balance changes affect crop N supply and may significantly affect seasonal fertiliser N requirement. This explains why many soils in their virgin state and after highly productive legume pasture ley can supply the entire crop N requirement based on the quantity and efficiency of supply and why similar amounts of N supplied as fertiliser are unable to reach the same yields and grain protein outcomes. It may also factor in the ’better than expected’ N responses following canola and pulse crops for the quantity of N available. The relative uptake efficiency from the different soil N pools often explains the difference. While recent research suggests that the net soil N gain from pulse crops may be large (Brill et al. 2022; Kirkegaard et al. 2021), minimal and even negative (Sands et al. 2022), the faster rate of N turnover from these residues with lower C/N ratios and higher uptake efficiency can significantly influence yield and quality in the following crop (Kirkegaard et al. 2021).

Where the crop N supply quantity is heavily skewed toward the higher or lower uptake efficiency pools, there is a significant change from the widely adopted ’average’ crop N efficiency (50 %, commonly represented as crop N demand equals 2 x removal) that the “standard” N budget may significantly over or underestimate the crop fertiliser N requirement.

Table 1. General range short-term crop uptake efficiency of N from 4 major supply pools by cereals.

Major soil N supply pool (and crude working definition)	**General crop uptake efficiency in cereals**	**Characteristics**
Humic OM – contribution from sources more than 3 seasons after incorporation to thousands of years old (Baldock 2019)	70 – 90%	• Largest organic N pool with a regular slow turnover rate of ~2% of total soil organic N annually • Losses via erosion; not subject to leaching, denitrification or volatilisation • Converted to crop-available mineral forms based on favourable soil temperature and moisture conditions • Highest efficiency where most of the contribution is released in-crop • If released during a fallow, it becomes part of the soil mineral N pool and is potentially vulnerable to multiple N loss pathways.
Labile OM – contributed from crop residues with less than 3 seasons of mineralisation (Peoples et al. 2017)	70 – 90%	• Variable size organic N pool based on quantity and quality (C/N ratio) of plant and animal residues returned • Losses dominantly via erosion; not subject to leaching, denitrification or volatilisation • Converted to crop-available mineral forms based on favourable soil temperature and moisture conditions • Net annual contribution depends on the outcome of net mineralisation/immobilisation processes • Legume residues provide up to 30% of total N in residual DM in the following season (Peoples et al. 2017). Some studies suggest that canola residues can perform similarly • Highest efficiency where most of the contribution is released in-crop • If released during a fallow, it becomes part of the soil mineral N pool and is potentially vulnerable to multiple N loss pathways.
Soil profile mineral N – nitrate and ammonium below 10 cm at sowing (Bell et al. 2010)	50 – 70%	• Variable size mineral N pool is based on a combination of residual mineral N from previous crops and N mineralised in the previous fallow • Losses dominantly via leaching and denitrification • Uptake efficiency is affected by N depth relative to rooting depth, soil water and constraints distribution • Quantity available below 60 cm may be limited by root density but is crucial in seasons where the soil profile above has dried.
High concentration, rapidly mineralisable fertiliser N (Daniel et al. 2018) – • applied in the fallow and at sowing • applied in crop	 0 – 40 (70[1])% 20 – 60%	• Highest annual uptake efficiency when applied into an active root system • Lowest annual efficiency when lost during fallow and if stranded in dry soil above the active rootzone for a significant period • If not lost during a fallow, it can become part of the residual soil N for the following crop at up to 2 x higher efficiency than the year of application • Losses dominantly via volatilisation, leaching and denitrification.

[1] Wimmera

For the future, rebuilding soil capacity to supply the majority (>70 %) of crop N requirements from higher-efficiency, low-risk soil sources must be considered a priority to help dampen the adverse effects of seasonal weather extremes and increased agricultural market volatilities (e.g., urea price and commodity price variance) by regenerating soil nutrient supply plasticity (soil contribution more when it is wet and less when it is dry).

Nitrogen – strategies for building the pool and reducing losses

Research suggests that implementing best cropping practices may have, at best, halted the decline in soil organic carbon and nitrogen stocks in continuous cropping systems; however, in most cases, they are still declining. Fundamentally this means that in the long term, the conversion of available rainfall to plant biomass is less effective than previous land uses they are being compared to. To emphasis this point it is worth understanding that estimates of total soil N decline in continuously cropped soils indicate that total soil N haves every 23 (+/- 12) years (Angus and Grace 2017).

The Yield Gap project has identified that across most areas of Australia, the lack of nitrogen is a primary factor in not reaching seasonal and long-term water-limited yield potential (average 40 %) (Hochman and Horan 2018) and, by inference, soil C and N return to the soil in plant residues during grain production.

This issue brings into sharp focus the basis for determining appropriate crop N supply strategies. Current strategies are primarily based on using organic matter mineralised N (contributed to fallow mineral N and mineralised in crop) to minimise the fertiliser N requirements. While this may be a sound short term financial strategy (i.e., targeting optimum economic yield annually), from a longer term view and soil nutrient resource perspective, it can only lead to further declines in organic C and N if the long-term aggregate rate of addition of N for a rotation is less than crop N removal + annual mineralisation and losses.

e.g., Annual average grain N removal of rotation = 71 kg N/ha

- 2 x wheat @ 4t/ha @ 11.5% protein = 160 kg N/ha
- 1 x canola @3 t/ha @ 23% protein = 110 kg N/ha
- 1 x barley@ 5t/ha @10.5% protein = 85 kg N/ha
- 1 x chickpea @ 2.5 % @ 24% protein + N fixation = 0 kg N/ha

Soil total N (0 – 10 cm) = 0.1 % (OC% ~1.2)

Annual humic mineralisable N = 2% of soil total N% = 0.1 × 10,000 × 1.3 × 0.02 ≈ 26 kg N/ha

Minimum long-term annual N addition rate ~97 kg N/ha + seasonal N loss adjustment (15%?)

Some alternative approaches for consideration include:

- N strategy based on long-term crop + annual humic mineralisation replacement
- Replacement N based on long-term removal rates and strategic use of legume ley pasture (40 %) in mixed farming and pulse N
- N bank – N rate strategy based on long term crop available water
- N pools weighted budget + humic mineralisable N.

Use the greater of the above long-term minimum rate approaches and seasonal pools weighted N budget rate?

Spread urea or drill it in?

The answer to the question as to whether it is better to spread or drill urea can fall either way depending on factors such as physical soil conditions, soil chemistry, crop residue loads, beneficial or adverse effects of soil disturbance and application efficiency (including equipment and skilled labour) and cost. An individual situation should be evaluated on its merits considering the prevailing conditions. Table 2 highlights some pros and cons associated with each application method. The choice should also consider which method is most likely to promote the majority of mineral N in the 15 – 40 cm soil layer by crop establishment in summer dominant rainfall areas and other areas that rely significantly on stored soil water for crop production reliability.

Table 2. Pros and cons of spreading or drilling urea

	Pros	**Cons**
Spread	• Logistically, generally more efficient field coverage • Generally lower operator skill level required • Uses multi-purpose equipment • May avoid soil moisture loss associated with soil disturbance • Avoid potential plant establishment effects if urea is drilled at sowing. • Wider application window and conditions.	• Potentially high volatilisation losses, if not incorporated or not treated with a volatilisation inhibitor • Higher yield impacting immobilisation “losses” in high crop residues (5 kg/t compensation when residue volume >5 t/ha) • Calibration and spread pattern can be variable.
Drill	• Potential to delay mineralisation of urea/ammonia (slow release) from some application configurations. • Deeper application (>15 cm) may be less prone to stranding • Can be multi-tasked where soil disturbance is required for other purposes.	• If too shallow in wet alkaline soils, volatilisation losses can be higher than spread. • Potential for higher N_2O emissions during nitrification.

What does a systems approach look like?

We must develop practical long-term strategies and ensure strong alignment with short-term tactics when considering systematic restoration of the soil's nutrient-based production capability.

Some of the primary considerations for the long-term management of soils in the sub-tropical grains industry include:

- All nutrients have residual value when not taken up due to crop water deficit, positional unavailability or erosion
- Uptake efficiency of residual nutrients can be many times greater than freshly applied, if not lost during a fallow due to redistribution within the soil profile
- Reporting of single-year crop uptake efficiencies and profitability for nutrients is misleading where there is yield active residual value
- Plan to manage nutrients for a rotation first, then by crop
- Using nutrient removal is not an appropriate short or long-term application rate for all soils, nutrients and situations

- Monitoring soil nutrient and grain nutrient content trends and balance are essential for long-term management
- Soil phosphorus and potassium strategies need to include the 10 – 30 cm layer in sub-tropical Vertosols
- As seasonal and nutrient cost variability becomes more extreme, soil nutrient-based production plasticity becomes more important to help stabilise costs and income
- Nitrogen mineralised from organic matter annually may need to be added to, not deducted, from crop requirements to arrest further soil organic carbon and nitrogen decline.

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Matching canola variety with environment and management - time of sowing, flowering windows and drivers of phenology

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Key words

critical period of yield formation, phenology, optimal flowering, canola, vernalisation, photoperiod, thermal time, daylength

GRDC code

CSP2206012RTX
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Take home message

- Avoiding stress during the critical period of yield formation improves productivity
- Identifying optimal time of flowering for an environment helps avoid stress during the critical period
- Knowing the phenology of a cultivar helps target flowering to the optimal time.
- Tools like the flowering predictor use probability to show the risk of different genetics in different environments.

Background

Canola's diverse genetics allows it to be grown as a short-season spring crop or a long-season winter crop. In Australian cropping regions, avoiding damaging frosts or high temperatures during flowering and early podding and minimising stress during the critical period for yield formation is the key to maximising yield and oil quality (Kirkegaard et al., 2018). Having confidence that a cultivar will flower when expected, ensures timely management and that crops will flower at the optimal time (Lilley et al., 2019). Recent climatic changes and the logistics of planting large areas have resulted in canola being sown outside the traditional window. This has seen some cultivars behave unpredictably with flowering occurring earlier or later than expected. Phenology is the term used to describe the development or lifecycle of a plant. Understanding the phenological mechanisms within each canola cultivar allows us to predict when it will flower in different environments (Whish et al., 2020) or different sowing dates, allowing growers to choose better adapted cultivars and management strategies for different environments.

What do we mean by critical period?

The critical period of yield determination is defined as the physiological stage in which abiotic stresses have the largest impact on yield determination. The critical periods for many crops have been determined over the years (Fischer, 1985; Lake and Sadras, 2014; Kirkegaard et al., 2018; Lake et al., 2019) and the value of reducing stress during these yield formation periods has been demonstrated (Dreccer et al., 2018). For canola, Kirkegaard et al. (2018) demonstrated that the critical period for canola is centred around 300-degree days (°Cd) following the start of flowering (Figure 1), growth stage 60 BBCH (Meier, 2001). At this point the indeterminant nature of the canola plant means it is producing new flowers, while developing pods and filling seed. Any stress at this time affects the supply of resources to the yield components of the plant. Critical periods are usually depicted as a u shape (Figure 1) because the plastic nature of many plants mean that if the stress occurs before the critical period the plant can compensate. To determine the critical period researchers apply stress for short periods then remove the stress and compare the results to an unstressed control.

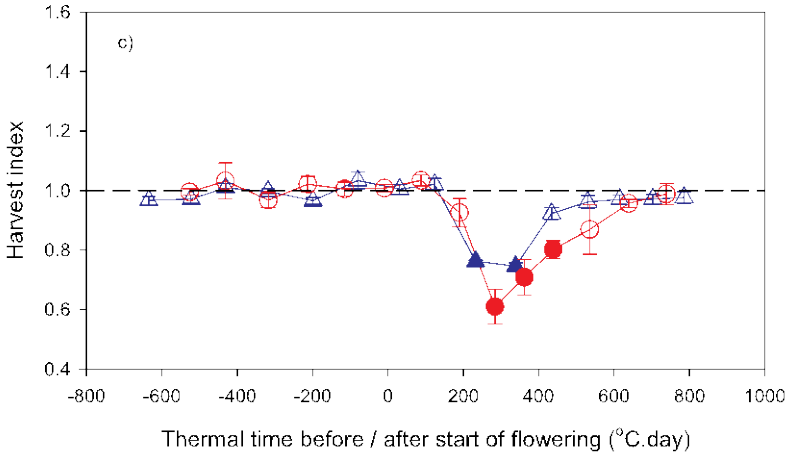


Figure 1. The impact of stress during the critical period on harvest index for canola crops sown at Wagga Wagga (triangles) and Riverton (circles). Filled symbols represent a significant difference from the control. Reproduced from Kirkegaard et al. (2018)

How do you reduce stress during the critical period?

Stresses on plants take different forms (disease, lack of water, high temperatures, low nutrition, low temperatures and pathogens). Some stresses can be controlled but most have to be avoided. In canola, the critical period for yield formation is 300°Cd after flowering. If we can identify periods within the season when the probability of frost is low, the risk of heat is low and there is a high probability of good soil water then we have the optimal time to flower and form yield (Figure 2). Simulation models are useful for identifying these periods because simulations can be run for many years beyond the average grower’s life experience and can identify the optimal flowering time with a higher degree of accuracy.

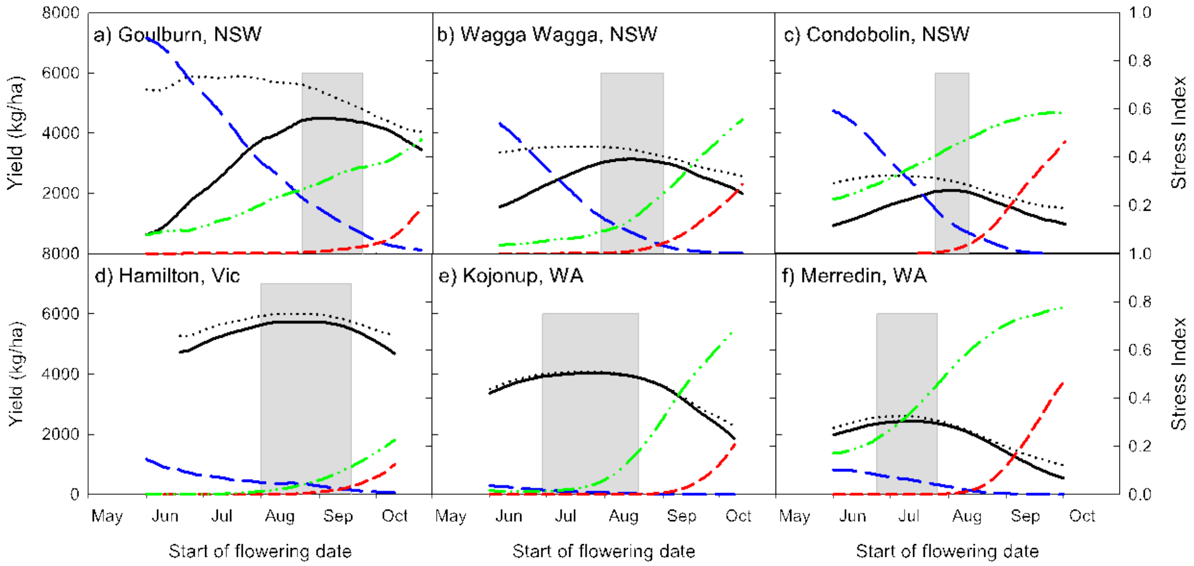


Figure 2. The optimal time to start flowering in different regions around Australia. Showing the simulated potential yield: no frost or heat limitation (black dotted), with frost or heat limitation (solid black). Frost potential (blue long dash), heat stress potential (red short dash) and water limited potential (green dash-dot-dot). The grey box represents the optimum time to start flowering to achieve 95% of the water limited yield potential. (Reproduced from Lilley et al., 2019).

How do we get a cultivar to flower in our environment at the right time?

Understanding the developmental processes of a plant, its phenology, allows the plants development to be predicted based on the daily temperatures and day length experienced within an area. Using this knowledge allows a matching of genetics to the environment and helps ensure flowering at the correct time.

Identifying canola phenology

Plants have distinct stages of development, and these describe the phenology of the plant. The most common and easily recognised canola stages are emergence, green bud, flowering, podding and maturity (Figure 3).

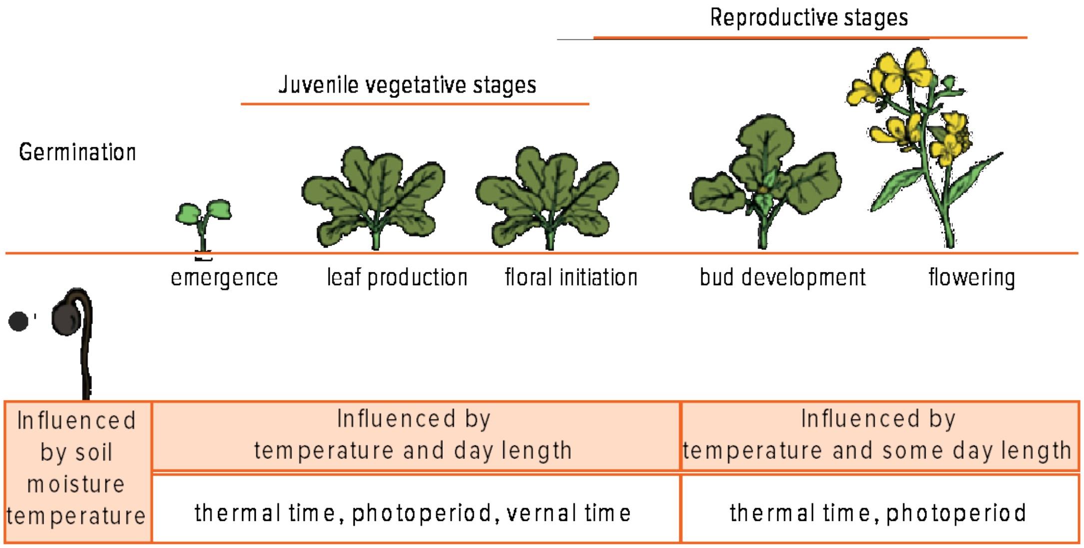


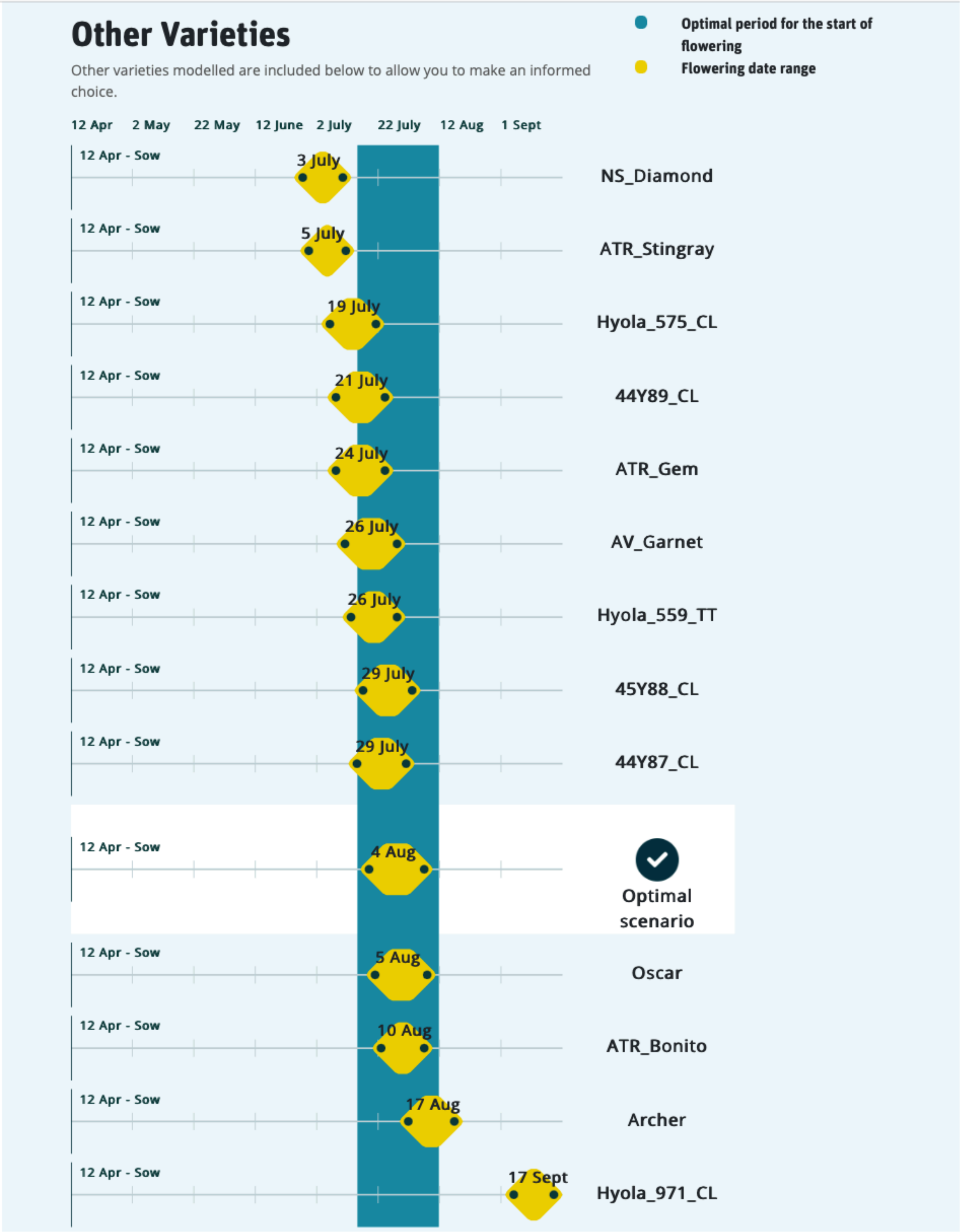
Figure 3. Growth stages for canola and the dominant environmental signals that influence growth in each stage.

Plants respond to environmental signals such as temperature to determine when they move from one developmental stage to another. At the biochemical level, this is caused by specific temperatures inducing the production of plant hormones until a critical concentration triggers the change within the plant. A simpler way to think of this is as a biological clock that accumulates average daily temperatures (day degrees) until a specific target (thermal time target) is achieved.

Why would we want to know this?

Understanding how the environment affects the growth of a plant assists in crop management and enables a grower to match the available canola cultivars to sowing times so that they start to flower at the optimal period. Flowering at this time helps reduce stress during the critical period of yield formation. In addition, many management decisions are time critical, that is, for optimum results the intervention (spray application, defoliation, stop grazing, add fertiliser) needs to occur before a plant reaches a particular growth stage. Identifying these stages can be difficult, for example, floral initiation can occur well before any visible sign appears in the plant. If the crops are grazed or stressed during this floral initiation period, then a yield penalty can occur (Kirkegaard et al 2008; Sprague et al 2014). Knowing the developmental stage of a plant can often help prevent yield loss or ensure that untimely management does not occur.

Rainfall at sowing time is generally unpredictable and may occur early or late. Understanding the phenology of different varieties allows selection of specific varieties to match the sowing time and ensure flowering occurs at the optimum time and the risk of crop loss is reduced (Figure 4).



Other Varieties

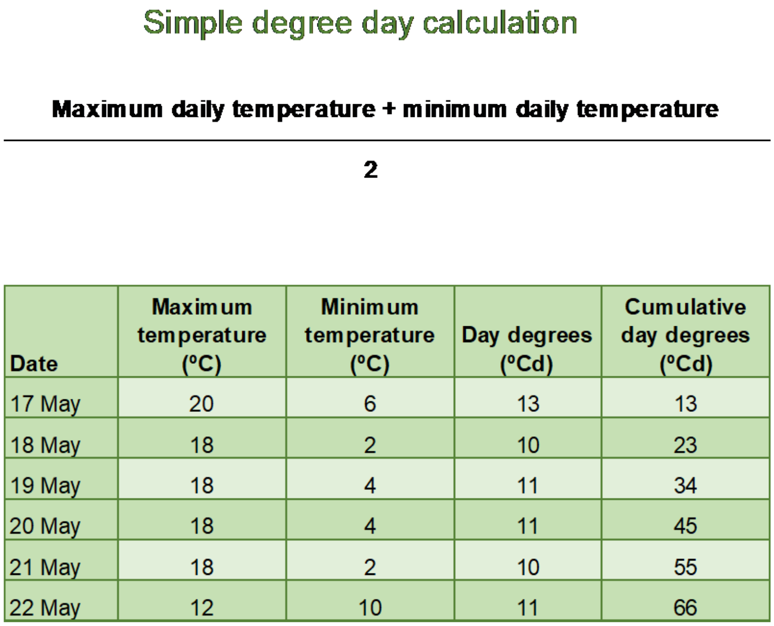
Other varieties modelled are included below to allow you to make an informed choice.

Figure 4. A screen shot from the Canola Flowering Calculator showing flowering data for several cultivars sown at Trangie, NSW on 12 April. At this sowing, short season cultivars Nuseed® Diamond, ATR Stingray⦶ and Hyola® 575CL all start flowering before the optimal starting window while slightly longer-season cultivars like ATR Bonito⦶ start flowering at the optimal time.

Several GRDC projects have contributed to our understanding of canola flowering in the Australian environment. More recently, this work has investigated the gene combinations that produce different flowering responses. The goal is to develop a simple PCR test to predict flowering of new cultivars in any environment. While this genetics work is progressing, breeding companies are adopting the same phenological testing procedures to ensure they recommend cultivars ideally suited to each region, sowing date and purpose.

How do you calculate the phenological response for a cultivar?

Day degrees, growing degree days, degree days or thermal time are the terms used to describe the units of a plant's biological clock. They are a way of combining time and temperature into a single number. In their simplest form, day degrees are based on the average temperature recorded during a day (Figure 5). To calculate the thermal time target for a plant's development stage, the day degrees are accumulated until a specific target is reached, e.g., variety X accumulates 500-degree days between emergence and flowering.



Simple degree day calculation

$$\frac{\text{Maximum daily temperature} + \text{minimum daily temperature}}{2}$$

Date	Maximum temperature (°C)	Minimum temperature (°C)	Day degrees (°Cd)	Cumulative day degrees (°Cd)
17 May	20	6	13	13
18 May	18	2	10	23
19 May	18	4	11	34
20 May	18	4	11	45
21 May	18	2	10	55
22 May	12	10	11	66

Figure 5. Simple calculation of day degrees (average daily temperature) and accumulation of day degrees over time to calculate a thermal time target.

This example is the simplest form and assumes that the plant has a base temperature of 0°C with no growth or development occurring below this temperature. It also assumes that growth and development will continue at high temperatures (>35°C) but this is not always the case.

The simple day degree calculation can be made more complex by identifying those temperatures where plant growth and development occurs and only calculating day degree temperatures when they are within this range. For this paper we use the average daily temperature, but more information and detail on calculating thermal time can be found at: https://www.youtube.com/watch?v=t-8bwU9ke2s

For some plants, development can be described using thermal time alone, as they will flower after accumulating the same thermal time no matter where they are planted. However, canola is more complicated than this, because in addition to accumulating thermal time, it has two other mechanisms

— vernalisation and photoperiod, that influence the time to flowering. The combination and interaction of these three mechanisms complicate the process of estimating when canola crops will flower.

Photoperiod (day length)

Photoperiodism describes the response of plants to increasing or shortening day lengths. Long day plants (canola) respond to increasing day length by reducing the thermal time required to flower.

For example, if it takes an accumulated total of 800-degree days to flower during a 12-hour daylight day it would take only 700-degree days if there are 16 hours of daylight. However, in Australia, canola is generally grown with <12-hour daylengths, so daylength does not influence flowering in most commercial crops.

Vernalisation

Vernalisation is described as low temperature promotion of flowering (Salisbury and Ross, 1969). It is similar to photoperiod, in that vernally sensitive cultivars require less thermal time to flower when grown in a cold environment. However, there are two types of vernalisation ‘facultative’ and ‘obligate’. Facultative vernalisation is when canola grown in cooler climates require less thermal time to flower than when grown in warmer environments. Obligate vernalisation occurs in winter canola and works like a switch with the plants remaining in a juvenile or vegetative state until about 13 days of vernal time have accumulated (this is 13 days with an average temperature of 2°C or 52 days at 12°C). Obligate vernalisation is the mechanism that keeps plants dormant during European winters, or in Australia make this type of canola good for forage or as a dual-purpose crop. Once the obligate vernalisation trigger occurs, the plant behaves similarly to a spring type often displaying a facultative vernal response to additional cold.

How do we know this?

By studying the climate of different regions, we can build a set of key environments to test for vernal responses in canola cultivars (Figure 6).

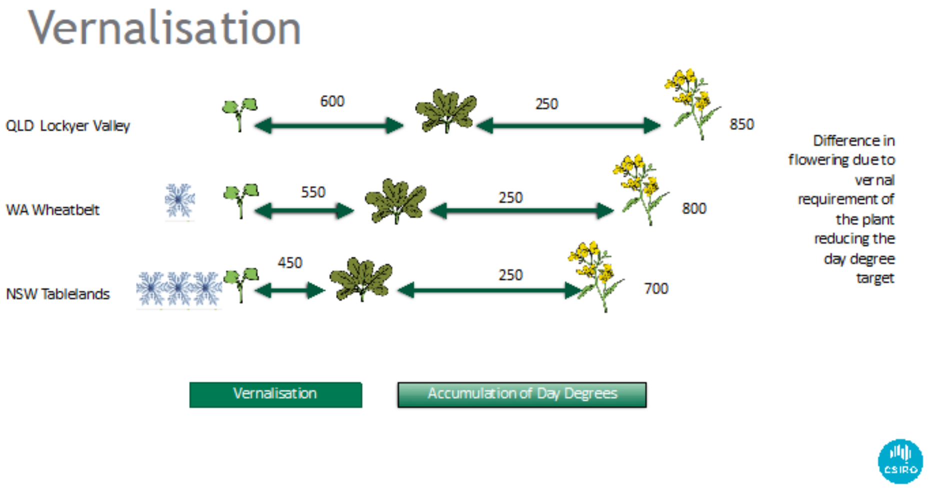


Figure 6. The influence of different rates of vernal accumulation from three sites across Australia on canola flowering time. Cooler regions require less thermal time than warmer regions to achieve flowering.

By strategically choosing sowing dates and sites that accumulate thermal and vernal time differently, we can calculate how each cultivar will behave in any environment (Figure 7). This selection of sites extends from the very cold extremes of the eastern tablelands, to areas with minimal cold, to capture all of Australia's canola growing regions.

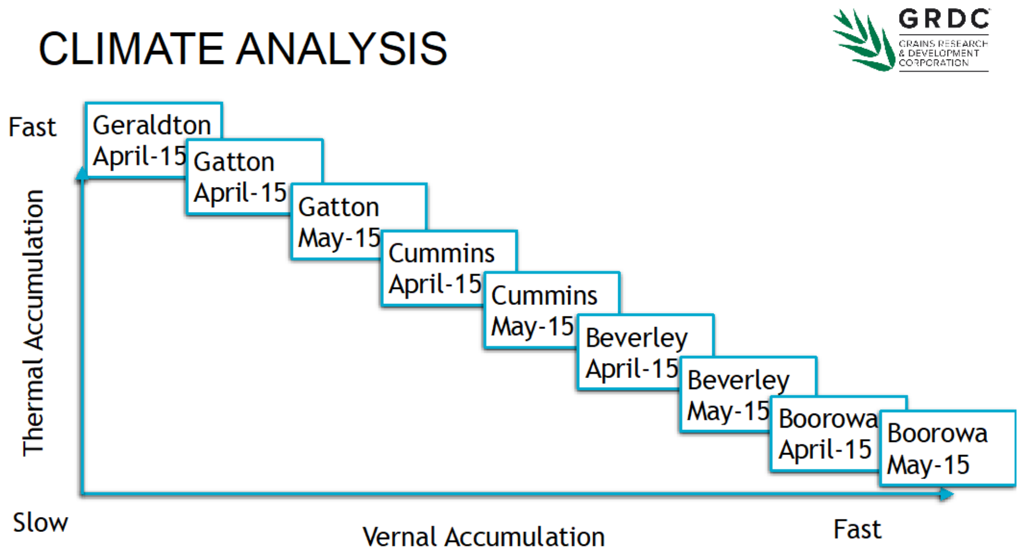


Figure 7. A selection of sowing dates and sites used to characterise the vernal to thermal ratio for Australian canola cultivars.

CSIRO's GRDC funded canola genetics project (Optimising Canola Production in Diverse Australian Growing Environments: CSP1901-002RTX) has used this approach to examine more than 300 different cultivars from around the world. The results demonstrate it is possible to identify different vernal responses (Figure 8).

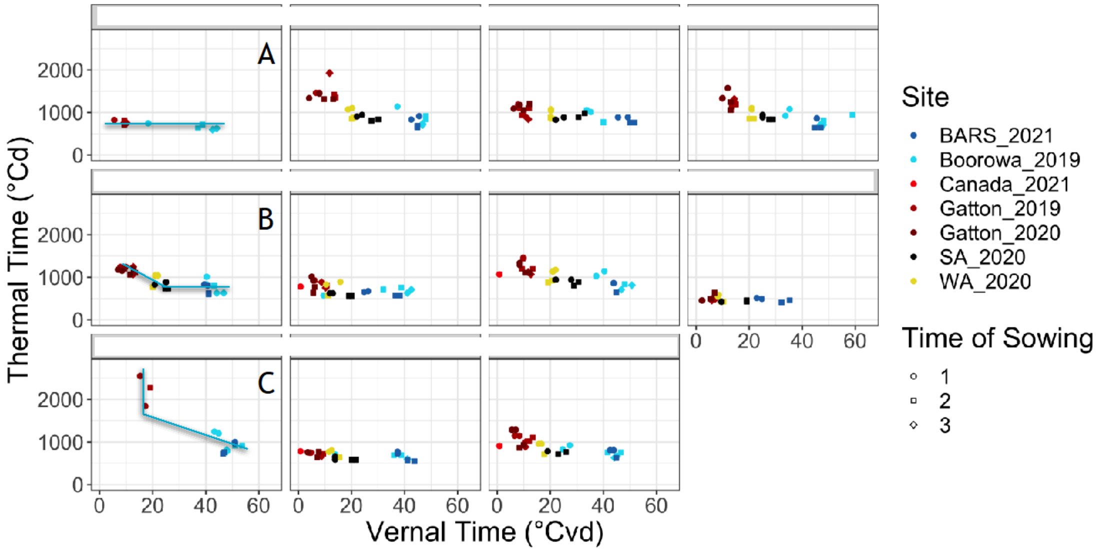


Figure 8. Data from the canola genetics project CSP1901-002RTX detailing three different vernal responses: A. no vernal response, B. facultative vernal response C. obligate vernal response.

Conclusion

Determining a cultivar's phenological characteristics suitable for simulation in APSIM by using the traditional approach of field-based assessment in a range of environments, as described here, is expensive and time consuming. As a result, few current or newly released varieties are ever listed or included within flowering support systems, such as the flowering calculator. At best new cultivars are compared to old cultivars at a few sites and a best guess is applied.

The ability to predict a cultivars time of flowering in many environments, helps refine management decisions (e.g., variety selection, sowing time, fop or dim sub class herbicide timing and nitrogen application timing) and reduces potential yield gaps. Over the last 5 years GRDC and CSIRO have been working to match the phenological parameters required by APSIM canola to gene combinations. The results reported in the next paper (Dillon 2023, Optimisation of canola phenology in diverse Australian growing environments using genomics), demonstrates a new approach to determining a cultivars phenological response. Based on the success of this approach a new GRDC-CSIRO project (CSP1901-002RTX) will deliver a new flowering predictor within the next 12 months. This predictor will work like the canola flowering calculator and will include wheat and barley.

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Optimisation of canola phenology in diverse Australian growing environments using genomics

Shannon Dillon, CSIRO

Key words

canola phenology, optimisation, optimal flowering window, genomic prediction, machine learning, APSIM

GRDC code

CSP1901-002RTX

Take home message

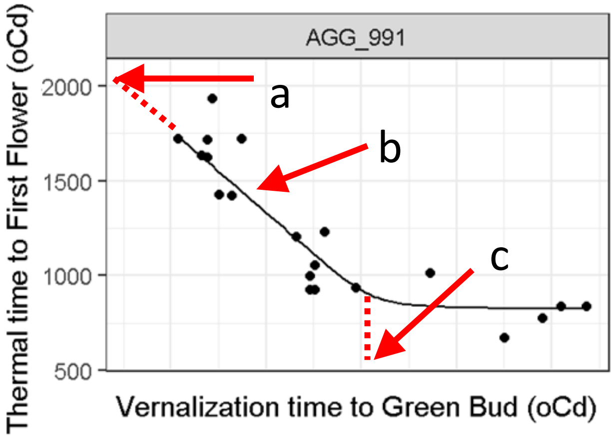
Current APSIM based tools for optimising canola productivity by targeting variety phenology to the optimal flowering window are limited by the time taken to parameterise new varieties, up to several years after release, further compounded by rapid turnover of canola varieties.

We leveraged genomic and environmental effects on flowering time to develop a robust hybrid model that brings together machine learning and process-based crop simulation modelling to predict flowering time for any canola variety based on its genome, which substantially speeds up the parameterisation process. Flowering time predictions with the new model were demonstrated to be highly accurate (R = 0.95-0.86) and can be generalised to a wide range of environments. This makes it a practical option for growers as a tool for managing region specific productivity of canola crops based on optimising phenology sooner than is possible with the current industry standard.

Background

Adverse environmental conditions during canola development have potential to significantly impact yield. In particular, the timing of the onset of flowering is an important driver of productivity. Previous GRDC funded research at CSIRO established that targeting canola phenology to match the optimal flowering window, thereby minimising the risk of yield impacts due to frost or extreme heat, is critical for maximising canola productivity and profitability (Lilley et al. 2019). In canola, variation in phenology, or the timing of transition through developmental stages from germination to maturity, is driven by both genetic and environmental factors and their interactions. Because of this it is possible to manipulate genetics to optimise the timing of phenology and target the optimal flowering window (OFW), and this has long been practiced by growers and breeders, by selecting varieties that have desirable phenology traits in a given environment.

There has been significant industry demand for the development of flexible tools that can reliably and efficiently optimise the deployment of germplasm across environments based on knowledge of these effects. Previous research addressing this challenge drove the development of the Canola Phenology Calculator (https://www.canolaflowering.com.au/), a web-based application that helps growers to choose released varieties that target the OFW at their location, based on estimates of flowering time generated via simulation with APSIM (Mason et al. 2017). This requires estimation of several phenology parameters that encapsulate the unique genetic response of each variety to temperature, by fitting the relationship between thermal and vernal time to key phenological stages (Figure 1). Currently this is achieved through resource and time costly field-based assessments of varieties in a range of environments as they are released, delaying optimisation by up to several years. This is compounded by rapid turnover of canola varieties meaning the characterisation process is on-going.



a = Intercept_1: The y intercept of the fitted model

b = VTGB_1: The slope for the linear parts

c = cp_1: The break point extrapolated to x-axis

Figure 1. Three phenology parameters (a-c) are estimated from the model fit of thermal time to flowering and vernal time to transition over multiple environments for each canola variety.

Optimising canola phenology project

The GRDC funded investment, Optimising Canola Phenology for Australian Growing Environments (CSP1901-002RTX), builds on this previous work to deliver a new model framework that leverages genomic SNP information (variations in the DNA sequence among canola varieties) to streamline the parameter estimation step, reducing the dependence of phenology model optimisation for new varieties on field-based assessments, and the time frame in which recommendations on variety selection can be made available to growers. This research explored an alternative approach that integrates genomic prediction and crop simulation modelling, whereby we train a model in a supervised way using observed parameter estimates and SNP data for a large number of varieties. This results in a model that can predict the APSIM phenology parameters using genomic (SNP) data. Since genomic SNP information can be obtained quickly and at relatively low cost, this model can feasibly be used to predict the APSIM phenology parameters for new varieties where only the SNP information is supplied. Predicted parameters are then passed into a simulation model framework using APSIM to predict flowering time across a range of possible environments.

Model training

We recorded phenology in a diverse set of 350 modern Australian and globally important canola varieties in a total of 18 site/year/TOS combinations over four years (Figure 2). To select sites, thermal and vernal accumulation from sowing was simulated for candidate sites and TOS combinations to identify those that gave a spread of environments representing the breadth of thermal and vernal variation across the Australian canola growing region. Observations of four key phenology developmental stages (emergence, leaf appearance, bud-visible and first flower) were made twice weekly. In total over 400,000 phenology observations were recorded. Phenology parameters were then estimated for each variety based on this data. We also obtained genomic SNP data for each variety using the Brassica 90K genotyping array (Holzworth et al 2014).

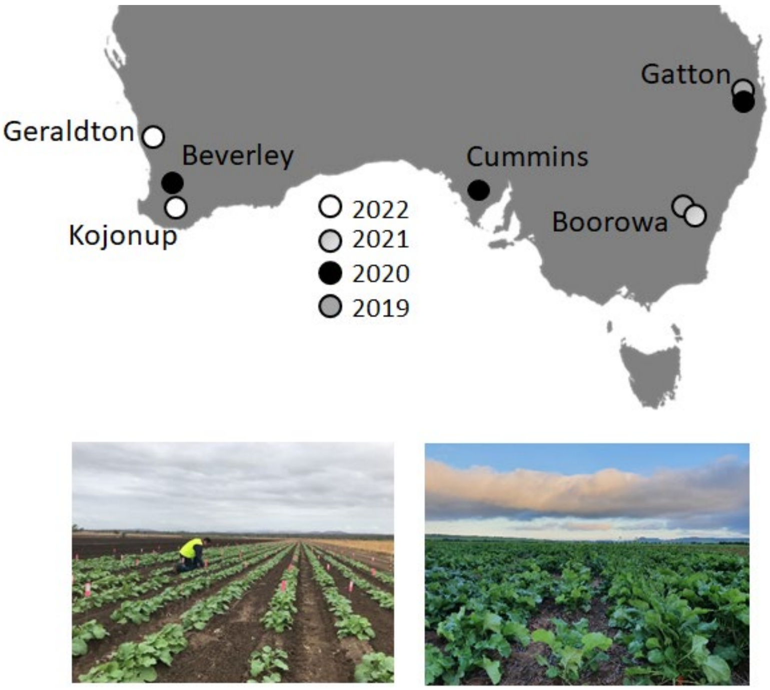


Figure 2. Year and location of trials conducted, with 2 TOS (mid-April and mid-May) at each site in 2020-2022 and three TOS in 2019 (mid-April, mid-May and mid-June). Trials at Gatton 2020 (left) and Kojonup 2022 shown at bottom.

Genomic models were trained using an ensemble machine learning method randomForest for each of three phenology parameters, and these parameters were then passed into APSIM-Next Gen (NG) to simulate flowing over a range of environments in a two-step process. The GP-APSIM-NG model was trained and validated under four scenarios (Table 1). The most relevant scenarios for indicating potential for broader application of the tool were scenarios 3 and 4, where the model predicts phenology over a range of environments for new varieties that were not previously observed in model training, based on their genome.

Table 1. The genomic optimised crop growth model (GP-APSIM-NG) was trained under four scenarios, which enabled performance of the model to be assessed against different levels of information provided for training.

	Observed genotype (OG)	**Unobserved genotype (UG)**
Observed environment (OE)	Scenario 1 E: All environments G: All varieties	Scenario 3 E: All environments G: ~100 varieties dropped out each time
Unobserved environment (OE)	Scenario 2 E: Environments dropped out one at a time G: All varieties	Scenario 4 E: Environments dropped out one at a time G: ~100 varieties dropped out each time

Model performance

The APSIM-NG model predicted phenology with high levels of accuracy across all four scenarios (Figure 3). For scenario 1, R = 0.95 overall (0.95 and 0.94 for flowering and green bud respectively). In scenario 2, accuracy dropped to R = 0.93 overall (0.93 and 0.91). In scenarios 3 and 4, overall accuracy reduced to R = 0.87 (0.88 and 0.86 for flowering and green bud respectively) and 0.86 (0.87 and 0.82), respectively. Overall, Australian lines performed better than international lines, but little difference in prediction accuracy was observed between current unreleased and released lines within the Australian set. This most likely reflects decreased representation of some international variants in the training set.

As a benchmark, performance of the genomic model was compared to that of the alternative APSIM-NG phenology model, which uses phenology parameters empirically estimated in APSIM (rather than using genomics) (Figure 4). For the latter, phenology estimates can only be tested for scenarios 1 and 2, where genotypes were observed in the field. The benchmark predicted flowering and green bud with accuracy of R = 0.95 overall (0.95 and 0.94 for flowering and green bud respectively) for scenario 1, which dropped to R = 0.93 (0.94 and 0.90) for scenario 2. It is notable that for scenarios 1 and 2, the only scenarios directly comparable with the traditional APSIM-NG model, the genomic model performed comparably well.

When the GP-APSIM-NG model performance was assessed as error in days between observed and predicted flowering, we saw that again the Australian material performed better with similar errors to the APSIM-NG model, again with international varieties showing a much wider distribution in error (Figure 5). Where genotypes were unobserved, error increased to within ~ 10 and ~11 days on average for scenarios 3 and 4.

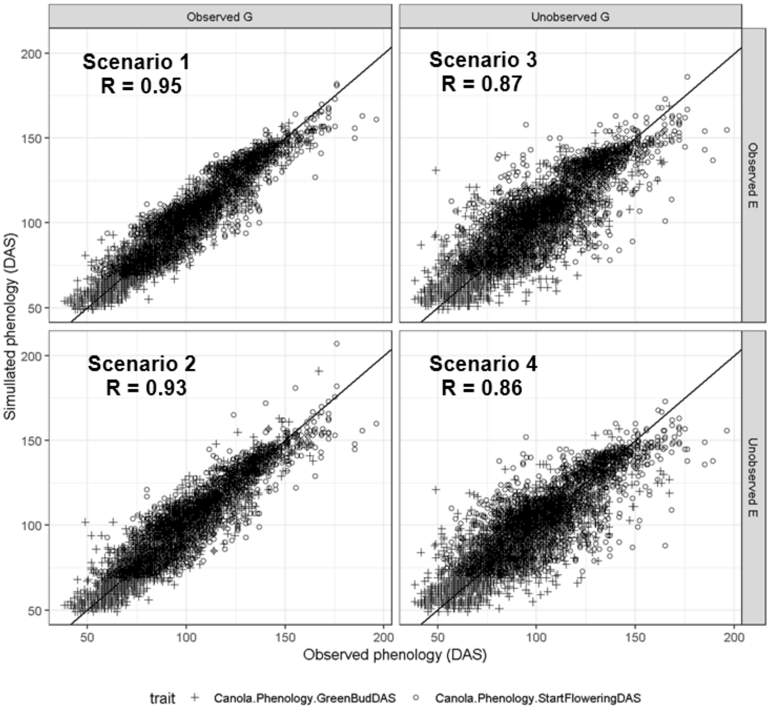


Figure 3. Comparison of observed and predicted phenology using the hybrid crop growth model GP-APSIM-NG, for scenarios 1 through 4.

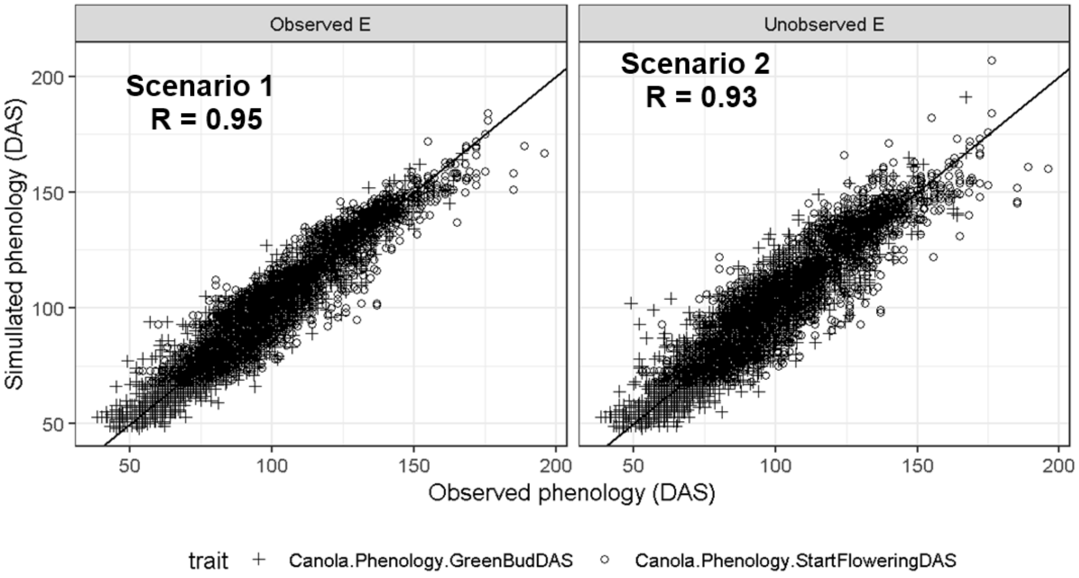


Figure 4. Comparison of observed and predicted phenology with the benchmark, only possible for scenarios 1 and 2 where genotypes were observed in the field.

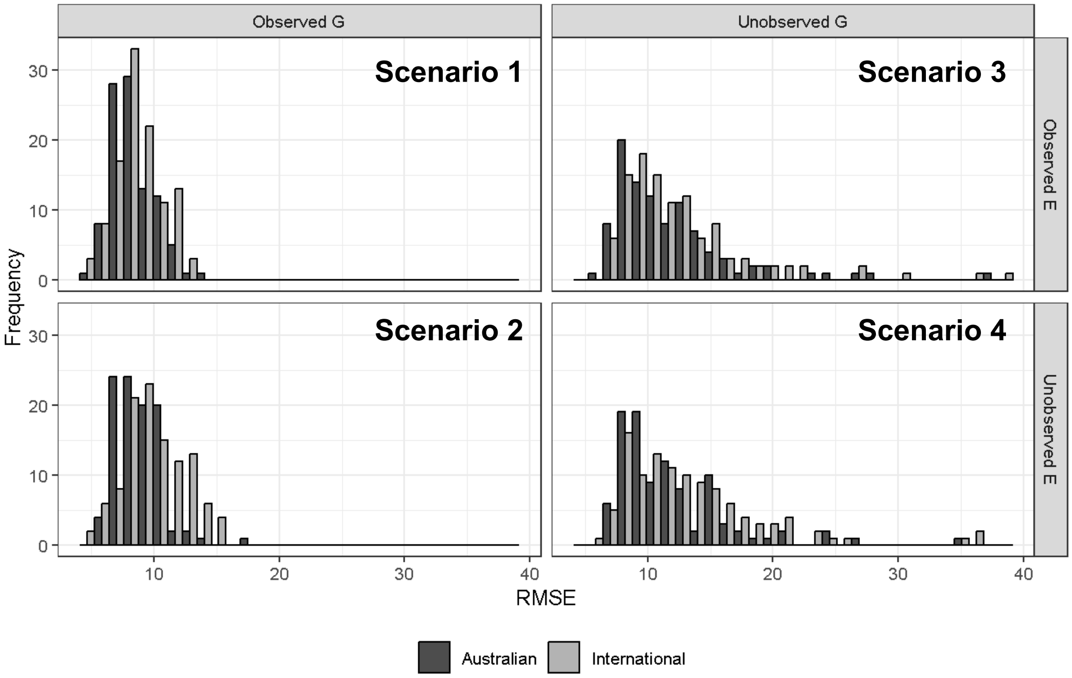


Figure 5. Prediction of flowering time represented as a histogram of predicted values based on error in days (RMSE) for the GP-APSIM-NG hybrid crop growth model.

Current directions

Further improvement of the model, through addition of genomic and phenology data for NVT varieties, is underway as part of a new GRDC investment (CSP2206-012RTX) which will update the existing Canola

Phenology Calculator web application with genomically parameterised estimates of flowering time across Australian canola growing regions. This project will also update the existing web app. to include genomically optimised phenology estimates for wheat and barley. The new and improved web app is anticipated to be available to Australian breeders and growers by 2027.

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Effect of heat stress on canola yield & quality - what's the impact of genetics?

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Notes

Concurrent session – Pulses

Pulse performance in regionally relevant environments

Rohan Brill[1]*, Michael Moodie*[2]*, Maurie Street*[3]*, Ben O'Brien*[3]*, Tom Price*[4]*, Ben Morris*[4]*,*
Barry Haskins[5] *& Rachael Whitworth*[5]

[1] Brill Ag
[2] Frontier Farming
[3] GOA
[4] FAR Australia
[5] AgGrow Agronomy

Key words

pulse, nitrogen, yield, NDFA

GRDC code

BRA2105-001RTX

Take home message

- Faba beans were the standout pulse crop across southern and central NSW pulse agronomy sites in 2021 and 2022, for grain yield and net nitrogen contributions to the soil
- Total N fixation of all pulses was measured using the ^{15}N natural abundance technique and ranged from 88 to 594 kg/ha with an average of 271 kg/ha
- N fixation was primarily driven by biomass production, with ~33 kg N/ha fixed per tonne of above ground biomass
- Total N fixation included a measure of nitrogen derived from the atmosphere (NDFA) in shoots which is then multiplied by established root factors for each pulse to determine above and below ground contributions
- The N balance provided by pulses (after subtracting grain N removal from total N fixed) ranged from 2 to 343 kg/ha, with an average across species of 146 kg N/ha
- Net N contributions were greatest after faba beans (average 194 kg N/ha) and lowest after lentils (43 kg N/ha).

Introduction

The GRDC funded 'NSW Pulse Agronomy Project' commenced in 2021 and has two major themes of research activity:

1. Assessment of the yield and nitrogen fixation of different pulse species in regionally relevant and often challenging environments. This work is conducted across the project area including sites at Barellan, Canowindra, Caragabal, Buraja, Ganmain, Gol Gol and Parkes.

2. Locally relevant research, addressing local limitations to pulse production. Research to date has included plant density, disease management, nutrition management, inoculation strategy, phenological development, and herbicide tolerance.

Trial results from 2021 are published on the GRDC website and a link to this information is provided in the 'further reading' section of this paper. Trial data from 2022 will be published in the same way in the first half of 2023. This paper provides an update of progress on point number 1 above, with a full set of data from 2021 available including grain yield, peak biomass, and nitrogen balance of pulse species. Data available from 2022 at this point includes peak biomass and grain yield but not nitrogen balance.

Materials and methods

Trials were conducted at seven sites across southern and central NSW in 2021 (Table 1). Sites were selected to be regionally relevant with challenges (both perceived and real) 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 nitrogen fixation performance in the local environment where adapted species may thrive, but less adapted species may struggle. Each site had their own specific challenges (Table 1) including surface acidity (Barellan, Buraja, Canowindra); subsoil sodicity (Caragabal, Ganmain, Parkes), low rainfall (Gol Gol); waterlogging (Caragabal, Ganmain, Parkes) and calcareous subsoil (Gol Gol).

Table 1. Site description of seven pulse agronomy research sites from 2021

Site	Sowing Date	Rain Jan-Mar	Rain Apr-Nov	pH (Ca) 0-10 cm	Site description
Barellan	13 May	270 mm	435 mm	4.5	Acidic sandy loam soil with 3.3% Al.
Canowindra	3 May + 20 May[1]	290 mm	490 mm	4.8	Moderately acidic, well drained red loam soil
Caragabal	29 April + 18 May[1]	280 mm	480 mm	5.0	Slightly acidic loam (chromosol) with sub-soil sodicity
Buraja	7 May	180 mm	450 mm	4.6	Moderately acidic silty loam soil
Ganmain	28 April + 18 May[1]	220 mm	360 mm	5.3	Slightly acidic loam soil with sub-soil sodicity (15% Na in 30-60 cm)
Gol Gol	31 May	0 mm	115 mm	7.7	Alkaline calcarosol, sandy loam topsoil with clay increasing with depth
Parkes	31 May	290 mm	485 mm	5.7	Neutral pH, moderately heavy soil type with sub-soil sodicity

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

Several trials were sown at each site, driven by local demand to fill knowledge gaps and nitrogen balance of key pulse species was measured at all sites. Nitrogen balance was determined by collecting biomass samples at peak biomass (i.e., 30-50% 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 Nitrogen 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 nitrogen fixation (N fix) was calculated by multiplying by 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 is a rule of thumb to provide an allowance for below ground biomass so an improved estimate of total nitrogen fixed can be provided. Finally, the nitrogen balance is calculated by subtracting the nitrogen removed in grain.

Results 2021

Total nitrogen fixation (kg/ha): Total nitrogen fixation was highest in faba beans (405kg N/ha average) in four of the six sites where NDFA was measured (Table 2). Three of these sites, Caragabal, Ganmain and Parkes had sodic subsoils and experienced periods of waterlogging through the season, while the Barellan site experienced no waterlogging, but was moderately acidic soil (4.5 $CaCl_2$, 0-10 cm). Lupins had very high biomass and total nitrogen fixation on a red loam soil at Canowindra, while at Buraja, chickpeas continued growing later into the season and had the highest total nitrogen fixation. Lentils had the lowest total nitrogen fixation at all five sites where NDFA was measured (113kg N/ha average).

Nitrogen off-take (kg/ha): Nitrogen removal in grain was highest or equal highest for faba bean (211kg N/ha average) in five of the six sites where they were grown and NDFA measured (Table 2) and lowest in lentils (71kg N/ha) in all five sites where NDFA was tested. Average grain yields across sites ranged from 5.05t/ha for faba bean to 1.70t/ha for lentil while nitrogen removal per tonne ranged from 55 kg N/t for lupin to 34 kg N/t for chickpea. The contrast in nitrogen off-take results is therefore primarily explained by grain yield differences which varied on average by 3-fold with nitrogen removal per tonne varying 1.6-fold.

Nitrogen balance (kg/ha): Positive nitrogen balance numbers indicate a net contribution of nitrogen to the soil system from atmospherically derived nitrogen while negative numbers indicate a loss of nitrogen from the soil system. Despite large nitrogen off-take in faba bean they provided the largest contribution of nitrogen to the soil (194 kg/ha average N balance) at Barellan (followed by field pea), Caragabal (followed by vetch), Ganmain (followed by field pea) and Parkes (followed by chickpea). Faba beans had a high harvest index at Buraja and removed 42 kg of nitrogen per tonne of grain resulting in a more modest nitrogen balance of 86kg N/ha.

Species and site insights: Lentils and chickpeas generally had lower N fixation but combined with lower yield and for chickpeas low N concentration in grain, they still had a positive N balance and a potentially higher value grain produced. Lentils had an average N balance of 43 kg/ha and chickpeas 165 kg/ha. Vetch and field peas generally had moderate N fixation and removal, but removal would be much higher if cut for hay. Vetch is widely used as a brown manure crop to supply N to the system, but other options such as beans and lupins may provide greater N fixation benefits for this role, although with different challenges such as very high seeding rates (faba beans) and rotational effects of diseases (e.g., sclerotinia in lupins).

N balance in lupins was variable, limited by waterlogging at Parkes, but very high at the Canowindra site which had few growth constraints. Where lupins had high biomass, N fixation was also high, but they had high grain N concentration, with close to 60 kg of N per tonne in albus lupins (Murringoⓟ and Luxorⓟ) and just above 50 kg of N per tonne in narrow leaf lupins (PBA Batemanⓟ).

Table 2. Peak biomass (30-50% podding), total N fix (including below ground roots), grain yield, N removed in grain and overall nitrogen balance of pulse species at research sites in NSW for 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	148	2.2	72.1	76
	Faba beans	*PBA Samira*⌽	9.4	335	4.4	171	164
	Field Pea	*PBA Wharton*⌽	9.9	287	3.9	146	141
	Lentils	*PBA Hallmark XT*⌽	6.8	129	2.6	105	24
	Lupins	*Luxor*⌽	5.5	188	3	174	14
	Vetch	*Timok*⌽	9.3	240	3.5	162	78
Buraja	*Chickpea*	*CBA Captain*⌽	7.1	220	2.3	74	146
	Faba beans	*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 beans	*PBA Samira*⌽	15	395	5.8	230	165
	Lentils	*PBA Hallmark XT*⌽	6.7	124	1.4	58	66
	Lupins	*Murringo*⌽	17.6	525	4.3	263	262
	Lupins	*PBA Bateman*⌽	15.6	519	3.4	179	340
Caragabal	*Chickpea*	*CBA Captain*⌽	9.6	278	2.1	72	206
	Faba beans	*PBA Samira*⌽	17.4	594	5.7	251	343
	Field Pea	*PBA Taylor*⌽	7	278	3.4	134	144
	Lentils	*PBA Hallmark XT*⌽	7.2	133	1.7	71	62
	Lupins	*PBA Bateman*⌽	9.7	313	2.1	112	201
	Vetch	*Timok*⌽	11.1	345	1.6	92	253
Ganmain	*Chickpea*	*CBA Captain*⌽	5	164	Not harvested due to hail		
	Faba beans	*PBA Samira*⌽	12	347	5.2	211	136
	Field Pea	*PBA Wharton*⌽	8.3	294	2.7	104	190
	Lentils	*PBA Hallmark XT*⌽	5.5	93	2.1	91	2
	Vetch	*Timok*⌽	6.6	166	2.7	127	39
Gol Gol	*Chickpea*	*CBA Captain*⌽	1.7	*	0.6	*	*
	Faba beans	*PBA Samira*⌽	1.5	*	0.5	*	*
	Field Pea	*PBA Wharton*⌽	2.4	*	1	*	*
	Lentils	*PBA Hallmark XT*⌽	1.8	*	0.6	*	*
Parkes	*Chickpea*	*CBA Captain*⌽	9	328	2.6	89	239
	Faba beans	*PBA Samira*⌽	15.1	552	6.3	282	270
	Lentils	*PBA Hallmark XT*⌽	3.9	88	0.7	29	59
	Lupins	*Murringo*⌽	3	98	0.8	47	51
	Lupins	*PBA Bateman*⌽	7.9	318	2.6	132	186

Overall, there was a consistent increase in total nitrogen fixed with increases in above ground biomass for all crops, with on average, each tonne of above ground biomass (above ~1 t/ha) resulting in 33 kg/ha total N fixation allowing for below ground N estimated by using root factors (Figure 1).

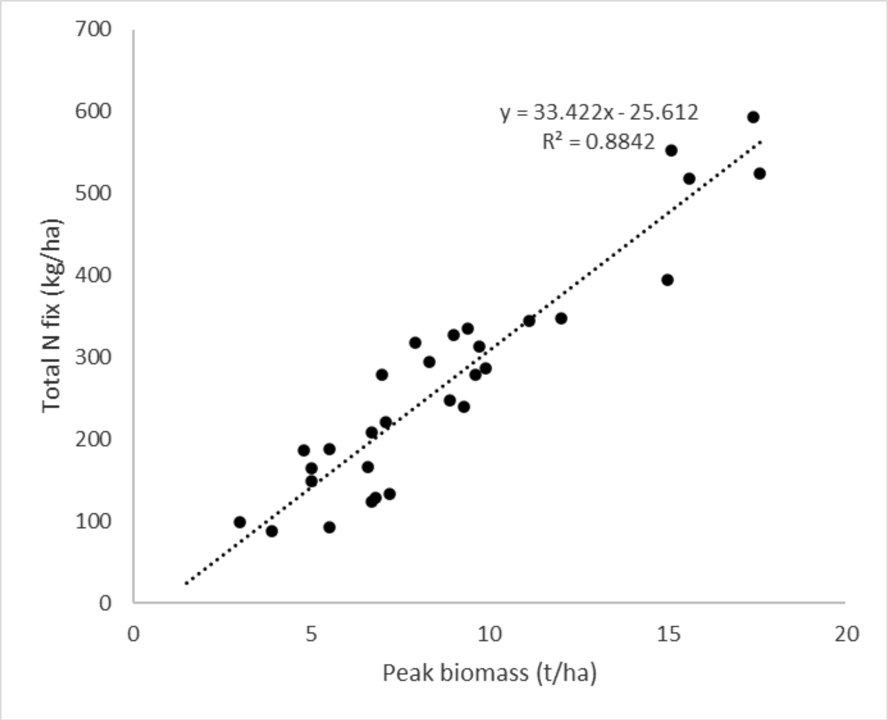

Figure 1. Relationship between peak biomass (above ground, measured at 30-50% podding) and total N fixation in 2021. Crops included = chickpeas, faba beans, lentils, lupins, field peas and vetch.

Results 2022

Research conducted in 2022 had similar themes to 2021, with locally driven research combined with evaluation of key pulse species for nitrogen balance. With the very wet season, five of the sites provided data on full peak biomass and grain yield, with N fixation and grain N samples yet to be processed. The Southern NSW site around Coreen/Buraja was sown successfully but was severely impacted by waterlogging and not harvested. The Caragabal site was not sown at all and in its place, a second site was sown at Ganmain in late July, simulating sowing with a spreader with and without incorporation (data not yet available). The main Ganmain site was sown on a more favourable soil type than was initially planned due to very wet conditions at sowing. As a result of the need to shift sites and the loss of planned sites, the data is skewed toward relatively well drained soils, but even these sites were impacted by waterlogging in the very wet 2022 season (Table 3).

Table 3. Site description of five pulse agronomy research sites from 2022.

Site	Sowing Date	Rainfall Jan-Mar	Rainfall Apr-Nov	pH (CaCl2) 0-10 cm	Site description
Barellan	*6-May*	255 mm	536 mm	5.2	Slightly acidic sandy clay loam
Ganmain	*9-May*	184 mm	555 mm	5.7	Sandy clay loam with minimal constraints
Trundle	*28-Jun*	154 mm	712 mm	5	Slightly acidic sandy clay loam
Wellington	23-May	287 mm	815 mm	5	Slightly acidic clay loam soil
Wentworth	*12-May*	25 mm	381 mm	8	Alkaline sandy soil, part of Mallee Dune/Swale system

Overall and like 2021 results, faba beans generally grew very high quantities of biomass (12.7t/ha average across sites) but didn't always have the highest biomass at individual sites (Table 4). Vetch had the most biomass on the sandy soil at Wentworth (7.8t/ha), lupins grew the most biomass at Barellan (16.5t/ha) and field peas grew the most biomass at Wellington (14.8t/ha). Except for Wentworth, faba bean biomass was always >12 t/ha. It is expected that N fixation analysis will show high amounts of N fixation by beans again in 2022. Average vetch biomass (8.9t/ha) was about average of all species (8.8t/ha), generally not getting to very high levels but also consistent throughout.

Lupins had relatively high biomass on the drier Wentworth and well drained Barellan sites, but biomass was lower at the wetter Trundle and Wellington sites. Lentil biomass was relatively low overall (5.2t/ha) and was very low at the wet Trundle site.

Table 4. Peak biomass (30-50% podding) of pulse species at five pulse agronomy research sites in 2022.

		Peak Biomass (t/ha)				
Species	**Cultivar**	**Wentworth^2**	**Barellan**	**Ganmain**	**Trundle**	**Wellington**
Chickpea	*CBA Captain*ᶲ	3.8	12.4	9.7	4.2	5.5
Faba bean	*PBA Samira*ᶲ	3.8	13.0	17.8	16.3	12.4
Field pea	*PBA Butler*ᶲ	4.8	11.3	8.7	5.6	14.8
Lentils	*PBA Hallmark*ᶲ	3.7	7.7	7.5	1.0	6.2
Lupins	*Luxor*ᶲ	5.2	15.0	*^{1}	*	6.1
Lupins	*PBA Bateman*ᶲ	6.0	16.5	*^{1}	9.7	8.1
Vetch	*Timok*ᶲ	7.8	10.7	12.2	7.0	6.8

[1] Lupins not sown at Ganmain due to rabbit and hare issues

[2] Wentworth sampling was done early to beat rising river flood water that would restrict site access. Further growth was likely on most species after sampling was conducted.

Faba beans had the highest grain yield at three of the five sites (4.5t/ha average, Table 5). Chickpeas had the highest yield at Wentworth (4.1t/ha) and Luxorᶲ albus lupins had the highest yield at Barellan (5.0t/ha). Grain yield above 4 t/ha was achieved at each site, but there was often high variability with chickpeas yielding 34% of albus lupins at Barellan; chickpeas yielding 5.3% of faba beans at Ganmain; Albus lupins yielding 4.9% of faba beans at Trundle and Lentils yielding 8.3% of faba beans at Wellington.

Grain nitrogen analysis will be completed on each species in 2023 and will be subtracted from total N fixation to determine the nitrogen balance of each species at each site.

Table 5. Grain yield of pulse species at five pulse agronomy research sites in 2022.

		Grain Yield (t/ha)				
Species	**Cultivar**	**Wentworth**	**Barellan**	**Ganmain**	**Trundle**	**Wellington**
Chickpea	*CBA Captain*ᶲ	4.1	1.7	0.3	1.2	1.1
Faba bean	*PBA Samira*ᶲ	2.4	4.5	5.6	4.1	6.0
Field pea	*PBA Butler*ᶲ	2.7	2.2	2.9	1.6	3.7
Lentils	*PBA Hallmark*ᶲ	2.7	2.4	1.1	0.4	0.5
Lupins	*Luxor*ᶲ	4.0	5.0	*	0.2	2.1
Lupins	*PBA Bateman*ᶲ	3.6	3.8	*	0.7	2.7
Vetch	*Timok*ᶲ	3.3	4.5	2.4	2.2	1.7

Discussion and conclusion

The above average rainfall in 2021 and 2022 have led to some very high grain yields being achieved across the project region, most consistently with faba beans. Other pulses such as lupins, lentils and chickpeas had more variable yield responses. Field peas and vetch (for grain) performed consistently across sites and seasons, only occasionally being the best performer but also rarely being the poorest performer. In addition to their excellent yield performance, faba beans had an average net benefit of 194 kg/ha nitrogen after accounting for N removal as grain in 2021. The total value of the faba bean crop (in simple terms) = grain yield * grain price + N benefit * N price. It is likely that at high N cost but even modest faba bean prices, they would still compete with most other crops in a gross margin comparison. For example, at an on-farm price of $360/tonne, with a grain yield of 4 t/ha and a nitrogen value of $2 per kg of N, gross income = $1820/ha. This is roughly equivalent to the gross income of a 5 t/ha APW wheat crop, but with the added benefit of the break crop components such as weed control and disease break. In reality, pulses should not compete with cereals and oilseeds for cropping area but should complement their production as part of a system.

This project will continue for the next two years to generate more data on pulse production on regionally relevant soil types across species and seasons. It is highly likely that seasons will return to a more normal or even drier pattern, so different results will be expected.

Acknowledgements

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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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Investing in the farm system - legume manure

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Key words

legume, manure, nitrogen, carbon, soil

Take home message

- Understand the long-term implications of rotational choices
- Legume manures provide whole system benefits including:
  - A 'free' natural source of nitrogen
  - Improved soil condition
  - Increased diversity of Integrated Pest Management (IPM) strategies
  - An aid to affordable carbon capture.
- Farm systems including a legume manure phase are profitable.

Setting the scene

Historically, soil erosion was a major problem in Australian farming systems. In the mid-late 1970s, researchers at Condobolin, Cowra and Rutherglen began working on cropping with reduced tillage. This led to minimum tillage (min-till), and now, zero/no till. This transition was made practically feasible with modified seeding equipment and herbicides that allowed growers to spray and seed.

Until the advent of these new technologies, most farms had been mixed farming systems with crops and legume-based pasture in a rotation. This pasture history meant that soil organic matter (SOM) levels were relatively high.

The early 1990s saw the advent of canola as a major break crop.

In 1991, the wool floor price scheme was stopped and 'overnight' half to two thirds of most farms were losing money!

Combine these factors with the drought of 1994 and interest rates rising to 20%+; and the financial pressures created were the catalyst for rapid uptake of min-till cropping systems. Wider, fit for purpose seeding equipment made it an 'easy' decision for many farmers to move to cropping intensive systems.

The result was intensification of cropping on large numbers of farms while the area of pasture and sheep numbers declined dramatically. The loss of legumes in many farm systems has increased reliance on 'bagged' nitrogen fertilisers and overtime, has contributed to a decline in soil organic matter.

Considerations

Farming is a nutrient exporting business. For the business and the key asset of the soil to be sustained, not only do those nutrients need to be replaced, but also sufficient must be available in a specific ratio (Kirkby et al 2011) to capture and store carbon.

In many areas after thirty years of no till continuous crop farming systems, there is considerable evidence that the soil resource is being run down, particularly with regard to SOM i.e., your asset is depreciating. SOM is a key to soil health and is directly related to the amount of carbon within the soil.

The decline or absence of legumes in the system contributes to an ongoing decline in soil nitrogen. Without a surplus of nitrogen (beyond what is required for farm produce), the capacity for affordable carbon capture and storage in soil is impacted.

In addition, more and more synthetic fertiliser is now required just to maintain yield potential, with rates of up to 400kg/ha of urea now not uncommon. This adds to escalating input costs and without an associated yield improvement, puts further pressure on farm margins.

Another factor of concern is that continuous cropping is still largely based on cereal and canola. The lack of diversity in such tight sequences has increased pressures on weed control and overtime has contributed to the rise of herbicide resistance in an increasing number of weed species.

In other words, asset management is now more expensive, more difficult and there is an urgent need for change.

The fix

There is a tool available that can help address several of these challenges.

Legume manures are an excellent tool for assisting the farmer to:

1. Provide a natural source of soil nitrogen
2. Increase available strategies for weed control and herbicide resistance management
3. Reducing soil borne disease levels
4. Over the rotation as a whole - lower input costs, lower risk, more flexibility and potential for profit.

The choice of species or combination of species to target maximum biomass will depend on your location, rainfall, and seed availability and cost. Treat it as any other crop and prioritise which paddock/s based on fertility status and weed control issues as fits your long-term rotational plan.

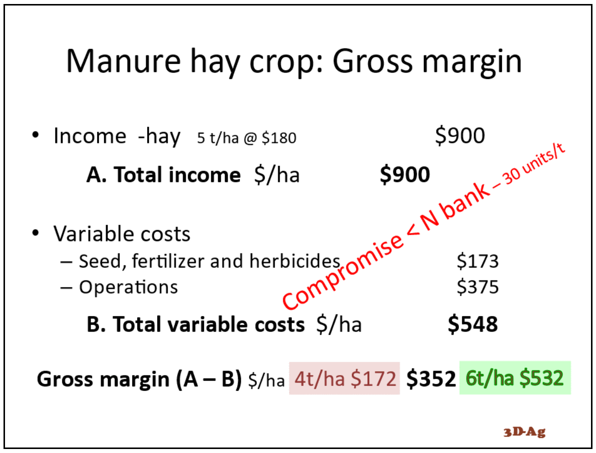
A legume (pulse) manure phase provides 20-25kg N/ha/t biomass depending on rainfall, i.e., 160-300kg N/ha. In a drought year, this contribution may be reduced to 100kg N/ha, but it is still nitrogen that does not have to be purchased. This natural source of nitrogen is a slow-release form available to following crops or to facilitate carbon retention. To retain a tonne of carbon, 80kg nitrogen is required (Kirkby et al 2011). Home grown nitrogen is obviously a more cost-effective means of building soil carbon. Improving soil carbon in turn improves soil condition making your soil resource more resilient under a wider range of seasonal conditions (i.e., your asset is appreciating).

A wider range of IPM strategies becomes available with an increase in the diversity of rotation. A legume manure phase is an excellent opportunity to manage herbicide resistance issues through termination of the manure crop prior to weed seed set. With a follow up control of any survivors this can provide 98% reduction in resistant individuals. If available in suitable numbers for the required grazing pressure, animals can be used in a spray graze scenario as an alternate strategy. Using non-selective sprays also saves selective herbicides which develop resistance faster from over-use and the risk of them losing efficacy.

A legume manure provides flexibility as an alternate break ‘crop’ to canola and reduces the potential risk of disease build up under a ‘double break’ of two broadleaf crops in succession. In addition, soil borne diseases such as take-all and crown rot can be significantly reduced, especially if the crop following the manure is not a cereal!

Despite the growing evidence, there remains a perception that having a paddock produce no revenue for a season must be a drag on profitability. It’s time to think beyond season by season and consider a legume manure phase as an investment, rather than a cost. As a relatively low-cost investment it provides many benefits to the farm system. Over the life of a well-designed rotation, where subsequent species complement those that follow, the whole system improves over time. The value of a legume manure in the system comes from the benefit to successive seasons with home grown nitrogen for following crops, better soil condition and improved capacity to manage weed and disease.

While the maximum benefit of legume manure is achieved through termination of growth at the appropriate time, if seasonal or financial circumstances dictate, growth can be utilised by making silage or hay or grazing animals to make a cash contribution to the business. The loss of biomass and export of nutrient in product will necessarily compromise additions to the nitrogen bank and progress of SOM improvement.



Manure hay crop: Gross margin

• Income -hay 5 t/ha @ $180	$900
A. Total income $/ha	**$900**
• Variable costs	
– Seed, fertilizer and herbicides	$173
– Operations	$375
B. Total variable costs $/ha	**$548**
Gross margin (A – B) $/ha	4t/ha $172 **$352** 6t/ha $532

Compromise < N bank – 30 units/t

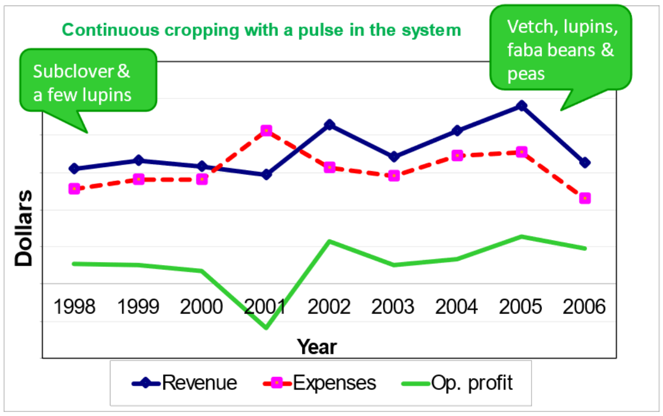
3D-Ag

Figure 1. Gross margin of manure hay crop

Evaluation

Case study

An early adopter's experience from near Oaklands, with 240mm growing season rainfall. Typical of many who are drawn to the 'idea' of a manure phase, but not quite enough to follow through against the temptation of harvesting the field peas sown as a manure. The turning point came when a faba bean crop became an 'accidental' manure in 2001. The following barley crop still yielded 2.5t/ha in the drought of 2002. Thereafter a manure crop was routinely used to revitalise a 'tired' paddock. Vetch became the legume of choice because it removed the incentive to harvest. In the drought of 2006 the 300 ha of vetch was the only green thing in the district –around 3,000 lambs were bought for $23 and 12 weeks later sold for $90 - Result!


Case study – early adopter of continuous crop

Courtesy Kerlanco

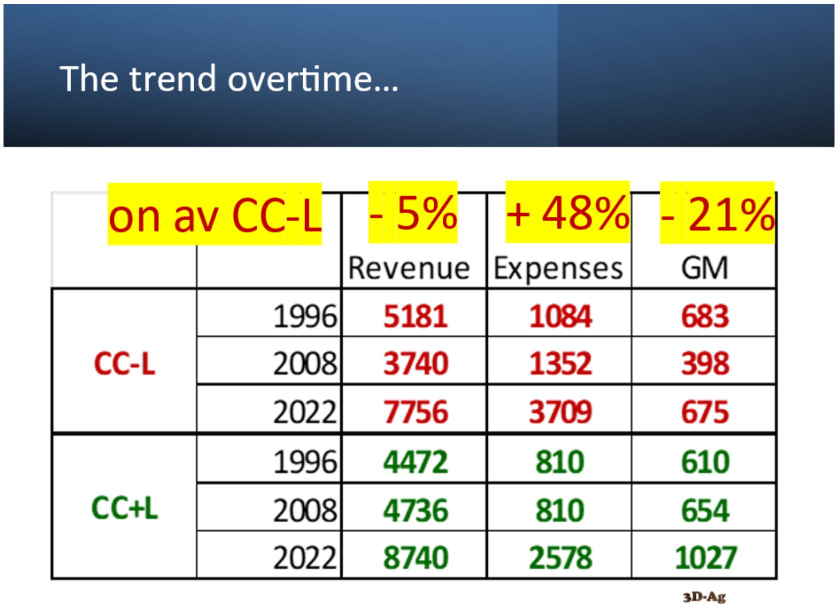
GSR 240 mm **Av GM across WB L Peas =$270**

Figure 2. Case study of early adopter of continuous crop

Assessing impacts overtime… To assess continuous crop scenarios with and without legumes, a modelled case study follows, based on actual client information and supplementary data, initially prepared in 2014 then updated for subsequent years.

A continuous crop system without legumes (CC-L) is compared with a more diverse rotation including legumes (CC+L) over a 30-year period. Each is based on six phase cycle. The cropping sequence for CC-L is canola-wheat-wheat and repeat initially, moving to canola-wheat-barley repeat, in more recent times. The rotation for CC+L is wheat-manure-wheat-canola-wheat-faba beans throughout.

Revenue and costs are an expression of an amalgamation of client and district data with appropriate market values for the time. From these gross margin values are calculated and presented as a table (Figure 3) and graph (Figure 4).



The trend overtime…

on av CC-L		- 5%	+ 48%	- 21%
		Revenue	Expenses	GM
CC-L	1996	5181	1084	683
	2008	3740	1352	398
	2022	7756	3709	675
CC+L	1996	4472	810	610
	2008	4736	810	654
	2022	8740	2578	1027

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Figure 3. Mean annual gross margin values per 6-year crop sequence based on cropping sequences with (CC+L) and without (CC-L) a legume manure phase.

The trend over time is clear – average **revenue for CC-L is 5% less** relative to CC+L.

On a similar basis, **expenses for CC-L are 48% greater** than those of CC+L.

Overall the average **gross margin for CC-L was 21% less** than for the CC+L rotation

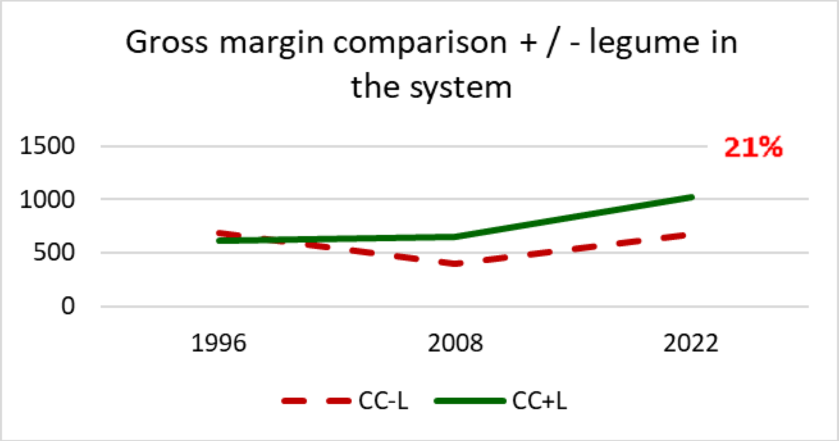

Figure 4. Mean average gross margin comparison per 6-year crop sequence with (CC+L) and without (CC-L) legume manure crops in the system.

In conclusion

Legumes in all forms;

- Increase diversity of crops grown
- Provide opportunities for strategic weed, pest and disease control
- Reduce requirements for bagged fertilizer N
- Lower cash requirement, particularly up front
- Allow flexibility and lower risk
- Provide flow on benefits to following crops
- Support a stronger balance sheet
- Contribute to nitrogen bank and potential carbon capture.

The question

Why hasn’t the use of legume manure crops become standard best practice?

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Aphids in faba beans - an update with a review of management strategies of faba bean aphid

Zorica Duric, Grace Gillard & Mukti Chalise, NSW DPI, Tamworth

Key words

aphid landing rate, *Megoura crassicauda*, pulses, insecticide efficacy

GRDC code

BLG214, CES2204-001RTX

Take home message

- Aphid activity was low in faba beans in 2022.
- The faba bean aphid - FBA (*Megoura crassicauda*) was recorded in multiple sites in New South Wales and spread in Queensland and Victoria.
- Tested chemicals reduced FBA numbers compared to the control. Both foliar treatments, pirimicarb and pymetrozine, were highly effective. Likewise, imidacloprid seed treatment was observed to have a high effect on FBA numbers on emerged faba beans. In addition, pirimicarb is a selective insecticide which is mild for beneficial insects and is therefore recommended to be included in FBA management strategies.
- In general, aphid management needs to be based on controlling green bridge and volunteer plants before season, monitoring pests and beneficials during season, and insecticide application with respect to economic threshold where possible.

Background – Aphid update in northern NSW

Aphids are considered major pests of field crops if observed in moderate to high numbers. They can cause damage by direct feeding, forming dense colonies, producing honeydew, and most notably by transmitting plant viruses (Duric & van Leur, 2022). The yield losses could be substantial, particularly if aphids infest young plants in autumn.

Aphid landing rate generally depends on the availability of hosts over summer, such as summer growing pasture species, weeds, and volunteer crops. Apart from host resources, aphid migrations are affected by abiotic factors, including temperature, moisture, photoperiod, and wind direction. The 2021/22 summer was wetter than average in NSW, and the moisture, together with favourable temperatures, supported development of a green bridge. A green bridge can provide shelter and food sources for aphids over summer in the form of volunteer crops and weeds that grow around or within cropping areas.

Even though the green bridge was well-established and high aphid numbers were recorded in lucerne in March 2022, unfavourable weather conditions caused a decline in numbers before the winter season. Low numbers of incoming aphids were recorded in faba beans (Figure 1); as such, early sown faba beans generally had relatively low levels of virus infection.

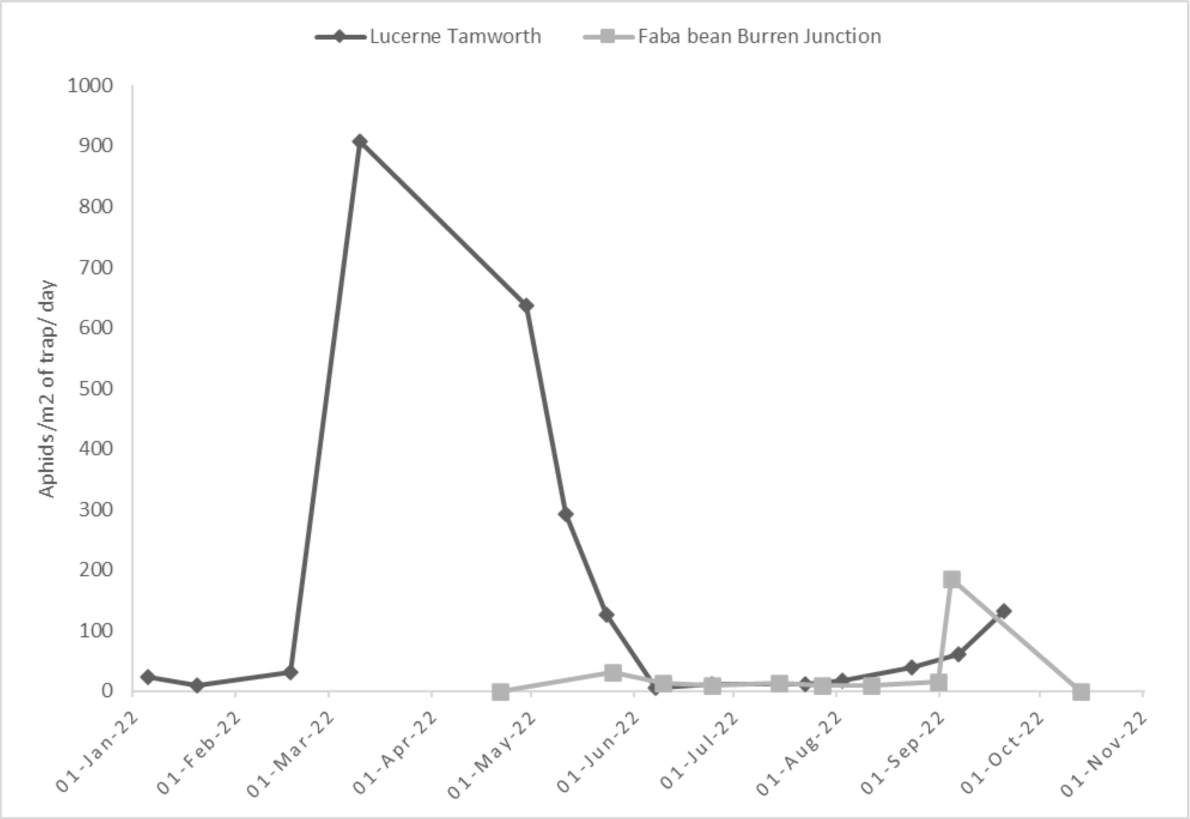

Figure 1. Aphid numbers on yellow sticky traps in lucerne and faba bean in 2022
(The aphid numbers are transformed as number of aphids/ m^2 of trap/ day)

In contrast to the population trends observed in other pulse aphids, faba bean aphids (FBA - *Megoura crassicauda*) were detected in multiple sites in Darling Downs (Queensland), northern, central, and southern New South Wales, and Victoria (Julia Severi - Cesar, pers. Comms). Based on our previous studies, FBA are known to form dense colonies starting at the tips of faba bean plants and moving downwards, causing additional damage such as necrosis, wilting, stunting, and defoliation (Duric et al., 2021). In addition to the invasive behaviour of FBA, they can act as vectors for viruses such as *Bean leafroll virus* (BLRV) and *Pea seed-borne mosaic virus* (PSbMV). Apart from faba beans, FBA preferentially feed on vetches, and reproduce on common peas, common beans, and lentils, while lucerne and sub clover are suitable alternative hosts.

Prior to 2022, outbreaks of FBA occurred from late winter to spring. However, in 2022, FBA was detected for the first time in early established faba bean and volunteer faba beans in north-west NSW. Clearly, the populations have survived and built up over the past six years, since it was first recorded in Australia (Hales et al, 2017). It is likely that FBA used alternative hosts such as pasture legumes, volunteer faba beans, and woolly pod vetch (*Vicia villosa*) on roadsides to survive outside of the winter season.

The majority of infestation sites reported well-established and vigorous colonies, requiring chemical control in 2022. As such, further studies on management options of FBA are being conducted, the results of which will be communicated to the industry before the 2023 winter season.

Methods

The objective of this study was to analyse the efficacy of different readily available chemical products for the control of FBA in faba beans. Rates used in the table below are given in grams active ingredient (g a.i.) applied per ha. As this study was conducted in glasshouse conditions, additional caution should be taken when applying chemicals in the field.

The host plants, faba beans (Warda⦶), were sown in a standard potting mix. Four treatments were used: control, imidacloprid, pirimicarb, and pymetrozine (Table 1). Imidacloprid was applied as a seed treatment prior to sowing, while the remaining insecticides were sprayed onto plants after the development of second leaves of faba beans. The control plants remained untreated.

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

Active ingredient (a.i.)	Formulation	Application rate	Recommended field rate	Type of pesticide	Critical Use Comments
Imidacloprid	600 g/L	120 mL/100 kg of faba bean seed		4A group Insecticide	Do not graze or cut for stockfeed within 16 weeks of sowing.
Pirimicarb	800 g/kg	125 g a.i. / ha	160-190 g/ ha	1A group Insecticide/ Aphicide	Minimum retreatment intervals 14 days. Do not apply more than 2 applications per crop. Withholding Period: Do not harvest, graze or cut for stock food for 21 days after application.
Pymetrozine[1]	500 g/kg	50 g a.i. / ha	200 g/ha for faba bean aphid	9B group Insecticide	Minimum retreatment interval 14 days. Withholding Period: Harvest: Not required when used as directed. Do not apply after BBCH 70 Do not apply more than 2 applications per crop. Do not apply consecutive applications. Grazing: Do not graze or cut for stock food for 21 days after application.

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

After the foliar spray was absorbed, all plants were re-planted in boxes with 0.5% agar. Each plant was infested with 10 wingless adults, and the boxes were covered with aphid-proof mesh. The number of live adults and nymphs was observed 3, 7, and 14 days after treatment (DAT). The experimental design was a randomised complete block with four replicates.

To determine the effect of pesticide treatment and host plant on aphid survival and progeny production, the data were analysed by Generalized linear mixed model (GLMM) with poisson link before performing the analysis of variance (ANOVA). Means were transformed and separated at 5 (%) level of significance. Henderson-Tilton's formula was used to calculate percentage efficacy of the treatments against FBA adults:

$$\%\,efficacy = \left(1 - \frac{n\ in\ Co\ starting\ population \times n\ in\ T_{\ 3,7,14\ DAT}}{n\ in\ Co_{\ 3,7,14\ DAT} \times n\ in\ T\ starting\ population}\right) \times 100$$

n = adult aphid numbers, T = treated, Co = untreated, DAT = days after treatment.

Results and discussion

Significant differences existed between the insecticide treatments in the mean number of FBA adults and nymphs (Table 2). All insecticide treatments resulted in reduced aphid populations. In contrast, the populations in the control treatments increased gradually up to the final observation (14 DAT).

Table 2. Mean number of faba bean aphid adults and nymphs on faba beans observed 3, 7 and 14 days after treatment (in the case of the seed treatment 'imidacloprid', DAT can be interpreted as 'Days After Infestation')

Treatment	3 DAT			7 DAT			14 DAT		
	Mean No of nymphs	Mean No of adults	% Efficacy	Mean No of nymphs	Mean No of adults	% Efficacy	Mean No of nymphs	Mean No of adults	% Efficacy
Pirimicarb	0 a	0 a	100	0 a	0 a	100	0 a	0 a	100
Imidacloprid	2 b	3.7 b	48.28	0 a	0 a	100	0 a	0.2 a	98.68
Pymetrozine	9.2 bc	5.7 b	20.69	0.2 a	0 a	100	0 a	0 a	100
Control	27.5 c	7.2 b	-	64.5 b	7.7 b	-	31.3 b	16.8 b	-

Means within columns followed by the same lower case did not differ significantly at 5 (%) level of significance.

Data analysis indicated the FBA populations significantly decreased with the foliar treatments. Pirimicarb was highly effective (100% efficacy). Based on our results reported previously (Duric, 2022), such high efficacy was expected. In addition to its high efficacy in reducing FBA populations, pirimicarb is fast-acting and a selective aphicide, which has mild toxic effect on various beneficial insects and predatory mites (McDougall et al., 2022).

Pymetrozine is a slow-acting chemical. Three days after treatment FBA populations were reduced, with only 20.67% efficacy in faba beans. However, the insecticide was highly efficient at 7 and 14 DAT, with 100% efficacy. It is important to rotate chemicals throughout the growing season, using chemicals with different modes of action. Here, the slow-acting nature of pymetrozine recommends it as a suitable alternative treatment.

Imidacloprid seed treatment did not provide a knockdown effect 3 DAT (days after treatment for foliar sprays, interpreted as days after infestation for seed treatments), but was found to be highly effective 7 DAT in faba bean (100%) with high levels of efficacy maintained to 14 DAT (98.68%). Clearly, FBA are susceptible to imidacloprid which could be used to prevent early aphid infestation and delay colonisation.

The efficacy data are presented in a graph for easier comparison of tested treatments (Figure 2).

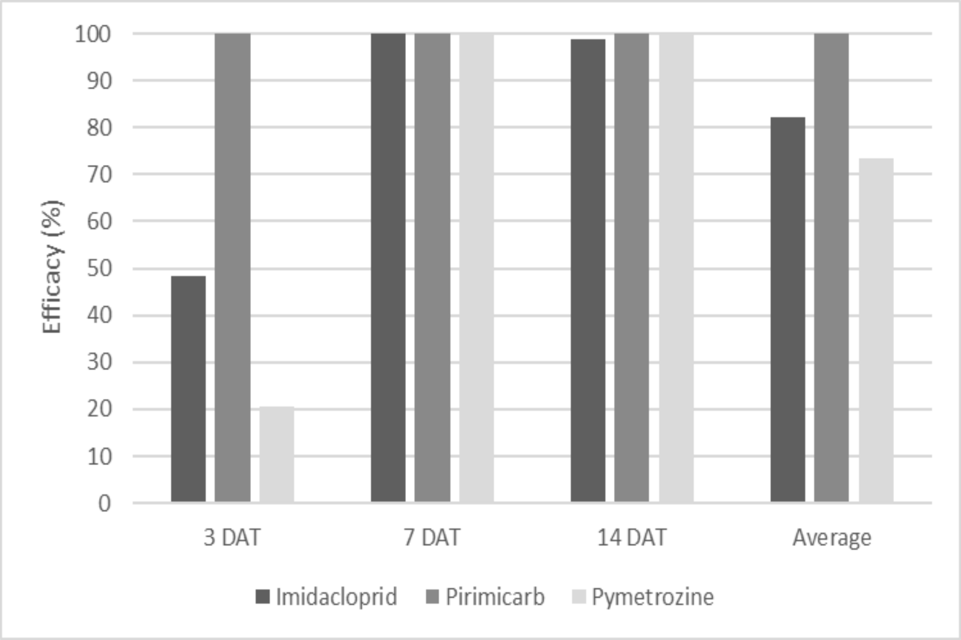

Figure 2. Efficacy (%) of insecticides on faba bean aphid adults in faba bean 3, 7, and 14 days after treatment

Conclusion

Low aphid numbers were recorded in pulses in 2022; however, FBA established in northern NSW and spread to Queensland, southern NSW, and Victoria. As FBA are highly invasive and act as virus vectors, it is essential to monitor and manage their populations in order to minimise their impact on pulse crops and practice non-chemical control before and during the growing season.

We have conducted this study to evaluate the potential value and uses of market-available insecticides for controlling FBA populations and, as such, provide data to inform management strategies for FBA. The results of this study indicate that the efficacy of the tested insecticides differs significantly, providing further insight into the suitability of different chemicals.

While imidacloprid as a seed treatment was relatively slow-acting compared with the pirimicarb foliar treatment, it successfully reduced FBA population numbers at 7 and 14 DAT in faba beans.

In all observations, the efficacy of pirimicarb was high. In addition to its high efficacy, pirimicarb has a mild impact on beneficial insects, recommending it for use in FBA control. Pymetrozine was likewise effective 7 and 14 DAT and is a potential alternative foliar treatment and supplement of pirimicarb during the growing season. Together, these chemicals are potential candidates for a management program of FBA.

The results of this study provide preliminary data to inform management strategies for FBA populations using readily available insecticides, in the case when monitoring confirms developed colonies and preventive actions do not adequately control FBA populations. As this study was conducted under glasshouse conditions, future research is required to evaluate the effect of seed and foliar treatments on FBA in the field condition.

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Concurrent session – Phenology

Introducing the Australian Cereal Phenology Classification (ACPC) scheme for wheat and barley

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Keywords

anthesis, flowering time, heading, maturity

GRDC codes

ULA00011, BLG104, DAN00213

Take home messages

- A new phenology classification scheme was created for wheat and barley cultivars
- The scheme was derived and validated using genotype (70 wheat, 30 barley) × environment (QLD, WA, SA, VIC, NSW) × management (sowing dates from 1 March to 15 June) field experiments conducted across Australia
- The scheme provides a standard approach to describing development based on thermal time to heading that can give consistency to descriptions provided by breeding companies
- This phenology classification methodology can be extended internationally and to other crops.

Introducing the Australian Cereal Phenology Classification (ACPC)

Until recently, there have been no nationally accepted industry standards for describing cereal phenology. This has frequently led to misclassification, confusion and difficulties with making informed decisions regarding cultivar selection and time of sowing. In 2020, Australian Crop Breeders Pty Ltd published ‘An industry guide for wheat variety maturity description’ (‘ACB Guide’). The guide used relative heading dates of locally adapted cultivars planted at their target sowing dates to classify wheat varieties into nine spring and three winter classes. The ACB Guide represented an important step forward for the grains industry.

As part of the GRDC National Phenology Initiative, the 2020 ACB Guide was revised and extended to make it more robust, agronomically functional and meaningful to industry. A new cultivar phenology classification scheme for wheat and barley – the Australian Cereal Phenology Classification (ACPC) – has now been published and is available to industry. The ACPC was derived and validated using a phenological data set with a diverse array of genotypes (70 wheat and 30 barley), environments (WA, SA, VIC, NSW and QLD) and management (sowing dates from 1 March to 15 June). The development of the ACPC is described in full in Celestina et al. (2023). In brief:

- thermal time to heading data were collected from national field experiments
- wheat and barley data were combined, cultivars were split into winter or spring habit, and then ranked from quickest to slowest by median thermal time from sowing to anthesis
- spring and winter habit cultivars were separated into equidistant classes that encompassed the range of phenology observed
- cultivars corresponding to the boundary between neighbouring classes were selected.

A visual representation of the ACPC showing the phenology of wheat and barley cultivars studied and the location of the classes and boundary cultivars is shown in Figure 1.

The classes and boundary cultivars that define the ACPC can be seen in Table 1. Wheat and barley cultivars are divided into nine spring classes and five winter classes from quickest to slowest. In spring cultivars, these classes correspond to a change in optimal sowing date of about one week.

Note that phenology classifications according to the ACPC are only applicable to cultivars sown at the optimal time in a region to which they are adapted. When sown outside their optimal period, cultivars are likely to change rank (and therefore class) with sowing time and environment. This is particularly true of winter and facultative spring cultivars.

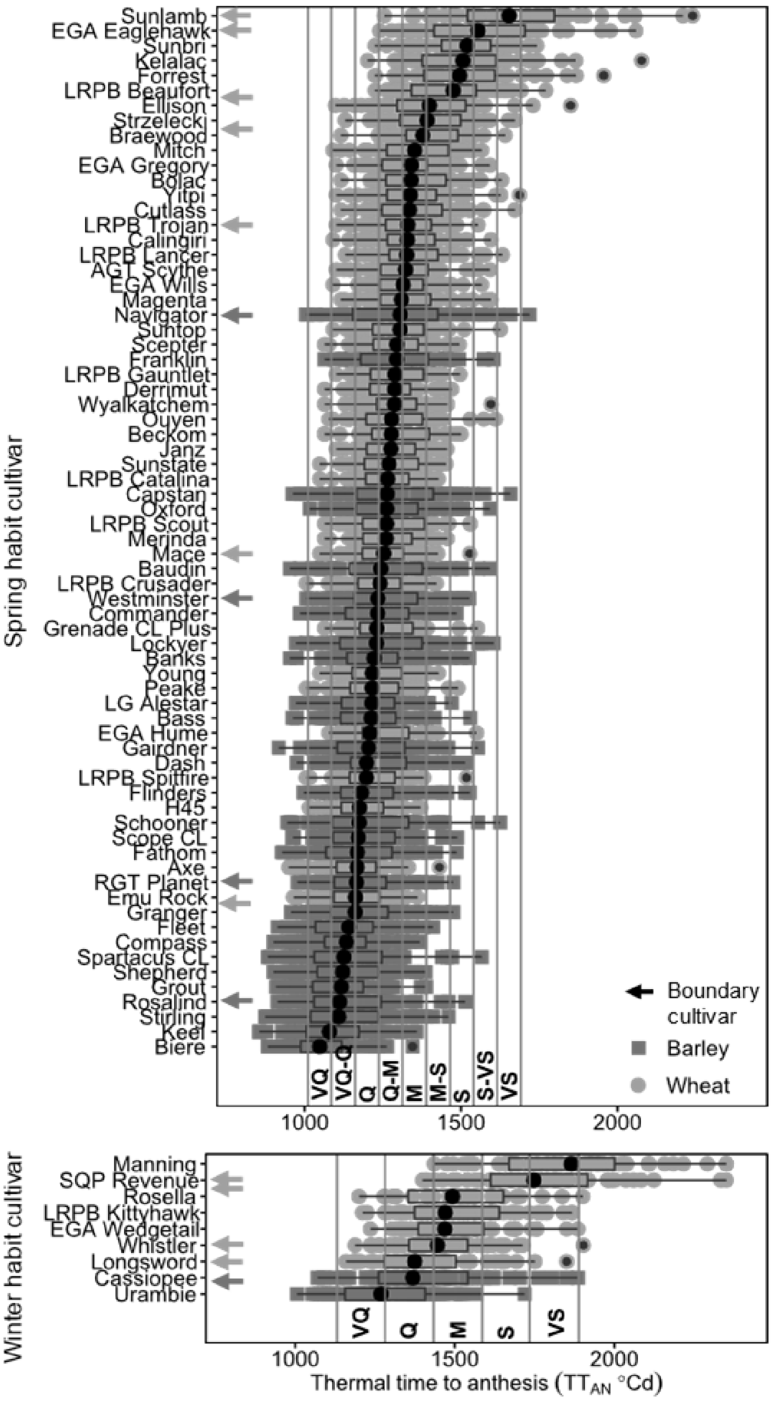

Figure 1. Model of the Australian Cereal Phenology Classification (ACPC) derived from the GRDC National Phenology Initiative G×E×M experiments. Cultivars are ranked from quickest to slowest according to median thermal time from sowing to heading. Vertical lines indicate the division of spring and winter cultivars into classification groupings. Arrows indicate the location of wheat and barley boundary cultivars separating each class. VQ, Very Quick; VQ-Q, Very Quick-Quick; Q, Quick; Q-M, Quick-Mid; M, Mid; M-S, Mid-Slow; S, Slow; S-VS, Slow-Very Slow; VS, Very Slow.

Table 1. Classes and boundary cultivars in the Australian Cereal Phenology Classification (ACPC).

	Wheat		**Barley**	
Spring	Quick boundary	Slow boundary	Quick boundary	Slow boundary
Very Quick (VQ)				< RosalindⓅ
Very Quick-Quick (VQ-Q)		< LRPB DartⓅ	≥ RosalindⓅ	< RGT PlanetⓅ
Quick (Q)	≥ LRPB DartⓅ	< MaceⓅ	≥ RGT PlanetⓅ	< WestminsterⓅ
Quick-Mid (Q-M)	≥ MaceⓅ	< LRPB TrojanⓅ	≥ WestminsterⓅ	< Navigator
Mid (M)	≥ LRPB TrojanⓅ	< CoolahⓅ	≥ Navigator	
Mid-Slow (M-S)	≥ CoolahⓅ	< RGT Zanzibar		
Slow (S)	≥ RGT Zanzibar	< EGA Eaglehawk		
Slow-Very Slow (S-VS)	≥ EGA Eaglehawk	< SunlambⓅ		
Very Slow (VS)	≥ SunlambⓅ			
Winter	Quick boundary	Slow boundary	Quick boundary	Slow boundary
Very Quick (VQ)		< LongswordⓅ		< Cassiopee
Quick (Q)	≥ LongswordⓅ	< Whistler	≥ Cassiopee	
Mid (M)	≥ Whistler	< DS BennettⓅ		
Slow (S)	≥ DS BennettⓅ	< SQP RevenueⓅ		
Very Slow (VS)	≥ SQP RevenueⓅ			

How to classify new cultivars according to the ACPC

To classify a newly-released cultivar according to the ACPC, the phenology of the new cultivar must be assessed relative to that of the boundary cultivars across a range of environments and times of sowing to which the cultivar is adapted. Multiple site-years of data are required for accurate classification because heading date can vary substantially across latitudes, seasonal conditions and sowing dates.

To classify a new cultivar according to the ACPC:

- conduct a field experiment with the new cultivar and the boundary cultivars of that species
- collect data on head emergence and air temperature
- for every plot, calculate the 50% heading date and the thermal time from sowing to 50% heading
- calculate the median thermal time from sowing to heading for every cultivar
- rank the cultivars from quickest to slowest by median thermal time to heading
- assign a classification to the new cultivar based on where it is ranked relative to the boundary cultivars
- repeat this process for every site-year

- determine the overall classification for that cultivar based on the most common classification across all site-years.

For accurate measurements of crop development in a population of plants, heading should be measured as per Celestina et al. (2023), whereby a subset of plants in each plot is tagged and monitored twice a week to record the number of fertile culms that have the spike fully emerged with the peduncle visible (for wheat) or the awns visible above the flag leaf ligule (for barley). The 50% heading date is calculated as the date on which half of all spikes in the sample area have headed, and then thermal time from sowing date to heading date is calculated as the cumulative average daily air temperature, adjusted for species-specific cardinal temperatures as per Celestina et al. (2023).

Case study: classifying new wheat and barley cultivars

Data from field experiments carried out in New South Wales in 2021–2022 were used to classify some of the more recent wheat and barley cultivars released to market. There were 45 wheat and 16 barley cultivars, around half of which had not previously been classified according to the new ACPC scheme. Spring cultivars were sown at Breeza (2021), Condobolin (2021–2022) and Dirnaseer (2021–2022) across three times of sowing from 22 April to 16 June, and winter cultivars were sown at Wagga Wagga (2021–2022) at three times of sowing from 10 March to 25 April.

The protocol above was used, whereby new cultivars were compared to the boundary cultivars at multiple site-years and then the most common classification assigned. Note that these experiments used the original boundary cultivars published in the ACB Guide (2020), so the ranking and classification shown in Figure 2 is tentative and may be subject to change with more data. However, although some cultivars may change classes, they generally only move +/- one class and so the implication for cultivar selection and time of sowing decisions is minimal.

Figure 2 shows the overall phenology classification of each cultivar based on the most common classification for that cultivar across all site-years. The thermal time to heading of previously unclassified spring barley cultivars ranged from Beast⌽ (VQ) to Nitro (Q), but most were classed as VQ-Q between the boundary cultivars Rosalind⌽ (VQ-Q) and RGT Planet⌽ (Q). Previously unclassified spring wheat cultivars ranged from Borlaug 100⌽ (Q) to Valiant CL Plus (M-S), with most falling in the middle of the range on either side of LRPB Trojan⌽ (M) and Coolah⌽ (M-S). All unclassified winter wheats were determined to be slower than DS Bennett⌽ (S). These classifications now need to be validated by assessing their phenology relative to that of the ACPC boundary cultivars.

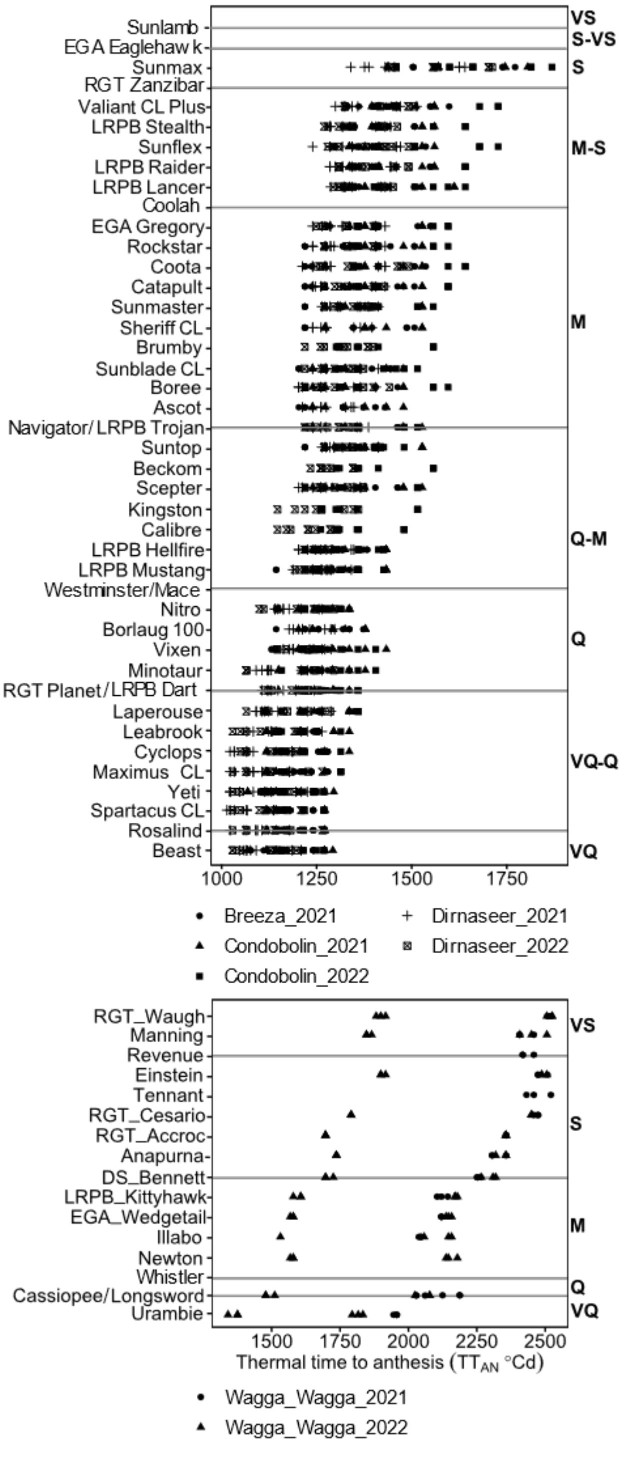

Figure 2. Cultivars in the 2021–2022 field experiments conducted in Breeza, Dirnaseer, Condobolin and Wagga Wagga classified according to the Australian Cereal Phenology Classification (ACPC). Cultivars are ranked from quickest to slowest according to their overall phenology classification across all site-years. VQ, Very Quick; VQ-Q, Very Quick-Quick; Q, Quick; Q-M, Quick-Mid; M, Mid; M-S, Mid-Slow; S, Slow; S-VS, Slow-Very Slow; VS, Very Slow.

Conclusion

The Australian Cereal Phenology Classification (ACPC) has been derived from a dataset representing the full diversity of G×E×M for wheat and barley in the grain producing regions of Australia. This classification scheme will help growers better match crop life cycle to seasonal conditions in their environment, maximise yields achieved with new cultivar releases, and reduce confusion across regions. The same methodology used to derive the ACPC can be applied to other cereals and crop species to standardise descriptions of crop phenology across Australia.

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Novel seed traits - An update on recent R&D

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Key words

breeding, climate resilience, seedling establishment and growth, weed competitiveness

GRDC codes

CSP00182, SLR2103-001RTX, DAQ2104-005RTX, CSP1907-001RTX

Take home messages

- The long-term climate trend is for increasing summer rain and later autumn sowing breaks throughout the Australian wheatbelt. Long coleoptiles and hypocotyls will permit deeper sowing of winter crops into summer-stored subsoil moisture allowing timely, earlier germination, and crop growth to occur under conditions optimal for maximising water productivity.
- Breeding improved establishment, which together with greater early vigour, should increase weed competitiveness to aid in weed and herbicide management, and increase nutrient uptake/nutrient-use efficiency. Greater biomass with higher vigour should also facilitate the breeding of crop varieties for later sowing in frost-prone regions or where dry sowing and double-knock weed control strategies are commonplace.
- Methods developed in assessment of seedling vigour in wheat are being translated into canola and other crops to hasten the identification of new genetics and speed the delivery of improved crop varieties for changing climates.

Aims

To identify and validate traits contributing to timely and reliable seedling emergence and greater seedling root and shoot growth.

Translate learnings in genetic improvement of seedling establishment and growth in wheat to other crops in order speed delivery of new crop varieties with improved adaptation to changing climates.

Background

The seed contains all the necessary nutrients, sugars, and primordia for the first 3–4 weeks of seedling growth. All components are necessary in optimising coleoptile (or hypocotyl) and shoot and root growth, highlighting that seed quality sets the potential for establishment and early growth of the crop.

Environmental challenges including competition by weeds, reduced soil moisture and high temperature, chemical and physical soil constraints, and sowing depth can act to limit this potential to reduce plant numbers and, where extreme, result in crop failure. Genetic variation is available to meet these challenges, and tools are being developed to assist breeders in the release of new crop varieties that, together with improved systems knowledge, will improve early crop growth, particularly with increasing climate variability.

This update paper highlights current research in genetic understanding to improve seedling growth and particularly increased emergence and establishment, and early leaf and root development. Presented examples are focused on wheat and include translation of learnings from wheat to adoption in other crops.

Improved wheat establishment

Timely and successful plant establishment is critical to crop productivity in rainfed farming systems. Early emergence combined with optimal phenology increases yield potential due to a longer duration for root, tiller and crop growth while ensuring conditions are suitable for growth and flowering, and during grain-filling. Well-established crops also provide ground cover to protect soils, reduce water loss through soil evaporation, and increase crop competition with weeds.

Changing weather patterns are associated with proportionally greater summer rainfall and increasingly later sowing breaks (Flohr et al. 2021; Scanlon and Doncon 2020). There is increasing interest in deep sowing into subsoil moisture (at depths up to and exceeding 10cm) to better utilise sowing opportunities after summer and early autumn rainfall and ensure earlier germination and establishment (Rich et al. 2021; Flohr et al. 2022). However, the shorter coleoptiles and hypocotyls of many current crop varieties limit sowing depths to less than 10cm and commonly as shallow as 3–5cm. High-throughput phenotyping methods have been developed and fine-tuned to screen global germplasm and identify genetic sources for use in breeding. At the same time, recognition of the critical importance of characteristics in the seed in improving seedling establishment and early growth has focused efforts in assessment of global germplasm in breeding greater shoot and root vigour.

The long coleoptile Mace⦶ experimental line (‘Mace18’), containing a new *Rht18* dwarfing gene, established well at sowing depths of 120–140mm (up to 80% of 40mm control depth) across southern, eastern and western Australia in 2020, 2021 and 2022 (for example, see Figure 1). Establishment with deep sowing of the experimental line Mace18 was as good as the older tall, long coleoptile wheat variety Halberd. Coleoptile lengths were measured at lengths of 120mm+. By contrast, the shorter coleoptile of commercially available Mace⦶ reduced establishment with deep sowing (30–40%). The new AGT variety Calibre⦶ also emerged well with deep sowing compared to Mace⦶ and Scepter⦶ (Figure 1). Grain yields were significantly ($P<0.01$) greater for deep-sown Mace18 in 2020 and 2021, and we are awaiting yield data in 2022 at up to 10 sites throughout Australia. Crop modelling analysis of previous research and grower data suggests an 18-20% increase in wheat productivity with improved establishment when deep-sowing particularly when targeting early-to mid-April sowing dates (Zhao et al. 2022).

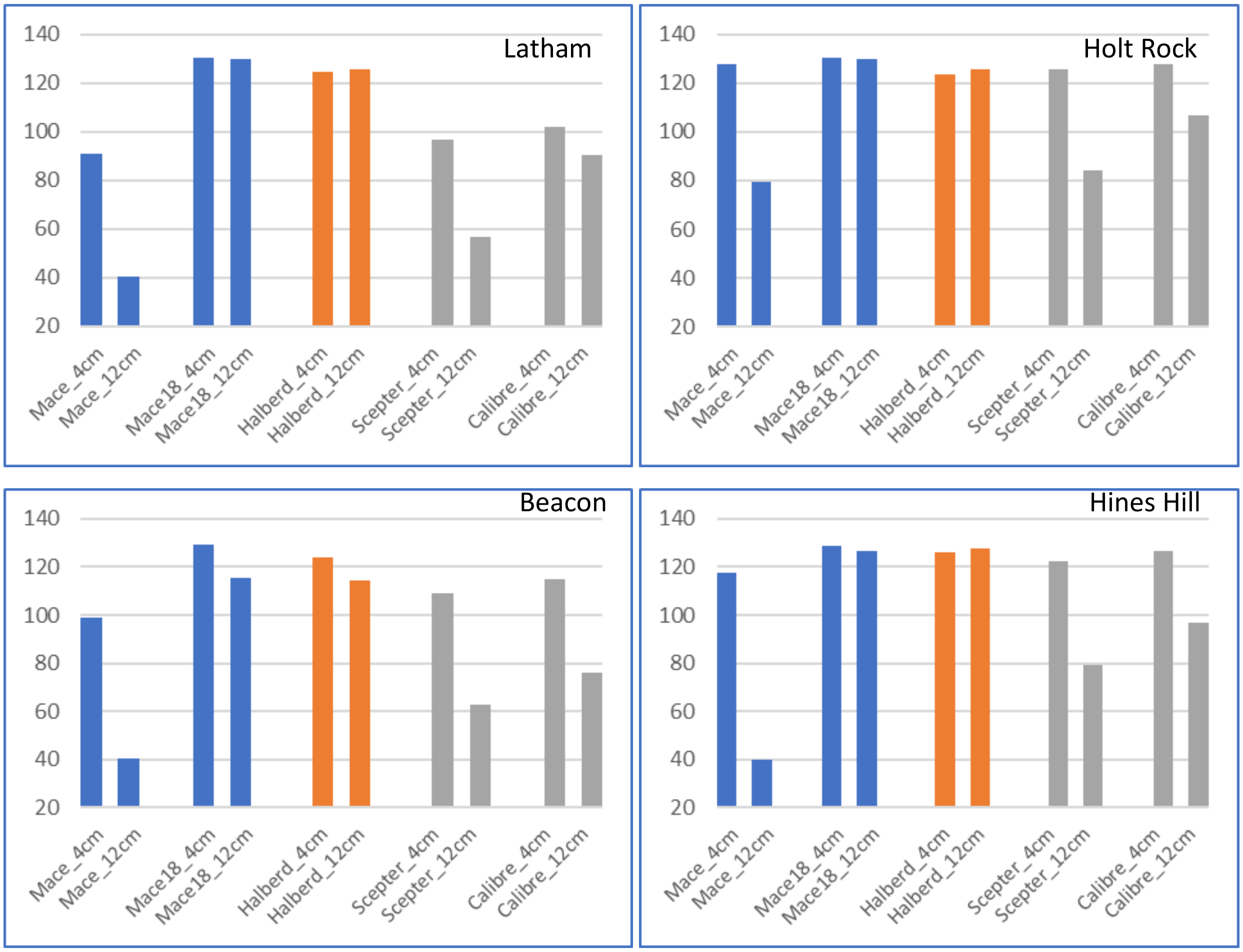

Figure 1. Mean number of plants/m² (at 200°Cd) at four WA sites in 2021 for shallow-sown (4cm) and deep-sown (12cm) Mace⏀ *Rht2* and *Rht18* NILs ■, tall, long coleoptile variety Halberd ■, and commercial *Rht2* dwarfing gene varieties Scepter⏀ and Calibre⏀ ■. Lsds were 8, 16, 6 and 6 plants per m² for Latham, Holt Rock, Beacon and Hines Hill, respectively.

Improved canola establishment

Poor establishment of canola (*Brassica napus* L.) is a widespread problem in Australia and globally with an average 50% or less of germinable seeds successfully establishing (McMaster et al. 2019). New laboratory-based, screening methods were adapted from wheat for high-throughput assessment of hypocotyl length. Figure 2(a) shows significantly ($p<0.05$) longer hypocotyls in three overseas canola varieties compared with representative Australian varieties. As in wheat, validation of laboratory conditions was needed to confirm performance with deep sowing in the field. Figure 2(b) summarises emergence data for Boorowa (one of four sites) in 2021 for the best Australian and overseas canola varieties under laboratory conditions. At the 50mm sowing depth, the three longest hypocotyl overseas varieties had significantly ($p<0.05$) higher emergence rates than the best Australian variety. As in wheat, rapid laboratory-based screening methods appear effective in identifying varieties with improved establishment potential. Experimental data from 2022 confirm these field-based results are repeatable.

Similarly, preliminary results indicate genetic variation for greater mesocotyl length among oat gene breeding germplasm (Tanu et al. 2023). As for wheat and canola, the potential exists in breeding oats with improved establishment when deep-sowing. As oats are the only winter cereal possessing a mesocotyl, sowing deeper than wheat maybe possible but requires validation.

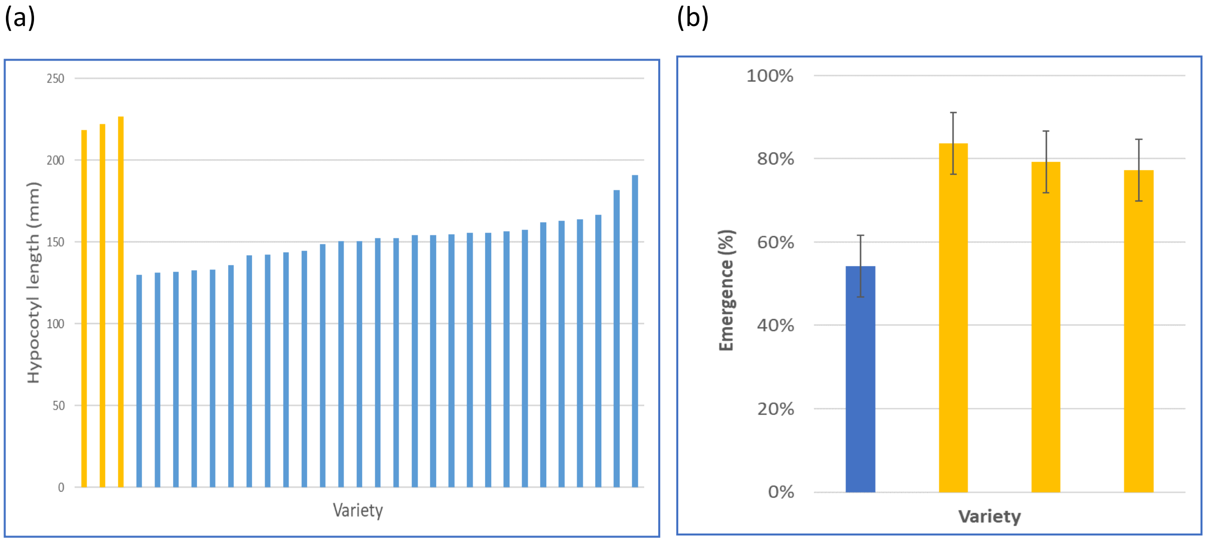

Figure 2. (a) Laboratory-based hypocotyl length for three selected overseas canola accessions (yellow) and 28 Australian varieties (blue) (Lsd = 25mm); and (b) percentage seedling emergence with deep-sowing (5cm) in the field for the best overseas long hypocotyl accessions (yellow) and best Australian canola variety (blue).

The laboratory-based methods and physiological understanding developed over three decades in wheat are being translated and modified accordingly to fast-track breeding in other crops. It is predicted that crop varieties with potential for deep-sowing will be available across most crops in the next decade to aid in de-risking poor establishment with predicted changes in the amount and timing of Australian rainfall and increasing soil temperatures.

High early vigour for improving performance with late sowing

Reductions in April–May rainfall have been mirrored by a shift in increasing rainfall later in the season (Cai et al. 2012). Growers are therefore faced with the decision to sow dry and risk poor germination. Additionally, double-knock herbicide strategies, soil amelioration, double-cropping, and pest and disease control all take considerable time to complete at the beginning of the season. The option to sow later in the season would provide more time to remediate soils and implement necessary weed control strategies. However, later sowing is tightly linked to growth under cooler temperatures, in turn reducing crop biomass and grain number to reduce yield.

New high early vigour genetics bred over 30 years at CSIRO has shown promise in rapid growth after emergence, even when sown later in the season. Figure 3 summarises grain yields at Wagga Wagga in 2021 for experimental high vigour breeding lines (CW17#66-35, CW18#58-B11 and LCH9396) and commercial varieties at two sowing dates. Later sowing reduced time to flowering from an average 133 to 107 days ($p<0.001$), and reduced grain yields (yet still exceeded 5t/ha). The experimental high vigour lines (‘CW_’) achieved the same higher yields as the more vigorous commercial varieties Condoᶲ and Vixenᶲ despite not being selected for grain yield. Of the different plant traits measured, the strongest association with grain yield in the later sowing was with increased plant height, greater early biomass and ground cover (Green et al. 2023). These high vigour genetics have been delivered and are being used in commercial breeding programs.

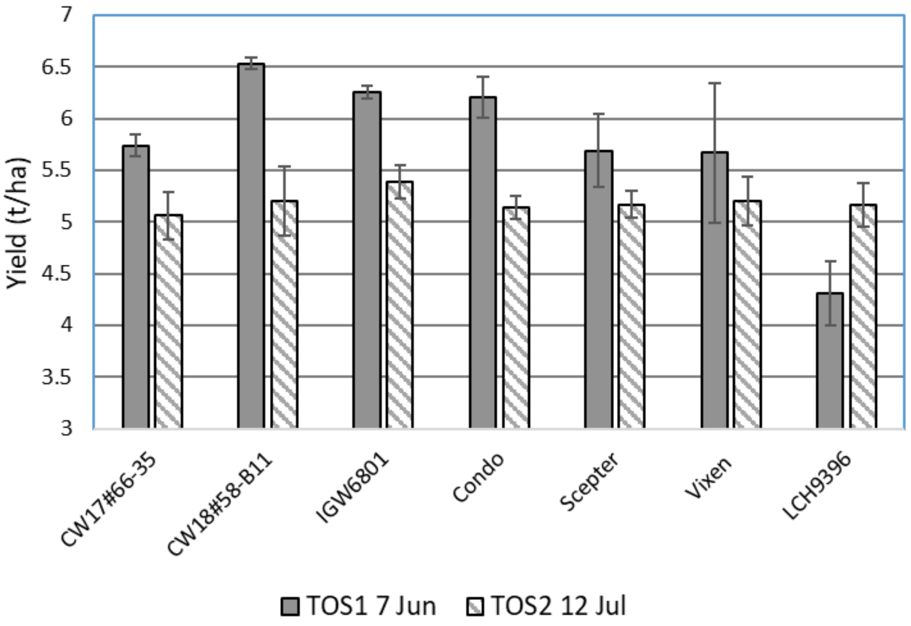

Figure 3. Grain yields of selected wheat lines sown on two sowing dates (TOS) at Wagga Wagga in 2021. Closed horizontal bars represent standard errors. Lsd (Genotype) = 0.75t/ha, Lsd (TOS) = 0.11t/ha, Lsd (Genotype × TOS) = 1.07t/ha.

Greater seedling vigour to increase crop competitiveness

Herbicide resistance, together with the high cost of pre-emergent herbicides, represent a substantial cost to Australian growers. Yield losses of up to 25% are sometimes reported where weed control is inadequate, while carryover of weed seed can present a major cost in subsequent crops while increasing risk with herbicide resistance with already limited chemical control options. Older crop varieties were very effective in competing with weeds. They were taller and produced greater leaf area early in the season to compete with weeds for light, while there was indication of their ability to also compete effectively below-ground (Hendriks et al. 2022).

Figure 4 summarises the significant ($p<0.05$) reduction in ryegrass biomass in high early vigour (HV) selected Wyalkatchemᶲ and Yitpiᶲ derivatives carefully assessed in seedling pouches. The influence on wheat vigour in reducing ryegrass growth was consistent at moderate (635 plants/m^2) and high (1270 plants/m^2) ryegrass densities, and whether growth of the ryegrass was competing above- or below-ground with the wheat. The suppression of ryegrass growth by the high vigour lines was more than two-fold the suppression of ryegrass growth by the low vigour parents. The results in this controlled laboratory assessment are consistent with field observations currently being analysed (P. Hendriks unpublished data).

Conclusions

The seed contains all the necessary machinery to assure the first 3–4 weeks of seedling growth. The potential for excellent establishment and early growth can be massively enhanced with the right genetics and high quality seed. Seed quality is determined by conditions through seed growth, harvest and storage, and can be readily assessed with germination and vigour testing.

Current research into genetic control of coleoptile and hypocotyl growth, and seedling shoot and root vigour are highlighting the potential for new crop varieties to be more resilient with changes in climate. Together with improved climate modelling and agronomy, new genetics will support opportunities in breeding for system resilience to climate change while reducing risk in weed and nutrient management. Learnings from wheat are being translated into other crops, thereby fast-tracking the breeding and farming systems requirements with the new genetics.

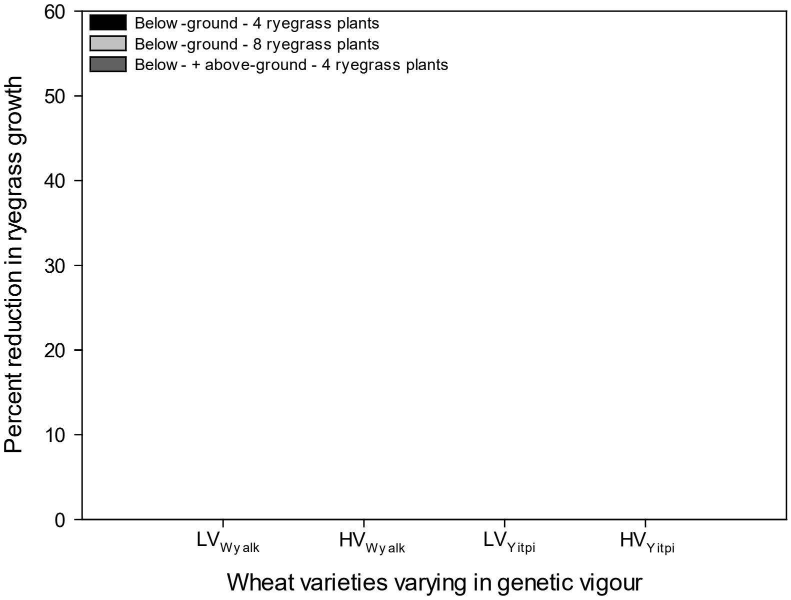

Figure 4. Reduction in ryegrass growth (biomass) for low vigour (LV) wheat varieties Wyalkatchem and Yitpi and their high vigour (HV) bred derivatives when assessed for below-ground competition in seedling pouches containing four or eight ryegrass seedlings and with above- and below-ground competition with four ryegrass seedlings. The four and eight plants correspond to 635 and 1270 ryegrass plants/m^2. Differences between high and low vigour varieties for ryegrass biomass was statistically significant ($p<0.05$) for all treatments.

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Dual purpose wheat and canola research in northern New South Wales – varieties, agronomy, TOS and production performance

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Notes

HOW ARE YOU GOING? LOOKING AFTER YOU TO LOOK OUT FOR OTHERS

CAMILLA HERBIG & TAMMY ELWIN
RURAL ADVERSITY MENTAL HEALTH PROGRAM

'You are your biggest asset'

In any business, the wellbeing and decision-making abilities of the operators can significantly impact profitability and effectiveness. Wellbeing and stress management is an integral component to any successful operation.

Mental Health

Mental health is a state of wellbeing where we can cope with normal stressors, work productively and contribute to our community.
Mental illness is a diagnosable condition affecting thoughts, emotions, behaviours and relationships.
We all sit on the continuum from well to unwell depending on our stress and coping. The earlier we can identify and manage stress, the more likely we are to recovery quickly. However unaddressed stress can lead to a larger range of concerns or illness.

We all carry an invisible 'stress bucket'. Stressors fill the bucket and if unaddressed it can become hard to carry or overflow if we can't cope. It is important to recognise what contributes to your stress bucket and what strategies help to relieve the stress.
The cost of mental illness is up to $70B/year including cost of services, carer support and lost productivity (absenteeism = $9.6B, presenteeism = $7B).

So what can you do?

SUPPORT OTHERS

Signs someone is struggling:

- Angry or irritable
- Worried or nervous
- Loss of concentration or interest
- Low energy
- Unusual headaches and body aches/pains
- Relationship issues
- Changes in sleeping and eating patterns
- Increased drug and alcohol use to cope

How to open the conversation:

- Choose a quiet, comfortable place
- Talk about what you have noticed and why you are concerned
- Listen, don't just try to solve their problems
- Reassure that help is available

Some starting questions:

"I haven't seen you lately, what's been happening?"
"You look a bit run down, how are you going?"
"I've noticed..."

Getting help

See a GP and get a Mental Health Treatment Plan (referral to a mental health professional)

Specialised Clinicians: ask the GP about a local or online psychologist, mental health nurse, social worker, or counsellors, or visit healthdirect.gov.au to find someone.

Phone and online supports: *Lifeline* - 13 11 14 *Head to Health Information* - headtohealth.gov.au *MensLine* - 1300 789 978 mensline.org.au *Kids Helpline* - 1800 55 1800 kidshelpline.com.au

NSW Mental Health Line: for advice and referral - 1800 011 511

AccessLine: Murrumbidgee area advice and referral - 1800 800 944 **Emergency Services:** 000

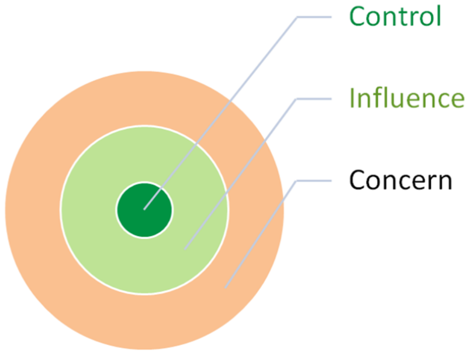
ASSESS YOUR OWN WELLBEING

Take time to reflect and recognise stressors and symptoms being experienced. Use a self assessment tool to see where you're at and identify actions you can take. Examples include RAMHP 'How Are You Going' poster or BeyondBlue online 'Mental Health Check-in Tool'

REORIENT/REFRAME THINKING

- Control: sleep, diet, exercise, socialising, media intake, taking steps to plan your work day and scheduling holidays
- Influence: conversations with others, family reactions, the decisions our clients make
- Concern: community issues, media, adverse events, weather

Focus more on what is within control to feel more proactive and responsive rather than reactive to concerns you cant impact.



'Circles of Control, Influence and Concern' (Stephen Covey)

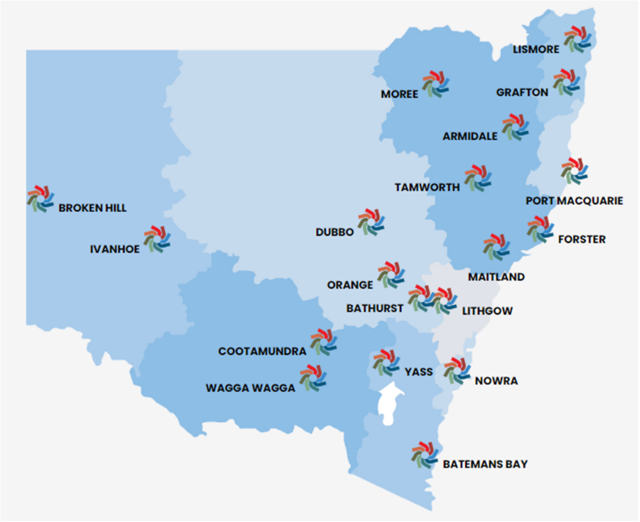
LOOK AFTER YOURSELF

Find what works best for you:

- Reach out for support, debriefing
- Do things you enjoy
- Be mindful, take some time out
- Eat well, sleep well
- Moderate use of alcohol
- Be active – physically, mentally, socially
- Set goals
- Plan/prepare for busy times
- Seek help early

For more models, search PERMA or Recovery Rocket

RAMHP has 20 Coordinators across rural NSW who provide specialist knowledge and support for people experiencing mental health concerns. To find your local Coordinator or view our range of downloadable resources, factsheets, podcasts and research visit **www.ramhp.com.au**



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Finding profit in the face of increasing input costs, interest and land value

Simon Fritsch, Agripath

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Notes

Day 2 – Early risers discussion – Soil acidity

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Notes

New pre-emergent herbicides – how are they performing?

Christopher Preston, School of Agriculture, Food & Wine, The University of Adelaide

Key words

crop safety, pre-emergent herbicide, solubility, annual ryegrass, dry sowing

Take home messages

- Understanding the properties of pre-emergent herbicides and soil types is essential for the effective use of pre-emergent herbicides
- Crop damage most often occurs in soil types with low organic matter or where the herbicides are not adequately separated from the crop seed
- Less soluble pre-emergent herbicides are generally safer to use for dry sowing

Understanding pre-emergent herbicide behaviour

Annual ryegrass control is becoming increasingly reliant on pre-emergent herbicides due to the increasing frequency of resistance to post-emergent herbicides. Pre-emergent herbicides are more complex to use compared to post-emergent herbicides. There are a number of factors that need consideration for successful use of pre-emergent herbicides. These include: behaviour of the herbicide, soil type and organic matter content, rainfall patterns prior to and after application of the herbicide, seeding system and crop tolerance.

Table 1 provides the relative behaviour of recently registered pre-emergent herbicides and compares the newer products to existing products. The key factors are water solubility and binding to soil (K_{oc}). The more soluble a herbicide is, the further it will move through the soil with each rainfall event. On the other hand, higher binding to soil components will reduce herbicide movement.

Table 1. Behaviour of some pre-emergent herbicides used for grass weed control

Pre-emergent herbicide	Trade name	Solubility (mg L^{-1})		K_{OC} (mL g^{-1})	
Carbetamide	Ultro®	3270	Very high	88.6	Medium
S-Metolachlor	Dual Gold®, Boxer Gold®*	480	High	226	Medium
Metazachlor	Tenet®	450	High	45	Low
Cinmethylin	Luximax®	63	Medium	300	Medium
Bixlozone	Overwatch®	42	Medium	400	Medium
Prosulfocarb	Arcade®, Boxer Gold®*	13	Low	2000	High
Propyzamide	Edge®	9	Low	840	High
Triallate	Avadex® Xtra	4.1	Low	3000	High
Pyroxasulfone	Sakura®, Mateno® Complete*	3.5	Low	223	Medium
Aclonifen	Mateno® Complete*	1.4	Low	7126	High
Trifluralin	TriflurX®	0.2	Very low	15,800	Very high

*Boxer Gold contains both prosulfocarb and S-metolachlor, Mateno Complete contains aclonifen, pyroxasulfone and diflufenican

Solubility and binding need to be considered in relation to soil type and rainfall events. All herbicides will tend to move further in soils with a high sand content, due to the larger gaps between the soil particles. The main soil component responsible for herbicide binding is organic matter. Herbicides will bind less to soils with low organic matter and will be more mobile.

Rainfall is a key factor in herbicide performance. Low rainfall after herbicide application will not activate the less soluble herbicides, while high rainfall after application can move the more soluble herbicides further into the soil, resulting in crop damage. Whether the soil is dry or contains moisture at application will also influence herbicide movement. Herbicide movement through the soil will always be greater for a given rainfall size, regardless of herbicide solubility, if the soil is dry compared to a soil with moisture in the top few cm. Differences in environment between years means that pre-emergent herbicide efficacy and crop safety can vary.

Inherent crop tolerance is the ability of the crop to tolerate the herbicide if the herbicide reaches the crop seed, roots or coleoptile. Crop tolerance to pre-emergent herbicides is improved through the use of knife-point, press-wheel seeding systems that throw herbicide treated soil out of the crop row and onto the inter-row. The less inherent tolerance a crop has, the more important it is to keep the herbicide away from the crop seed. Where soil types or environmental conditions provide a greater risk of crop damage, sowing the crop deeper may mitigate some of the risk. Where a rate range is available on the label, using the lower rate in lighter soil types or higher risk situations can also reduce crop damage. Crop competition is an important component of effective pre-emergent herbicide performance. The crop will reduce seed set of survivors and later emerging weeds. Therefore, damaging the crop with pre-emergent herbicides to obtain extra weed control can be counterproductive.

New pre-emergent herbicide registrations and characteristics

Carbetamide (Ultro®) Group 23

This herbicide provides grass weed control in pulse crops. Despite its high solubility, most pulses (except chickpeas) have high inherent tolerance. This means there is little danger of crop damage in the tolerant pulse crops. In lighter soil types, high rainfall can move the herbicide too far and reduce the length of control provided.

Cinmethylin (Luximax®) Group 30

Luximax is registered for the control of annual ryegrass, barley grass and silver grass in wheat (not durum wheat). Its higher solubility means that it has provided high levels of control of annual ryegrass, particularly when there is less rainfall after sowing. However, moderate solubility and moderate binding to organic matter have resulted in crop damage where heavy rainfall has occurred after sowing, even on heavier soil types. Cinmethylin is safest to use when the soil profile is close to full prior to application.

Bixlozone (Overwatch®) Group 13

Overwatch is registered for control of annual ryegrass, silvergrass and some broadleaf weeds in wheat, barley, canola, field peas and faba beans. Overwatch is not as mobile as Luximax due to lower solubility and higher binding. However, in conditions when the soil is dry at application and there is heavy rainfall after sowing, crop damage can occur. Damage is greatest on barley crops, whereas other crops are more tolerant.

Metazachlor (Tenet®) Group 15

Tenet is registered for control of annual ryegrass, several other grasses and some broadleaf weeds in canola. The higher solubility of metazachlor and low binding have resulted in crop damage with the highest label rate of Tenet, particularly where there is high rainfall after sowing. The lower rate generally provides insufficient control of annual ryegrass. In TT canola, a lower rate of Tenet can be mixed with triazine herbicides. This provides effective control of annual ryegrass with generally good crop safety. Tenet also has an early post-emergent registration mixed with clethodim. The high solubility of metazachlor means little rainfall is required to activate the herbicide. However, control of ryegrass will be best when applied at the 2-leaf stage.

Mateno® Complete (a mixture of pyroxasulfone, aclonifen and diflufenican) Groups 15, 32 and 12

This herbicide can be used for control of annual ryegrass and some other grass weeds in wheat (not durum wheat) and barley. When used pre-emergent, control and behaviour will be similar to Sakura as all the components have low solubility. Rainfall is required after application to activate the herbicide. The aclonifen and diflufenican components of the product will improve control of other grass weeds compared with Sakura. Mateno Complete also has an early post-emergent registration at a similar timing to Boxer Gold. This provides the opportunity to extend annual ryegrass control and to control some broadleaf weeds. The lower solubility of the herbicides in Mateno Complete compared to Boxer Gold means more rainfall after application is required to activate the herbicide. This means the early post-emergent application of Mateno Complete will be most useful in higher rainfall regions.

What are the best products for dry sowing?

Using pre-emergent herbicides with dry sowing is challenging as there is no way of predicting when and how much rainfall will occur at the break. A long period between sowing and getting sufficient rainfall to activate the herbicides can lead to some herbicide losses and a shorter period of persistence after the crop emerges. Of more concern is where there is a large rainfall event to start the season. As the soil is dry, large rainfall events will move the herbicides further into the soil profile, increasing the risk of crop damage.

As with all other uses of pre-emergent herbicides, soil type, soil organic matter, herbicide behaviour and seeding system need to be considered when choosing an appropriate pre-emergent herbicide. In terms of herbicide behaviour, trifluralin remains the ideal pre-emergent herbicide when dry sowing. It has low water solubility and binds tightly to organic matter (Table 1). This means it has less chance of moving far enough into the soil to cause crop damage. Herbicides with high water solubility and more mobility in soil, such as Tenet and Luximax, are not suited to dry sowing.

The other aspect of dry sowing is managing the risk of the herbicides not activating in time to control weeds. This is most likely to happen with low solubility herbicides like Sakura and Mateno Complete. A way to manage this is to mix with a herbicide that needs less rainfall to activate, such as trifluralin or Avadex® Xtra. Trifluralin requires less moisture as it works as a gas and turns into a gas on contact with water. Avadex Xtra is absorbed by the coleoptile rather than the roots, so does not need to be moved as far through the soil.

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Advances in the biological control of flaxleaf fleabane with a novel rust fungus

Ben Gooden, CSIRO

Key words

Conyza bonariensis, crop weed, plant pathogen, *Puccinia cnici-oleracei* (ex. *Conyza*), weed biological control

GRDC code

RDC1607-003OPX

Take home message

The long-term aspiration of the biocontrol program is to reduce the growth and reproductive output of flaxleaf fleabane plants in marginal habitats, reduce invasion pressure on crop fields and in turn reduce the reliance on chemical herbicide application to control the weed, especially during fallow.

CSIRO's research has shown the rust fungus to be a safe addition to the flaxleaf fleabane control 'toolbox', yet research into the efficacy of the biocontrol agent in a field setting has only just commenced. Future research is needed to optimise release methods and monitor the effects of fungal infection on weed populations over multiple growing seasons.

Introduction to the biological control of flaxleaf fleabane in Australia

Flaxleaf fleabane (*Conyza bonariensis*) is an annual herb, native to South America, that has become a significant agricultural weed of the grain growing regions of south-eastern Australia, where it greatly disrupts crop production (Wu 2007). This weed is a prolific seed producer that can spread long distances by both wind and water, thus necessitating an area wide approach to its management (Wu 2007). Example images of plant morphology and habitats prone to infestation are provided in Figure 1.

Flaxleaf fleabane affects crop production by greatly reducing stored water supplies in fallow, which affects subsequent crop emergence and growth. In recent years, the density and geographic extent of flaxleaf fleabane populations have expanded across south-eastern Australia, in part as a result of the adoption of minimum tillage practices that enhance seed survival and provide suitable conditions for germination and establishment. Populations of flaxleaf fleabane have also evolved resistance to some herbicides, making herbicide-resistant populations increasingly difficult to manage in many agricultural environments. Consequently, flaxleaf fleabane has become one of the most damaging summer fallow weeds in the northern grain region, with an estimated revenue loss in excess of $43 million per year for Australian grain producers (Llewellyn et al. 2016).

Flaxleaf fleabane infestations are considered by many grain growers to be particularly problematic in fallow, along roadsides, fencelines and irrigation embankments adjacent to crop fields. Flaxleaf fleabane populations are often able to proliferate in marginal habitats due to limited resources available for their control and challenges in coordinating control actions across various stakeholder groups that manage different land tenures in cropping regions. Uncontrolled flaxleaf fleabane populations in these marginal habitats in turn produce copious seeds that easily disperse to nearby crop fields, replenish the soil seed bank, and emerge in subsequent seasons. A key aim of management, therefore, is to reduce the reproductive viability of marginal flaxleaf fleabane populations and invasion pressure in adjacent crops.

Classical biological control (hereafter biocontrol) involves the introduction of a plant's natural enemy (usually an herbivorous insect or fungal pathogen) sourced from its native range, with the aim of reducing the weed's performance (usually a reduction in growth, competitive ability and/or reproductive output). Biocontrol represents a potentially valuable complementary control method for the management of flaxleaf fleabane given the success of previous biocontrol programs against other weeds in the Asteraceae family, such as parthenium (*Parthenium hysterophorus*) and skeleton weed (*Chondrilla juncea*). Indeed, the biocontrol of skeleton weed is deemed one of the most successful broadscale weed biocontrol programs in Australia (Ward 2014). By the 1950s, skeleton weed was considered one of the most destructive weeds in Australian productive systems. In the 1960s, CSIRO established the CSIRO Biological Control Unit in France (now the CSIRO European Laboratory), with the aim of identifying natural enemies of the weed that could potentially act as biocontrol agents in Australia. Subsequently, a rust fungus (*Puccinia chondrillina*) was identified and found to be highly host-specific to skeleton weed after rigorous risk assessment. The fungus was released into Australia in the 1970s (the first plant pathogen approved for deliberate introduction to Australia to help control a target weed) where it became widely established and dramatically reduced the population of the weed (by >80% in some areas) – benefits that have been sustained over the following five decades (Cullen 2012 and data provided to Ward 2014 by J Cullen).

The aims of the current CSIRO-led research into the biocontrol of flaxleaf fleabane were to:

(a) identify candidate biocontrol agents that attack flaxleaf fleabane in its native range

(b) undertake comprehensive host-specificity testing to demonstrate that they do not pose a threat to non-target plant species, and

(c) if approved by the authorities, release the biocontrol agents into Australia to help control the weed.

In this paper, CSIRO presents a summary of research that was undertaken to:

- select the microcyclic rust fungus *Puccinia cnici-oleracei* from Colombia (South America) as a candidate biocontrol for flaxleaf fleabane in Australia
- undertake host-specificity experiments to demonstrate the candidate agent's safety for native and other important plant species in Australia, and
- undertake a small trial release of the rust fungus into the Australian environment in partnership with grain growers and other related stakeholders.

It should be noted that CSIRO has also identified and is currently undertaking host-specificity trials for several potential insect biocontrol agents on flaxleaf fleabane, including the stem-boring weevil *Lixus caudiger* identified in Brazil.

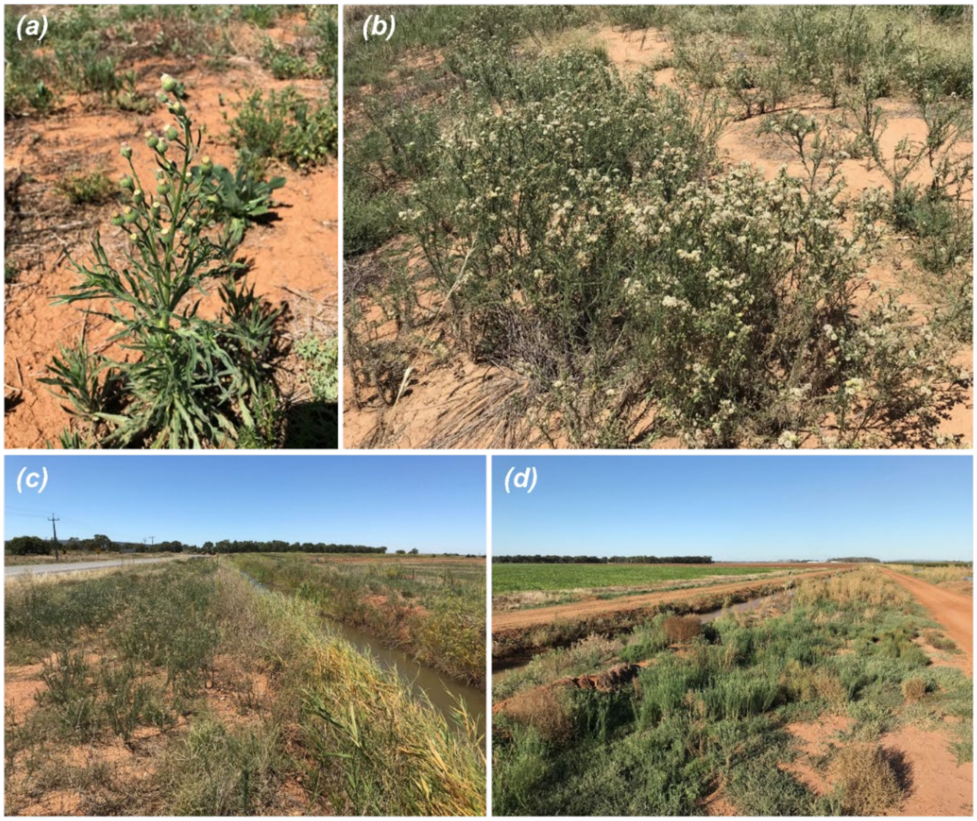

Figure 1. Example of (a) flaxleaf fleabane plant and (b) dense infestation in fallow; (c-d) examples of marginal habitats (e.g., roadsides, irrigation embankments, field margins, drainage lines) where residual flaxleaf fleabane populations are often not managed during the growing season and provide a seed source for re-invasion into adjacent crop fields.

Identification and risk assessment of the candidate biocontrol agent

In 2017, flaxleaf fleabane was endorsed by the Australian Government's then Invasive Plants and Animals Committee (currently Environment and Invasives Committee) as a target for biological control. Subsequently, between November 2017 and May 2019, exploratory surveys for pathogens on *Conyza* species were performed in different regions of Colombia (South America), where pathogenic fungi had been previously recorded on *Conyza*. A microcyclic rust fungus, *Puccinia cnici-oleracei*, was identified during these native range surveys and prioritised as a candidate biocontrol agent for further host-specificity testing as described below (Morin et al. 2020).

The rust fungus infects young and old leaves, stems, and green flower parts of flaxleaf fleabane (Figure 2). The fungus obtains all its nutrients from flaxleaf fleabane by establishing intimate contact with the plant's cells. Through continuous diversion of nutrients from the plant, the fungus reduces rates of photosynthesis, plant growth and reproduction but does not kill the plant altogether. Once a fungal spore germinates and penetrates the host plant leaf tissue, visible symptoms (yellowish speckling, followed by emergence of dark pustules where spores are produced) become evident after 2-4 weeks, after which time the infected leaves begin to die off (Figure 2). It is predicted that, if the fungus establishes widely and causes severe disease, it will decrease the reproductive output of flaxleaf fleabane populations and reduce the weed's invasion potential in cropping areas.

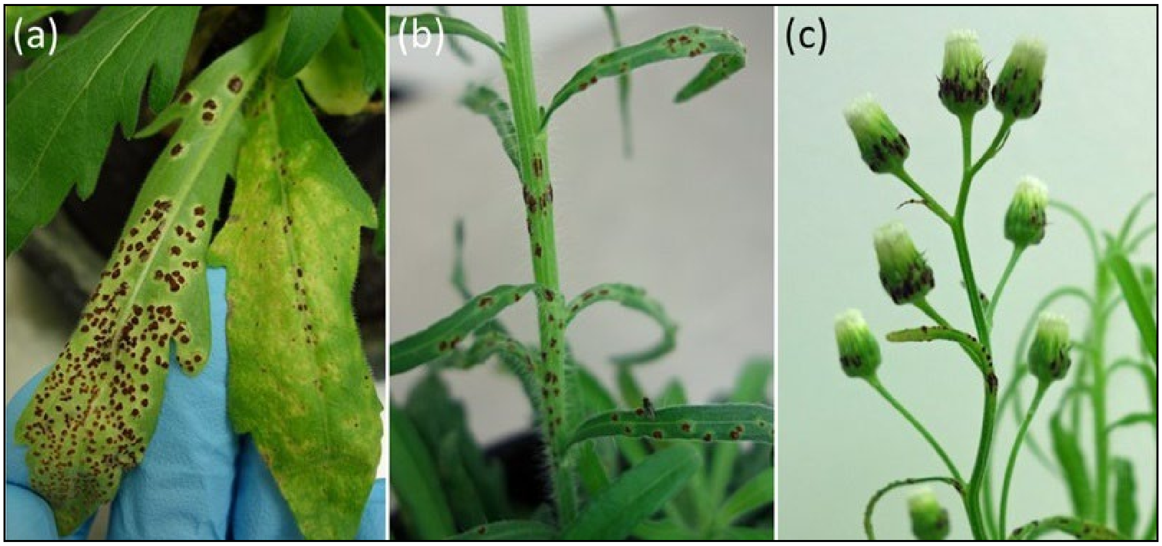

Figure 2. Characteristic disease symptoms caused by the flaxleaf fleabane biocontrol agent; a rust fungus named Puccinia cnici-oleracei. The fungus can infect leaves (a), stems (b) and flower heads (c). The dark brown pustules represent the reproductive stage of the fungal lifecycle, where spores are produced then released to infect nearby plants and gradually spread through the local flaxleaf fleabane population.

Candidate biocontrol agents are approved for release from quarantine into the Australian environment to help control a target weed only once rigorous host-specificity testing has been completed and the agent is shown to pose no risk of significant damage to non-target plant species. Such tests typically involve exposing a set of priority non-target plant species (including native Australian plants, ornamental and other important species) to the candidate agent under optimal conditions for growth and development, then assessing the level of damage to the plant and ability for the candidate agent to develop and complete its lifecycle.

In 2019, CSIRO commenced rigorous evaluation of the potential risks that the rust fungus could pose to non-target plant species in Australia (Morin et al. 2020). Research focused on species within the family Asteraceae that are most closely related to flaxleaf fleabane. This extensive host-specificity testing was performed in a quarantine facility and involved exposing flaxleaf fleabane and non-target plant species to the rust fungus under optimal conditions for infection. It was found that the fungus is highly host-specific to flaxleaf fleabane, is unable to complete its lifecycle on other plant species and poses no threat to the Australian environment (comprehensive results provided in Morin et al. 2020). Based on these research results and following a comprehensive risk assessment process and public consultation, the federal government regulators (then Department of Agriculture, Water and the Environment, DAWE) approved the release of the biocontrol agent into the Australian environment in June 2021.

An overview of current research on host-specificity trials for the stem-boring weevil *Lixus caudiger* can be found at https://research.csiro.au/flaxleaf-fleabane/progress-rrnd4p-rnd-4/.

Experimentally assessing the impacts of the biocontrol agent on flaxleaf fleabane

In December 2021, the fungus was experimentally released under field conditions on greenhouse-propagated flaxleaf fleabane seedlings. The aim of this experiment was to determine if flaxleaf fleabane plants could be successfully infected by the dried specimens of the lab-cultured rust fungus under variable light, humidity and temperature conditions in the Australian environment. The experiment was hosted outdoors at the CSIRO Black Mountain laboratories, as ongoing COVID-19 travel restrictions prevented us from undertaking the experiment in a crop setting.

The experiment consisted of planting multiple lab-germinated fleabane seedlings into a potting mix-sand propagation substrate within plastic tubs, exposed to the following treatments:

1. Seedlings inoculated with the rust fungus, surrounded by a plastic bag to create a humid microclimate to stimulate sporulation;
2. Seedlings inoculated with the fungus but without a plastic enclosure;
3. Seedlings not inoculated with the fungus (control; note the control plants were not covered by the plastic bags).

Twelve replicate seedlings per treatment were used. The fungal spores were applied using a passive process by first hydrating dried infected leaves obtained from the lab culture for 1-2 hours in a water bath, mounting them onto bamboo stakes with the pustules facing downwards, then covering the bamboo stake and healthy plants with a plastic bag to maintain a warm and humid microclimate for at least 12 hours until the fungal spores had been released (Figure 3). The seedlings were then placed on a nursery bench outdoors under prevailing light, humidity and temperature conditions, to allow for development of infection symptoms within an environmental context. Seedlings were watered *ad libitum* to prevent dehydration in between rainfall events.

Post-inoculation monitoring consisted of randomly selecting 15 leaves per seedling and estimating the % cover per leaf showing symptoms of fungal infection. Approximately 2 weeks after the recipient plants were inoculated with the rust fungus, we detected characteristic signs of infection – i.e., light yellow-green speckles across the leaf surface (Figure 4). Strikingly, all 12 plants within the infected-covered treatment showed signs of infection. On average, 53 % of leaves were infected (presence/absence) and 18 % of the surface area of those leaves showed symptoms. However, only a single leaf on a single seedling in the infected-uncovered treatment had symptoms of infection, and none in the non-infected control seedlings. This provided evidence that maintaining a still, humid microclimate at the time of inoculation is critical for successful infection transfer of the fungus to flaxleaf fleabane seedlings under field conditions. Approximately 6 weeks post-infection, the inoculated seedlings that showed the early signs of infection (yellowish speckles) had developed dark brown lesions consistent with severe fungal infection and completion of the fungal lifecycle (Figure 4).

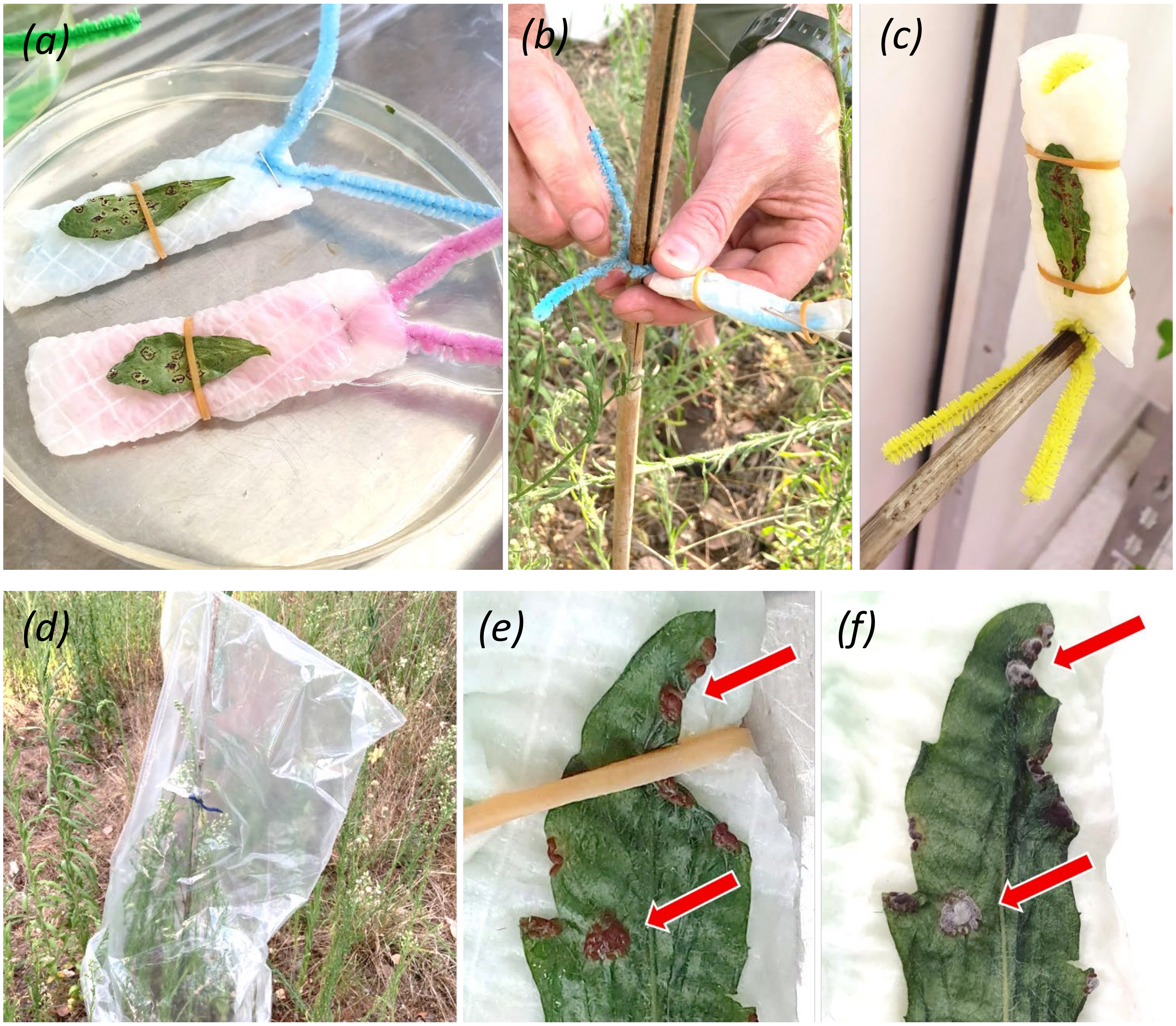

Figure 3. The process of setting up the biocontrol agent release. Dehydrated, infected leaves are (a) rehydrated in a water bath then (b-c) mounted and tied to a stake with rehydrated pustules facing downwards which is placed over a set of healthy flaxleaf fleabane plants and (d) covered with a plastic bag for at least 12 hours to maintain a humid and warm microclimate. Successful release of viable spores is indicated if the pustules turn from brown (e) to a fluffy grey colour (f).

Figure 4. Infection symptoms on flaxleaf fleabane plants experimentally inoculated with the rust fungus under field conditions.

Levels of infection, plant growth and reproductive output were monitored monthly to May 2022. Multiple infection events occurred between January and May 2022, whereby the first set of lesions that developed in January produced spores that spread to nearby healthy leaves that subsequently became infected, and so on. In this way, infection progressed over the entire body of each plant as they developed through to adulthood, with lesions eventually being detected on stems, inflorescences and flower heads. These observations confirmed that the fungus was able to readily infect flaxleaf fleabane plants growing outdoors over multiple months, under variable prevailing climate conditions.

At the conclusion of the experiment, plants were harvested, dried, and measured for height, biomass, number of inflorescences (flowering stems), capitulae (flower heads) and infection levels. There was no difference in the biomass of flaxleaf fleabane plants between the different inoculation treatments (data not presented). This may have arisen because the non-infected control seedlings eventually became infected with the fungus from spores spreading from the nearby infected plants. Future experiments would need to retain non-infected control plants for the duration of the experiment using fungal exclusion treatments to truly test the effects of infection on plant growth in the field.

A linear regression analysis revealed that reproductive output (measured as the number of flower heads per inflorescence, y-axis on Figure 5c) declined significantly with increasing percentage of leaves infected by the fungus ($R^2 = 0.15$, $F = 8.6328$, $P = 0.0050$); note the contrasting condition of the inflorescence with severe infection by the fungus and distorted, stunted flower heads (Figure 5a) versus the healthy inflorescence not infected by the fungus (Figure 5b). On average, severely infected inflorescences produced 50-60% fewer flower and seed heads than non-infected inflorescences (Figure 5c). These results indicate that, under optimal conditions supporting high infection severity, the fungus can reduce the overall reproductive output of host plants. Reduced reproduction is likely a direct consequence of the fungus lowering the photosynthetic efficiency of infected leaves, in turn reducing the plant's ability to assimilate available carbohydrates into inflorescence development and flower and seed production.

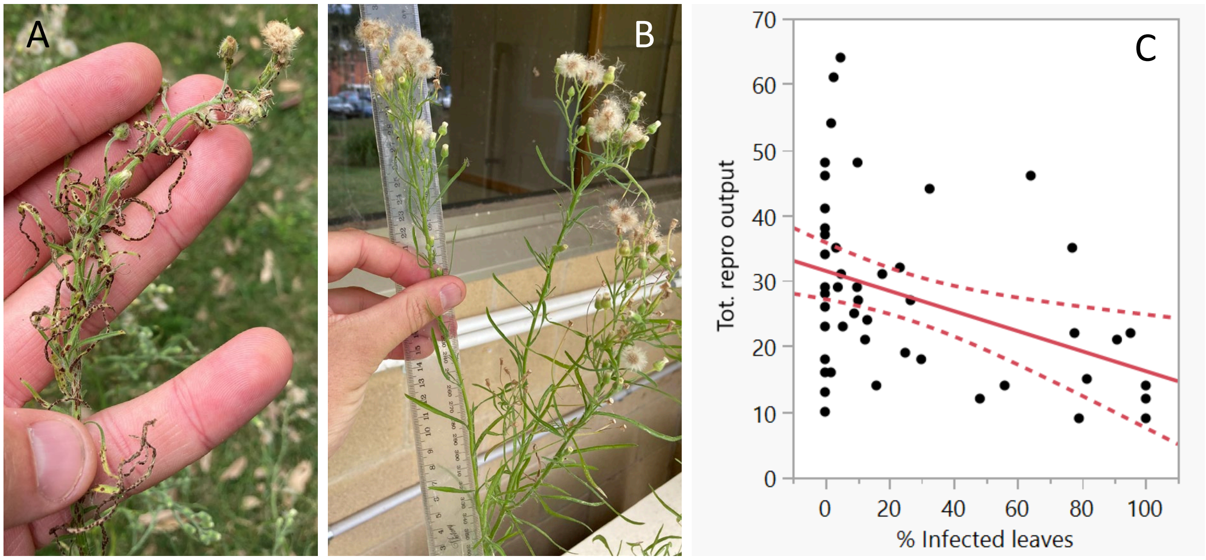

Figure 5. Results of fungal inoculation experiment on the reproductive output of host flaxleaf fleabane plants: (a) heavily infected and (b) non-infected inflorescences, and (c) linear relationship between reproductive output (number of flower heads per inflorescence) and % of infected leaves per inflorescence.

Pilot releases of the rust fungus throughout Australia with community stakeholders

Commencing in September 2022, CSIRO launched a small pilot program in partnership with select landholders and other weed management stakeholders from the grain sector that aimed to trial release of the rust fungus on flaxleaf fleabane across south-eastern Australia using the bamboo stake-bag method described above. Interest from potential participants in the program was elicited through a joint GRDC-AgriFutures-CSIRO media campaign. 54 stakeholders were selected for participation in the program, comprising 39 private landholders/growers, 7 professional agronomists, 3 research institutes (University of Sydney, CSIRO, Northern Territory Arid Zone Research Institute), 2 biosecurity officers from local councils, 2 plantation industry groups and 1 Landcare network. Altogether, participants were sent 336 biocontrol agent release kits for dissemination in the field using the agreed release method. Releases were made nationwide, focussing on the south-eastern parts of Australia where flaxleaf fleabane infestations cause the greatest impacts on crop yield (25 releases in NSW, 16 QLD, 5 SA, 5 VIC, 2 TAS, 1 NT, Figure 6).

Releases of the rust fungus were made by registered participants between late September and mid-December 2022 during fair weather days, usually shortly after periods of rainfall under high humidity conditions, in marginal areas adjacent to crop fields (e.g., fencelines, roadsides, drainage ditches, field in fallow) with a dense foliage coverage of flaxleaf fleabane. Participants were sent release kits containing dried flaxleaf fleabane leaves infected with the rust fungus and comprehensive instructions on how best to release the fungus to maximise likelihood of infection of recipient flaxleaf fleabane host plants. In March 2023, CSIRO will work with stakeholders to monitor for signs of fungal infection at the release sites and quantify overall rates of infection and identify regions and habitat conditions under which infection is most likely to occur. The results of this small pilot release program will improve the efficiency by which the biocontrol agent is released in future as part of a potential larger scale, nationwide mass-release program across Australia.

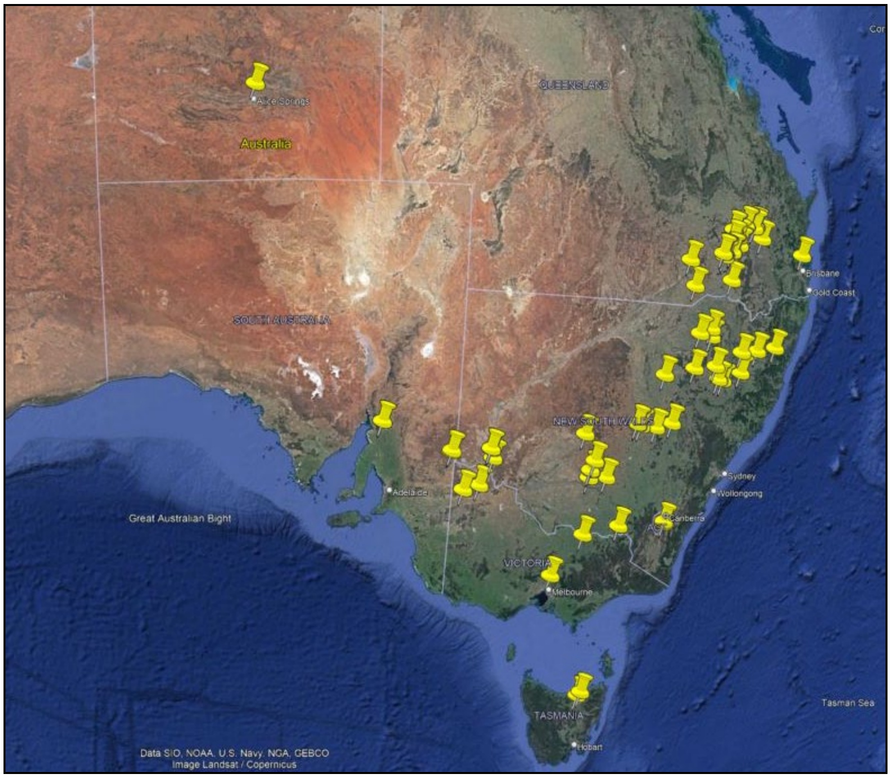

Figure 6. Distribution of biocontrol agent release sites across south-eastern Australia.

Management implications and future research aspirations

The long-term aspiration of the biocontrol program is to reduce the reproductive viability of flaxleaf fleabane plants in marginal habitats, invasion pressure on crop fields and in turn reduce the reliance on chemical herbicide application to control the weed, especially during fallow. CSIRO's research conducted over the past several years has shown the rust fungus to be a safe addition to the flaxleaf fleabane control 'toolbox', yet research into the efficacy of the biocontrol agent in a field setting has only just commenced, with future research needed to optimise release methods and monitor the effects of fungal infection on host plants over multiple growing seasons.

It is predicted that, even where the rust fungus establishes successfully in the field, infection is unlikely to result in significant reductions in the population size of flaxleaf fleabane for several years. As such, biocontrol represents a longer term and self-sustaining means of gradually reducing weed invasion pressure across productive landscapes. It is expected that the fungus will spread from one plant to the next very slowly at first, but the rate of spread will likely accelerate once the overall abundance of the rust fungus builds up in the local flaxleaf fleabane population. Based on our knowledge of other successful biocontrol agents that have been released previously in Australia (e.g., skeleton weed, Ward 2014), broadscale spread of the fungus would be expected to take several years. Furthermore, the combination of several biocontrol agents may enable more robust control of target weeds. In this way, further research into the biocontrol of flaxleaf fleabane with insects may provide enhanced biocontrol solutions.

When considered in isolation, classical weed biological control is not a silver bullet and will not eliminate flaxleaf fleabane from an area altogether or replace the need for deployment of chemical and mechanical control methods. However, by reducing flaxleaf fleabane's growth and seed set, biocontrol agents could slow the rate of weed spread both within and outside of cropping areas and hence reduce the frequency of re-infestation in fallow. Widespread establishment and spread of the rust fungus may gradually reduce the quantity of chemical herbicide required to suppress flaxleaf fleabane populations and may thus be especially valuable in areas where the weed has developed herbicide resistance. Future research would be required to develop methods of integrating the effects of the fungus (likely most active in marginal habitats comprising unmanaged flaxleaf fleabane populations) with intensive chemical and mechanical control methods deployed on flaxleaf fleabane infestation in fallow.

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Further information

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Exploratory surveys of the rust fungus in Colombia, South America, were coordinated by Dr Louise Morin (CSIRO), with assistance from collaborators based at the Universidad Nacional de Colombia Sede Medellín. Host-specificity testing of the rust fungus on native and other important plant species under quarantine conditions in Australia was delivered by CSIRO researchers Dr Gavin Hunter, Dr Kylie Ireland, Caroline Delaisse, and Isabel Zeil-Rolfe.

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Research into the biological control of flaxleaf fleabane with insects is being delivered by Dr Vincent Lesieur, Thierry Thomann, Mireille Jourdan, Dr Michelle Rafter and Dr Kumaran Nagalingam with assistance from collaborators based at the Universidade Regional de Blumenau (Brazil).

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Weed mapping using drones for targeted weed spraying

Ben Single & John Single, Single Agriculture

Key words

weed mapping, drones, spot spraying, weed management, chemical saving

Take home messages

- Weed maps are a significant tool in the fight against herbicide resistance, reducing the requirements for cultivation hence reducing farming carbon footprint
- Weed mapping using drones is now commercially available at significantly lower costs than conventional sprayer mounted optical spot sprayers
- Weed maps can be produced at rates of up to 250 ha/hr that can then be loaded into conventional sprayers to be used as spot sprayers
- Weed maps from drones allow for selecting weeds based on size as well as calculating the spray area prior to spraying which is the next step forward in selective spot spraying – know what to spray before you spray
- **Knowing what to spray before you spray allows for informed decisions maximising chemical efficacy and minimising spray costs resulting in cheaper, more effective weed control.**

Background

Drone-based weed mapping involves using a drone equipped with cameras or sensors to fly over a field and collect data on the location and size of weeds. The drone can be programmed to fly a predetermined flight pattern over the field, taking images at high frequency time intervals to ensure complete coverage and adequate resolution. The images and data are then processed to identify the location and size of the weeds in the mapped area, which is then converted, typically, into a prescription map. The map is then loaded into a spray rig display which turns on the individual spray sections to only spray the weeds in a spot spraying pattern across the field.

In this approach the mapping is completed prior to the critical spray timing windows and is not constrained by dust while stubble interference is minimal. The spray rigs can use standard spray nozzles (i.e. AI nozzles) to meet label requirements, can spray at full recommended speed and the capital outlay is lower than many fixed camera boom based spraying technologies. Drone-based weed mapping allows the location and size of the weeds to be identified and this enables the area to be sprayed to be calculated prior to spraying as well as options to filter based on weed size and spray area (radius) around the weeds. This is a very powerful tool and how this can be leveraged to optimise cost savings and maximise chemical efficacy will be explored in the rest of this paper. The technology described here does not distinguish weeds species from crop species unless there is a clear size difference where the weed is much larger than the crop, consequently the technology described here is mostly applied to fallow scenarios with some exceptions. The scenarios below are examples of completed weed maps and the advantages they offer in weed control.

Fallow situation with dual line spraying with one blanket spray line and one spot spray line

Situation

A winter fallow spray event in July 2022, near Coonamble NSW, with fresh weed germination (small weeds) after a rain event and advanced milk thistle (*Sonchus oleraceus*) that were randomly distributed across the paddock. Conventional spray application would require a blanket spray of glyphosate @ 2.2L/ha and mixing partner costing $42.40/ha which would be enough to target milk thistle as well as eliminate the smaller weeds, however if only the small germinating weeds were targeted, the chemical rates required to treat the weeds in the paddock would be significantly less. In this situation, this paddock would not be economically viable for conventional spot spraying (i.e., broom spray mounted camera with live weed recognition) due to the high density of small weeds that the conventional spot spraying systems would spray.

Drone weed mapping

The field was mapped using the Single Shot® drone weed mapping system with a coverage rate of 200ha/hr at a cost of $1.30/ha. The data was analysed using the inbuilt tools at various weed diameters to determine spot spray areas as per Figure 1.

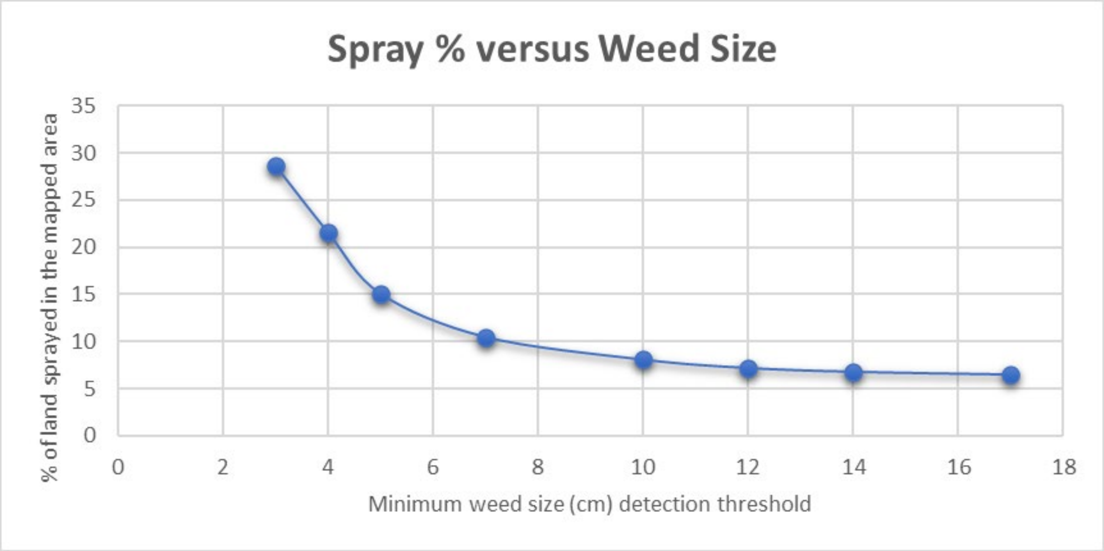

Figure 1. The estimated percent of land sprayed (y axis) in the mapped area as impacted by weed size (x axis). The smaller the weed size detection limit - the larger the land area that requires spraying.

The key observations from the graph are:

- Spot spraying milk thistle which had a diameter of 15cm or larger results in ~7% of the land area (done mapped area) being spot spray however;
- Reducing the minimum weed size threshold from 15 to 7cm results in the % of land sprayed in the mapped area increasing from 7 to 11%, meaning a greater number of weeds could be targeted with higher chemical usage without a dramatic cost increase,
- The drone mapping system has a minimum weed detection size of 3-4cm and size detection can be used to inform when it's most appropriate to move to a blanket application. For example, where the weed size detection limit is change by 1 cm (e.g. from 4 down to 3 cm detection) and the % of land sprayed in the mapped area increases significantly (e.g. >5% per cm of weed),

ground truthing with paddock inspection would be necessary to identify if blanket application was the best approach.

Solution

A blanket spray at 1.4L/ha glyphosate and mixing partner in spray line one, plus an additional spot spray in spray line 2 at 1.4L/ha glyphosate, and mixing partner as a spot spray rate on the weeds 7cm and greater. It should be noted that a higher chemical rate used on milk thistle did not significantly increase the overall cost, but the efficacy on milk thistle was significantly increased. This approach resulted in a saving of $13.40/ha as well as a much more successful control of milk thistle. This analysis and decision making was all made prior to any spraying and would not be possible without the ability to both calculate spray areas, spray volume as well as selectively targeting different sized weeds.

Green-on-green using size differences mapped by drone

Situation

Feathertop Rhodes grass (*Chloris virgata*) was growing in a wheat crop (Figure 2) after being unsuccessfully controlled prior to planting. There is no current in crop treatment available, with the typical treatment being an application of appropriate pre-emergent herbicides post-harvest as well as higher cost knock down herbicides applied during fallow periods.

Figure 2. feathertop Rhodes grass in wheat

Drone weed mapping

The field was mapped using the Single Shot® drone weed mapping system with a coverage rate of 200ha/hr at a cost of $1.30/ha. By using a minimum weed size detection diameter of 7cm, the wheat was removed from the weed map leaving just the feathertop Rhodes grass (FTR) displayed on the map. By itself, this isn’t particularly useful as the FTR will have matured and seeded by the time of mapping. The advantage in this situation is that the software also includes the ability to set a radius around each plant as a target zone which is part of a necessary solution.

Solution

A radius around each FTR plant was estimated to cover the likely seed rain area around FTR plants. This assisted the targeting of a pre-emergent herbicide applied post-harvest to control seed banks in these limited areas, killing FTR seedlings as they emerged and significantly reducing chemical usage. This strategy also reduces the risk level associated with herbicide residue impacts on future crops. Maps can be kept and used in later years for additional targeted pre-emergent applications as well as a useful forensic tool to determine the effectiveness of the control methods used. Additionally, a knock down can be used to target the existing plants if a registered option is available.

Of note in this example, is that there was an ideal time for weed detection (early crop development) and an ideal time for weed treatment (post-harvest) and they were vastly different. This process can also be applied to weeds that do have selective herbicides available, for instance marshmallow in wheat. Detection can be at an early stage of the wheat development, (e.g. similar to Figure 2), and then treatment can be at a later date to comply with the label and minimise crop damage.

Combine drone weed maps with other spatial data

Situation

A field with areas of black and red soil was due to be sprayed in November prior to sorghum planting which contained low levels of windmill grass and fleabane amongst other more easily controlled weeds. When inspecting the paddock, it was noted that the windmill grass was almost exclusively present in the red soil areas of the field while fleabane and other weeds were distributed across the paddock (both soil colours). Typical application would be to either blanket or spot spray to control both the windmill grass, fleabane and other weeds throughout the whole paddock, with products and rates determined by the harder to control weeds.

Drone weed mapping

The field was mapped using the Single Shot® drone weed mapping system and processed using a minimum weed diameter of 7cm and the weed map was then loaded into Google Earth® (Figure 3). The different soil types can clearly be seen. The processing software was used to draw polygons to only output weed maps in the red soil area and calculate the spray area for the selected polygon. This feature is normally used to define fields (field boundaries) but can also be used to define other areas (see Figure 3 example).

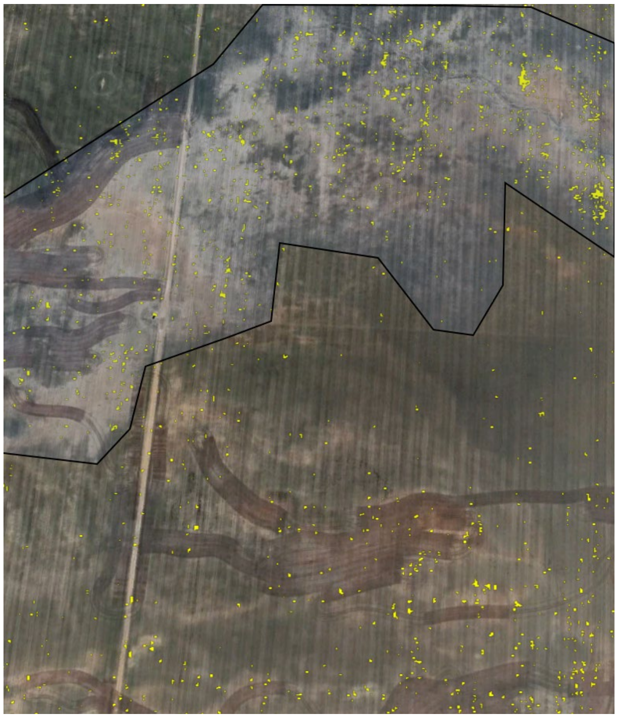

Figure 3. Google Earth® overlaid with weed locations (small yellow atches) and red soil area enclosed in the polygon. Windmill grass was confined to the red soil area. Other weeds were distributed across both soil types in the paddock.

Solution

The field was segmented as per Figure 3 with the polygon enclosed area (red soil) only sprayed with the herbicides needed to target the windmill grass. Then the entire field was spot sprayed in a second application with a broad-spectrum knockdown herbicide. Segmenting the field allowed for targeted chemistry to control the windmill grass which substantially reduced cost, as these higher cost herbicides were only applied to that portion of the field where windmill grass was a problem (polygon area).

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Practicalities of integrating alternate weed management strategies in regional farming systems

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Notes

Concurrent session – Insects and other pests

Minimising the impact of insecticides on beneficials in broadacre crops

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Take home messages

- Beneficials play an important role in supressing pest outbreaks in grain crops, but their populations are frequently diminished by the use of broad-spectrum insecticides
- 'The beneficials chemical toxicity table for Australian grains' is now available to help growers and agronomists choose options that have a better IPM fit
- Increased biological control in crops can reduce the frequency of insecticide application required for pest control and minimise the risk of insecticide resistance evolving in grain pests.

Background

Biological control is an integral component of integrated pest management (IPM). Historically, the use of broad-spectrum insecticides in the grains industry has been widespread. In some crops, like canola, several insecticides can be applied between sowing and harvest. Predominantly, these have been synthetic pyrethroids, carbamates and organophosphates. These are indiscriminately highly toxic to all invertebrates and their use, particularly their repeated use, also depletes populations of beneficial insects such as the natural enemies of pests. This increases the risk of future pest outbreaks and hinders IPM programs.

Many insecticides have been registered over the last decade to control aphid, caterpillar and mite pests in the grains industry. Several newer products are promoted as selective towards pests and soft on non-target insects (and other invertebrates). However, little information is currently available on how 'soft' they really are on key beneficial groups. Cesar Australia and the GRDC have recently released a table that summarises the toxicity of foliar chemical sprays on a wide range of beneficials relevant to the grains industry. In this paper we discuss the research that went into developing this table and how this information and IPM practices can be applied on farms in south-eastern Australia in 2023.

Importance of beneficials in Australian grains

Globally, over-reliance on prophylactic chemical control has led to the emergence and spread of insecticide resistance in a range of crop pests. In the Australian grains industry, increasing resistance in key pests such as the diamondback moth (*Plutella xylostella*), redlegged earth mite (*Halotydeus destructor*), green peach aphid (*Myzus persicae*), and corn earworm/cotton bollworm (*Helicoverpa* *armigera*) exemplifies the need for a shift away from broad-spectrum chemical use. The preservation of beneficials such as insect and mite predators and parasitoid wasps to help control pest species is a central pillar of IPM farming approaches, aiming to reduce the industry's current reliance on insecticides.

Beneficials make a valuable contribution in place of, or in combination with, chemical control in managing pest species. Beneficials in grains crops include generalist predators such as spiders, lacewings, ladybird beetles and damsel bugs, as well as parasitoid wasps such as *Diaeretiella rapae*, *Lysiphlebus testaceipes and Aphidius colemani.* When it comes to the control of aphid populations, farmers often use insecticides, but aphid parasitiod wasps and other insect predators have the capacity to suppress aphid populations and keep numbers below economic thresholds. Other examples of beneficials contributing to pest control include populations of redlegged earth mite and lucerne flea being consumed by predatory mites, including French Anystis mites and snout mites, and slugs being attacked by predatory beetles. Similarly, diamondback moths and other lepidopteran pests may be controlled by parasitiod wasp species such as *Diadegma semiclausum, Apanteles ippeus, Diadromus collaris and Trichogramma* spp., as well as by shield bugs, native earwigs, tachinid flies and spiders.

Impacts of current management practices on beneficials

The application of broad-spectrum foliar insecticides kills beneficials as well as pests. In some instances, this loss of beneficials from paddocks may lead to secondary pest outbreaks which would otherwise have been biologically controlled. This scenario is common and contributes to reliance on insecticides alone to control pest outbreaks. One of the easiest ways to reduce the impact of insecticides on beneficials is to use insecticides that have the least impact on these species (i.e., are the least toxic). Until now, the Australian grains industry has not had readily available information on the impact of insecticides on key beneficials. Between 2020 and 2022, Cesar Australia conducted standardised toxicity testing on many beneficials important to grains and assimilated this with existing studies into a toxicity table. This resource provides useful information growers and advisors need to make management decisions with preservation of beneficials in mind.

Methods

Generation of natural enemy toxicity data

Key beneficials and insecticides of importance to the Australian grains industry were identified through a literature review and industry consultation. Where knowledge gaps existed for particular beneficials or the results of previous studies were unclear, insecticide toxicity ratings through laboratory testing were generated following standardised protocols from the International Organisation for Biological Control (IOBC). In short, petri dishes were sprayed with insecticides at rates consistent with on-farm application at the maximum registered field rate (MRFR) in Australian grains. Once insecticide residue had dried (30-60 minutes), beneficials were added to dishes and their mortality observed over the next 2-3 days. This was repeated for 30 individuals of each species and survival percentages were calculated.

Development of the toxicity table

The resulting data was analysed, standardised and collated with previous research from Australia and overseas into a toxicity table. When needed, the data was condensed (e.g., by grouping related species) to make it a practical guide for growers and advisors. In the table, a rating of low (L) represents <30% mortality, medium (M) 30–79%, high (H) 80–99% and very high (VH) >99% mortality. These values represent mortality under controlled laboratory conditions – impacts in the field are likely to vary, especially if the crop gets multiple applications of insecticides. Where a range in toxicity was found among species or chemicals within a group, ratings are shown as cells with a diagonal slash, and the highest and lowest rating colours. The only natural enemy groups for which substantial gaps remain are those that cannot be obtained from commercial suppliers – namely, spiders and hoverflies. Research into these groups is ongoing, and subsequent revised table versions will be made available as these gaps are filled.

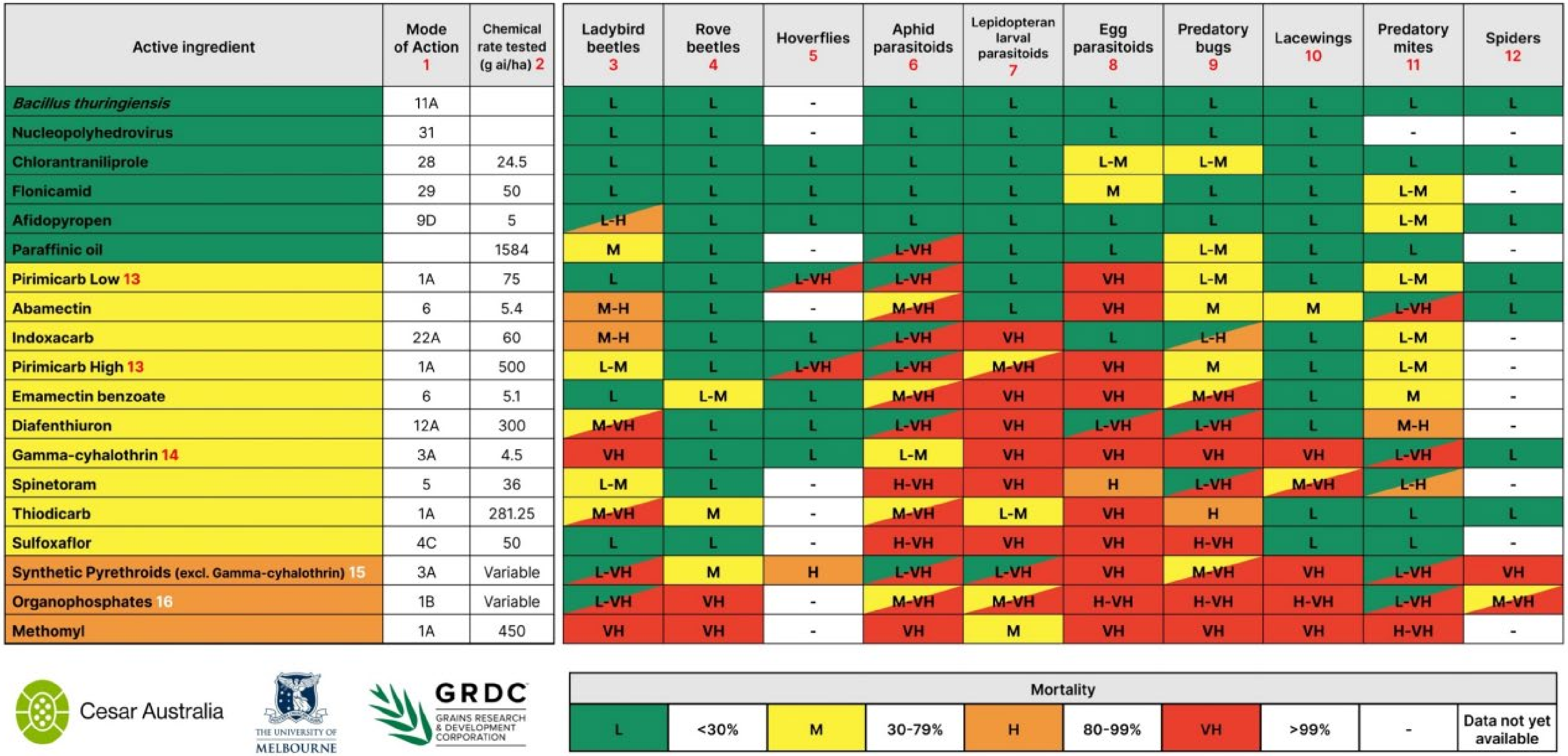
Results

In general, we found that active ingredients promoted as selective (or 'soft') produced low mortality rates (defined by the IOBC as <30% mortality) in beneficial species tested. This included the caterpillar selective chemical chlorantraniliprole, the newly registered aphid selective chemicals flonicamid and afidopyropen, and the bioinsecticides *Bacillus thuringiensis* and nucleopolyhedrovirus (NPV). These active ingredients are safe choices to use by growers dealing with caterpillars or aphids.

However, not all active ingredients marketed as soft on beneficials performed as expected. For example, despite being frequently promoted and discussed in the literature as a selective insecticide, pirimicarb was toxic to a range of beneficial species. Most striking is its very high toxicity (defined by the IOBC as >99% mortality) to some parasitoid wasp species, even at rates well below the MRFR. These parasitoids are key beneficials for the grains industry and make valuable contributions to the control of aphid pests. Pirimicarb application is therefore not compatible with IPM strategies seeking to make use of these beneficials in biological control.

A few of the tested species appeared particularly tolerant to a wide range of active ingredients, including rove beetles, hoverflies and spiders. These results show that certain beneficials may persist in a crop if it is sprayed with a relatively soft insecticide. This is encouraging for the future of IPM programs seeking to combine elements of biological and chemical control – if growers and advisers make careful selections in their choice of active ingredients, insecticides can still be used against pests with fewer detrimental impacts on their predators.

Table 1. The beneficials chemical toxicity table for Australian grains, published April 2022. https://cesaraustralia.com/resources/beneficials-toxicity-table/



Active ingredient	Mode of Action [1]	Chemical rate tested (g ai/ha) [2]	Ladybird beetles [3]	Rove beetles [4]	Hoverflies [5]	Aphid parasitoids [6]	Lepidopteran larval parasitoids [7]	Egg parasitoids [8]	Predatory bugs [9]	Lacewings [10]	Predatory mites [11]	Spiders [12]
Bacillus thuringiensis	11A		L	L	-	L	L	L	L	L	L	L
Nucleopolyhedrovirus	31		L	L	-	L	L	L	L	L	-	-
Chlorantraniliprole	28	24.5	L	L	L	L	L	L-M	L-M	L	L	L
Flonicamid	29	50	L	L	L	L	L	M	L	L	L-M	-
Afidopyropen	9D	5	L-H	L	L	L	L	L	L	L	L-M	L
Paraffinic oil		1584	M	L	-	L-VH	L	L	L-M	L	L	-
Pirimicarb Low [13]	1A	75	L	L	L-VH	L-VH	L	VH	L-M	L	L-M	L
Abamectin	6	5.4	M-H	L	-	M-VH	L	VH	M	M	L-VH	L
Indoxacarb	22A	60	M-H	L	L	L-VH	VH	L	L-H	L	L-M	-
Pirimicarb High [13]	1A	500	L-M	L	L-VH	L-VH	M-VH	VH	M	L	L-M	-
Emamectin benzoate	6	5.1	L	L-M	L	M-VH	VH	VH	M-VH	L	M	-
Diafenthiuron	12A	300	M-VH	L	L	L-VH	VH	L-VH	L-VH	L	M-H	-
Gamma-cyhalothrin [14]	3A	4.5	VH	L	L	L-M	VH	VH	VH	VH	L-VH	L
Spinetoram	5	36	L-M	L	-	H-VH	VH	H	L-VH	M-VH	L-H	-
Thiodicarb	1A	281.25	M-VH	M	-	M-VH	L-M	VH	H	L	L	L
Sulfoxaflor	4C	50	L	L	-	H-VH	VH	VH	H-VH	L	L	-
Synthetic Pyrethroids (excl. Gamma-cyhalothrin) [15]	3A	Variable	L-VH	M	H	L-VH	L-VH	VH	M-VH	VH	L-VH	VH
Organophosphates [16]	1B	Variable	L-VH	VH	-	M-VH	M-VH	H-VH	H-VH	H-VH	L-VH	M-VH
Methomyl	1A	450	VH	VH	-	VH	M	VH	VH	VH	H-VH	-

Cesar Australia

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GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

Mortality									
L	<30%	M	30-79%	H	80-99%	VH	>99%	-	Data not yet available

Use of toxicity table for informing management decisions

The beneficials chemical toxicity table for Australian grains (Table 1) is designed to assist growers and advisors in selecting insecticides that control pests while minimising the impact to beneficials. Where growers monitor and identify natural enemy species, spraying decisions can be made that preserve the biocontrol provided by resident beneficials. For example, if green peach aphids are building up and the grower wants to protect and encourage aphid parasitoids, the colour-coded mortality rating on the table makes it easy to see which chemicals to avoid, and which are safer for the parasitoid (e.g., pirimicarb could be replaced with flonicamid or afidopyropen). In situations where monitoring for beneficials is challenging, and knowledge of these species is limited, growers may select the overall least toxic chemical from the list (highest on the table) that is effective against the target pest. Table 2 gives examples of how changes in management practice of common pests in canola could have positive impacts on natural enemy populations.

Table 2. Examples of how softer pest management practices can benefit beneficials

	Historic management practices		**Softer alternatives**	
Pest issue	**Control method**	**Impacts to beneficials**	**Control method**	**Impacts to beneficials**
Redlegged earth mite	Organo-phosphates and synthetic pyrethroids	Very high toxicity to numerous beneficial groups, including predatory mites offering biocontrol	*Cultural*: Control broad-leaf weeds (e.g., capeweed) in paddocks and fence lines prior to sowing *Chemical*: Diafenthiuron	None Reduced off-target effects on rove beetles, hoverflies, predatory bugs and lacewings
Green peach aphid	Pirimicarb	Toxic to almost all parasitoids, as well as hoverflies, predatory bugs and predatory mites	*Biological*: Parasitoid wasps and generalist predators *Chemical*: Flonicamid or Afidopyropen	None Low to medium toxicity to most beneficials
Native budworm	Synthetic pyrethroids	Very high toxicity to almost all beneficial groups	Emamectin benzoate	Softer on ladybirds, rove beetles, hoverflies and lacewings
Corn earworm/ cotton bollworm	Synthetic pyrethroids	Very high toxicity to almost all beneficial groups	NPV	Soft on all beneficials

Future research

More research is needed to quantify the contribution of biological control to pest management in grain crops, as well as the sub-lethal impacts of insecticides on beneficials. In addition, field studies that validate the laboratory-derived toxicity ratings will build industry confidence in this information. While we have investigated the effects of foliar sprays, we have not considered the impacts of insecticide seed treatments on beneficial species, which, based on overseas research, are expected to be considerable to many non-target groups.

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Useful resources

Cesar Australia Beneficials chemical toxicity table (2022)
https://cesaraustralia.com/resources/beneficials-toxicity-table/

Cesar Australia blog post (2022) – “Why should we care about beneficials in grans?”
https://cesaraustralia.com/pestfacts/beneficials-in-grains/

Cesar Australia blog post (2021) – “Measuring the benefit of beneficials”
https://cesaraustralia.com/pestfacts/the-benefit-of-beneficials/

Beneficial insects – the back pocket guide (2021) GRDC
https://grdc.com.au/BPG-BeneficialInsectsSW

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How do new molluscicide products perform in wet conditions

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Key words

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

GRDC codes

DAS 00127 & 00134, MAN2204_001SAX

Take home message

"To manage we must understand."

To prepare for next season's threats, the pest's biology needs to be understood when they are breeding. For slugs, wetter and longer springs extend their breeding period, leading to greater numbers that survive over summer. Summer rainfall is not a good indicator of potential slug threats.

Management needs to choose appropriate crop protection tools based on the context in which they are to be applied. For slugs, late autumn rainfall determines what level of damage occurs: that is, a greater proportion of slugs are active the wetter it is and the slower the crop emerges.

The best product applied at the wrong time will result in poor outcomes. Choose the product based on the context in which it will be applied.

Background

Slugs are particularly damaging to establishing canola, with yield losses in untreated areas of experiments at 60%-80% (GRDC DAS00134 data). One way to estimate the cost of slugs is expenditure on molluscicide baits, which continues to increase in Australia. Bait costs are $30-$120/ha with 95% of canola in the high rainfall zone (>500mm annual rainfall) of western Victoria sown into burnt and/or cultivated ground. Where slugs are a high risk, some growers have shifted away from growing canola, especially where they cannot implement strategic burning and cultivation. That lost opportunity cost is estimated upwards of $270 million annually to the canola industry. A 5% production loss by slug and snail activity would represent a loss of more than $82 million to the Australian canola industry (2012 values).

Slug baits applied at crop establishment are protectants. Cultural methods are required to reduce populations along with the biological function of farming systems (Nash & Pilkington 2016). Baits often perform badly and must be re-applied due to field degradation and/or pest populations not actively feeding.

Slug bait technology has improved past the traditional bran-based dry processed pellets. The need to improve delivery of active ingredients to increase the number of slugs killed, while reducing environmental impacts, has seen the launch of new products with enhanced delivery systems for old active ingredients, resulting in greater return on investment due to a reduction in the kg/ha of product required. For example, new formulations of metaldehyde products kill a greater number of slugs, using less active ingredient under a broader range of conditions.

Industry research continues to focus on improving bait performance. However, the focus by some manufacturers on small pellets to increase the chance of encounter and/or harder pellets to increase rain-fastness may have also increased the chance of delivering sub-lethal doses of metaldehyde. This hypothesis needs testing relevant to Australian conditions.

Previous research (Nash *et al.* 2016) indicated some products commonly used have a limited field life; with the short-window, bran-based metaldehyde products lasting less than 2 weeks; thus, these need to be applied regularly. More expensive, long-window metaldehyde products will last 3-4 weeks when ground temperatures are below 50ºC. Temperature, not UV light, reduces the efficacy of metaldehyde baits.

Rainfall not only physically breaks down bran pellets: it causes a reduction in the number of slugs or snails killed (Table 1 Nash *et al.* 2016). Reduction of active ingredient by rainfall (metaldehyde and iron chelate) is the most important factor influencing field life of a product due to individuals being likely to consume a sub-lethal dose. Previous research recommended not to use iron chelate baits when >10mm rain is expected. However, robustness of these baits has recently been improved by the manufacturer.

All products may perform differently to manufacturer claims due to being 'rain-fast'; which is not the same as efficacy after rainfall. That is, hard pellets maintain integrity after rainfall whereas bran-based products do not; yet pellet integrity was found not to influence mortality. In this paper we present data on efficacy of products after exposure to rainfall, not 'rain-fastness'.

Data comparing physical characteristics of commonly available slug bait products (Table 1 Nash 2022[a] Slug Control Fact Sheet) indicates different products have various attributes which differ and influence field performance.

The overall aim of research presented in this paper is to improve decisions on bait applications due to differences in the field life of some products and the variable feeding of the targets; i.e., slugs and earwigs are not always active, thus do not always feed on baits. This paper combines the principles behind improving bait efficacy (Nash 2022[c]) with research on bait degradation. Laboratory assays were used to test causality of factors thought to effect field life, not compare mortality. Field trials and observations are used to support findings presented.

Slugs and other establishment pests can be controlled in no-till, full-stubble systems once growers understand the context of where and when controls are applied and follow a few basic guidelines. Bait needs to be applied when target pests are active and feeding, with the timing varying depending on paddock and seasonal conditions and the species present.

Methodology

Product field life (efficacy after exposure) was determined initially using field cages then laboratory assays run at 22ºC ± 1ºC, 80-100% RH (Relative Humidity) using field-collected Italian snails (*Theba pisana*). Bait products were weathered by spreading approximately 50g of each on the surface of soil (Warooka red loam) in large planter trays (400 x 300 x 120mm). Trays were placed on benches in an exposed position at Urrbrae, SA (2013-2015), Bairnsdale Vic (2017-2019), or Glen Osmond SA (2022). Baits were exposed to weathering for various intervals resulting in a variety of conditions. Initially, efficacy of three products was assessed by exposing them to weather at 10 day intervals over 0 – 40 days, then comparing different time periods. Then experiments focused on one factor, rainfall, for subsequent results presented in this paper, either exposed with or without rainfall at 14- or 28-day intervals. Rainfall data was collected in situ. All exposure details are provided with the results.

Field cages 2013: Cages consisted of round rings of 15cm wide flat galvanised metal sheeting formed into a 50cm diameter ring giving an enclosed area of 0.2m^2. A black fibreglass insect screen was secured over the open 'top' with taut wire and reinforced cloth tape. After snails were introduced, the cages were secured to the ground with tent pegs and loose soil was pushed up against the edges to form a seal with the ground surface. Bait product and weathering period were randomly allocated to 72 cages (n = 4) containing only dry grass and some eucalyptus tree leaf litter. The site received dappled shade from nearby trees. Cages each received 4L water to moisten the soil prior to placement of eight bait pellets (arrayed in a ring around the central snail release point) and 30 snails.

After 24 hours, 0.5L water was applied to maintain snail activity. After 2-3 days, all snails were retrieved by hand from each cage and returned to the laboratory for mortality assessment.

Lab bioassay: Adult snails were used to test the efficacy of molluscicide baits once they had been exposed to the environment on soil. Five snails were added to each test arena with eight baits as soon as practicable following the completion of weathering periods (usually within one week). Baits were removed three days after initiation of the experiment due to the formation of mould, which was scored as present/absent, and the number and condition of pellets remaining recorded. Snail mortality was assessed 4-5 days after bait was removed. Bait consumption was quantified by drying remaining product at 45°C once removed from arenas and prior to weighing. A subset of each product was used to calculate initial dry moisture content of pellets as the weight for each replicate used in assays was not a dry weight. Replicates varied per assay, with details provided with the results. All assays were fully randomised.

For a list of previously tested products see Table 1 (Nash *et al.* 2016), data is presented but note that some of those products may no longer be available or may have changed pellet properties.

Some changes to products commonly used metaldehyde in Australian broadacre and tested previously include: Metarex® and Metarex Micro® are no longer available, being replaced by METAREX INOV®. Meta® and Slugger® are no longer available, so have been replaced by Snailex as a bran-based product in more recent assays. Products commonly used in broadacre 2022:

Newly registered products: #APVMA Approval Number

- Axcela® Slug and Snail Bait, (2020-07-01) #87576 METALDEHYDE 30g/kg
- METAREX INOV® Slug and Snail Bait, (2020-07-01) #88160 METALDEHYDE 40g/kg
- IMATRADE TRANSCEND® Molluscicide and Insecticide, (2020-07-01) #88733 METALDEHYDE 50g/kg + 1.5g/kg fipronil
- IRONMAX Pro® Slug and Snail Bait, (2021-07-01) #89908 9g/kg Iron present as Iron Phosphate Anhydrous

Products with changed pellet characteristics since registered:

- IMATRADE METAKILL Snail and Slug Bait, #64990 METALDEHYDE 50g/kg
- ERADICATE Snail and Slug Killer, #68634 Iron EDTA Complex 60g/kg
- SlugOut® All Weather Slug and Snail Bait, #49324 METALDEHYDE 18g/kg
- Snailex Slug and Snail Pellets, #68580 METALDEHYDE 15g/kg

Existing products:

- Delicia® SLUGGOFF® lentils, #60931, METALDEHYDE 30g/kg

Results and discussion

What makes a good bait (adapted from Nash 2022[c])

For baits to work, some basic principles are relied upon.

Individuals must first encounter a pellet, which requires:

- Individual activity – slugs must be actively searching for food
- The number of baits to be distributed evenly – pellets/m2. Pellets need to be evenly applied across the full width of application. Consistent pellet size, weight and density ensure no area is missed. Patchy control can occur when products with high variability are used and/or application equipment is not calibrated
- Attractiveness of bait – individuals display non-random movement towards attractive pellets (true definition of bait). For example, grey field slugs are attracted to bran-based baits from 4cm whereas modern products claim grey field slugs are attracted from 6cm.

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

- Palatability – addition of feeding enhancers ensures individuals consume enough active ingredient to ingest a lethal dose. In the case of metaldehyde; which causes paralysis: consumption of a sub-lethal dose can be an issue with some products because individuals cannot ingest enough to destroy their mucous cells
- Enough bait for the target population – if product does not remain after a couple of days following application, it is usually due to large pest populations consuming it all. Re-application to those 'hot spots' will be required
- Enough toxicant in the bait – the loading of active ingredient determines the amount consumed; hence low loadings require more total product to be applied. In wet conditions, small pellets with greater surface area to volume ratios lose more active ingredient, hence less toxicant will be consumed. For products containing metaldehyde, it is generally recommended that 30–40g/kg is the optimum concentration.

Revisiting old data (adapted from DAS 00127) – Caged field data Italian snail response to baits exposed over time.

Data obtained using field cages indicated that the longer bran-based 15g/kg metaldehyde baits were exposed over the summer / autumn period, the lower their efficacy. This period corresponds with when applications are recommended to control snails in SA. The decline in efficacy fits with local management practices that re-apply 'short-window' bran-based 15g/kg metaldehyde baits in the autumn once snails are active, and before egg laying occurs. Efficacy data was analysed in response to accumulated temperature, accumulated rainfall, and UV exposure (Figure 1). A poor fit to data was observed, due to variance in field data and multiple factors contributing to the response. Further experiments were based on lab data with experiments designed to tease apart individual factors that cause a reduction in the field life, hence efficacy, of snail and slug baits. A summary of these results and recommendations were presented in Nash *et al.* 2016.

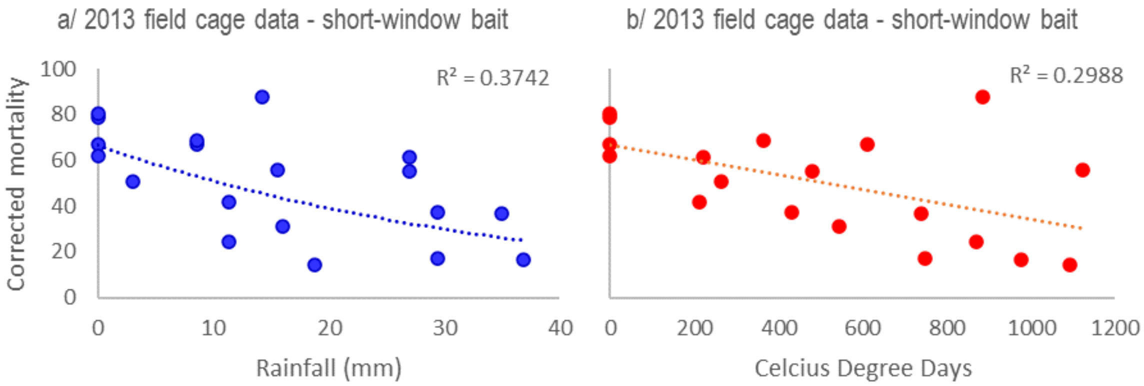


Figure 1. Italian snail response to Meta® exposed to the weather for up to 40 days under different weather conditions in SA. The relationship of mortality with a/ the total amount of rainfall baits were exposed to and b/ the accumulated temperature baits were exposed to, is presented. Weather data was obtained from nearest Bureau of Meteorology weather station.

Revisiting old data (adapted from DAS 00134) - Influence of pellet size on efficacy after rainfall.

Smaller molluscicide baits based on the same product resulted in a greater reduction in efficacy after rainfall, as assessed using snails in laboratory bioassays using a long-window 50g/kg metaldehyde product (2015, Table 1). Similar results were obtained using a short-window 15g/kg metaldehyde product (2016, Table 2).

Consumption data may provide some insights into mechanisms for why efficacy declined after rainfall. All placebo treatment was consumed; as assessed in 2015 by estimating the amount consumed (%) or by quantifying the amount consumed (mg) in 2016; lower amounts were consumed in treatments containing metaldehyde. This result could be due to snails dying, hence they stop feeding. Limited mortality (18%) with a 33% reduction in dead snails compared to the treatment without rainfall in 2016, yet similar consumption (97 vs 87mg) suggests another mechanism is at play. Metaldehyde reduces feeding of slugs and snails by affecting the mucous cells in the target's esophageal crop and causing loss of nerve function. Hence, as metaldehyde concentration increases above 50g/kg, without feeding stimulants in baits, feeding is inhibited. That is why recommendations for metaldehyde concentrations range from 30 – 50g/kg. One hypothesis is consumption of the 50g/kg metaldehyde product increased as the concentration of metaldehyde decreased due to leaching because of rainfall. This was not the case for 15g/kg product, likely due to the lower concentration of metaldehyde not inhibiting feeding in the first place. This work has underpinned the assumption that the greater the surface area to volume ratio, the greater the probability of rainfall leaching active ingredients from baits. This assumption needs to be revisited considering different active ingredients and how they are now incorporated into the pellet matrix of newly-released products.

Table 1. 2015 efficacy after rainfall (> 35mm) of Metarex (60,000 pellets/kg), a long-window bait, compared to the smaller Metarex micro (100,000 pellets/kg). Baits were exposed twice, each time for a period of two weeks, hence the repeated nature of this assay. Treatment ($F_{4,60} = 16.1$; $P < 0.001$) and assay run ($F_{1,60} = 11.7$, $P = 0.001$) caused significant group differences for the number of dead snails. The significance of Reduction in mortality due to rainfall was tested using Tukey's Least Significance Difference ($P < 0.05$) based on the difference in dead snails.

	Rainfall (mm)	*Dead*		*Consumption (%)*		*Mortality*	*Reduction*
2 by 7 reps		*Mean*	*Std. Dev.*	*Mean*	*Std. Dev.*		
Metarex micro	0	2.57	1.34	11%	7%	51%	
	35	1.14	0.86	22%	15%	23%	29%*
Metarex	0	2.14	1.23	6%	10%	43%	
	35	1.93	1.21	25%	19%	39%	$4\%^{NS}$
Placebo	0	0.00	0.00	100%	0%	0%	

Table 2. 2016 efficacy after rainfall (22.5mm) of Pestmaster® 2mm bran-based snail and slug bait (26,000 pellets/kg), a short-window bait, compared to a larger Pestmaster® 4mm dia. Bran-based snail and slug bait made from the same batch by the manufacturer for experiments to compare bait size influence on efficacy. Baits were exposed once for a period of two weeks. Treatment ($F_{4,35} = 12.0$; $P < 0.001$) caused significant group differences for the number of dead snails, hence mortality. The significance of *Reduction* in mortality due to rainfall was tested using Tukey's Least Significance Difference ($P < 0.05$ LSD = 24%) based on mortality.

8 reps	*Rainfall (mm)*	*Dead*		*Consumption (mg/snail)*		*Mortality*	*Reduction*
		Mean	*Std. Dev.*	*Mean*	*Std. Dev.*		
Pestmaster 2mm	0	2.50	1.07	19.44	2.80	50%	
	22.5	0.88	0.64	17.47	2.98	18%	$33\%^{*}$
Pestmaster 4mm	0	2.88	0.99	12.84	2.11	58%	
	22.5	2.00	1.31	13.12	3.23	40%	$18\%^{NS}$
Placebo	0	0.13	0.35	24.92	0.95	3%	

Revisiting old data (adapted from DAS 00134 and various other assays) – amount of rainfall influence on short-window baits efficacy.

As rainfall increases so the efficacy of short-window products declines, however this was difficult to test using snails in bioassays because often mortality in treatments that did not receive rainfall was below 20%. Statistically small effect sizes cannot be tested. For long-window products the amount of rainfall does not seem to affect efficacy, however bioassays used to test this specifically have also been confounded by limited efficacy. Recent research highlights the individual molluscs reproductive state has a greater impact on efficacy than product used (Perry *et al.* 2021) or rainfall. Hence, results from single trials comparing products should be treated with caution due to underlying variation.

Table 3. Short-window products reduction in efficacy due to the amount of rainfall. Only data from assays is presented where a significant reduction in snail mortality was found (LSD P < 0.05). Mortality = dead snails/ total snails. Mortality data presented is from treatments where product did not receive rainfall; reduction in mortality is the difference between treatment with and without rainfall; reduction (ratio) was calculated by mortality no rainfall/100 multiplied by reduction in mortality. That is, the reduction in efficacy was standardised to account for differences in mortality without rainfall.

Exposure date	Product	Mortality	Reduction in mortality	Rainfall (mm)	Reps	Reduction (ratio)
17/10/2016	Pestmaster	47%	33%	22.5	8	70
17/10/2016	Slugger	65%	20%	22.5	8	31
18/09/2015	Meta	29%	20%	35	7	70
9/03/2019	Pestmaster	21%	17%	44	10	80
28/01/2020	Pestmaster	52%	16%	21	5	31

Hard pellets compared to true baits

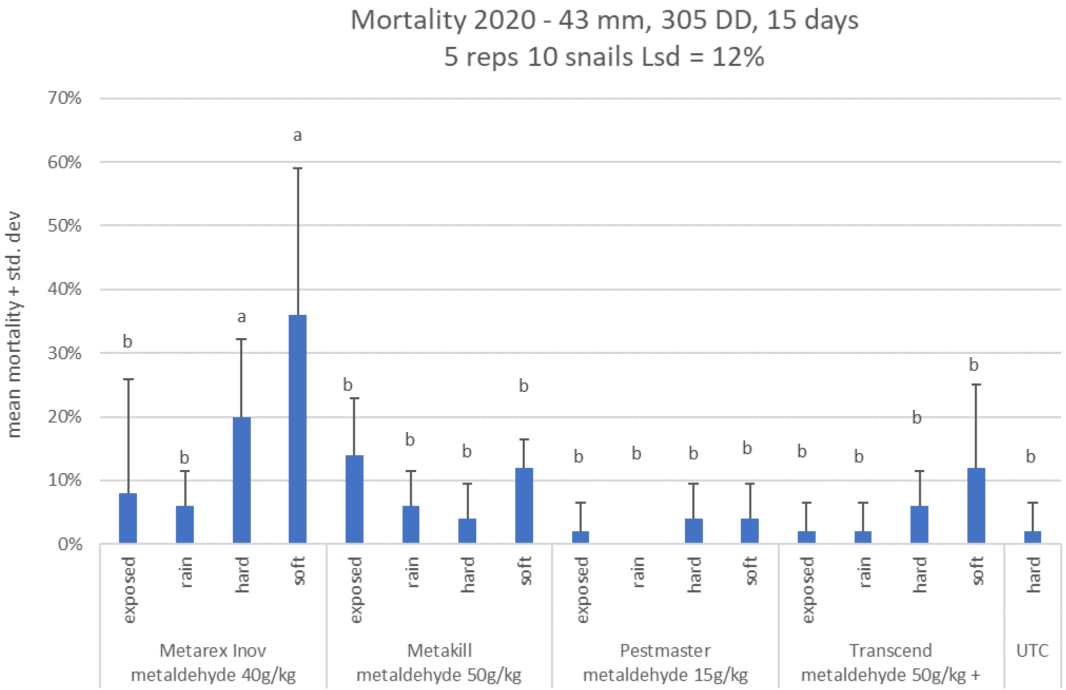
Baits were exposed twice over the summer of 2020 before assays were run in Jan and June 2020. A significant interaction was found between assay and treatment ($F_{16,136}$ = 4.1; $P < 0.001$), hence results were analysed and presented separately. For the first assay, baits were exposed for 15 days, received 43mm of rain and 305 DDC (Day Degrees Celsius), with 14.5 hours over 40^{o}C. Low mortality was observed even in the un-exposed treatments (Figure 2a), which were baits either softened by soaking for 2 hours in water (soft) or hard as out of storage (hard). Hence, there were four treatments for each of the four products tested. Treatment was a significant factor ($F_{16,68}$ = 4.1; $P < 0.001$), however only two resulted in significantly (LSD $P < 0.05$) greater mortality than the untreated control: Metarex Inov hard and soft un-exposed (Figure 2a).

Mortality was greater for all treatments in the 2nd assay (Figure 2c) where baits were exposed for eight days, received 21mm of rainfall and 175 DDC, without any temperatures over 40^{o}C. Treatment was a significant factor ($F_{16,68}$ = 7.0; $P < 0.001$), with all except one treatment (exposed Pestmaster) resulting in significantly (LSD $P < 0.05$) greater mortality than the untreated control (Fig. 2c). There was a significant reduction in mortality where the small Metakill pellets were exposed to rain compared to those exposed only to temperature (LSD $P < 0.05$).

Feeding was reduced in the 1st assay which, along with the low mortality observed, highlights the influence of 'when snails are collected', on the results obtained. This observation aligns with previous findings that demonstrate life stage influences efficacy (Perry *et al.* 2021)

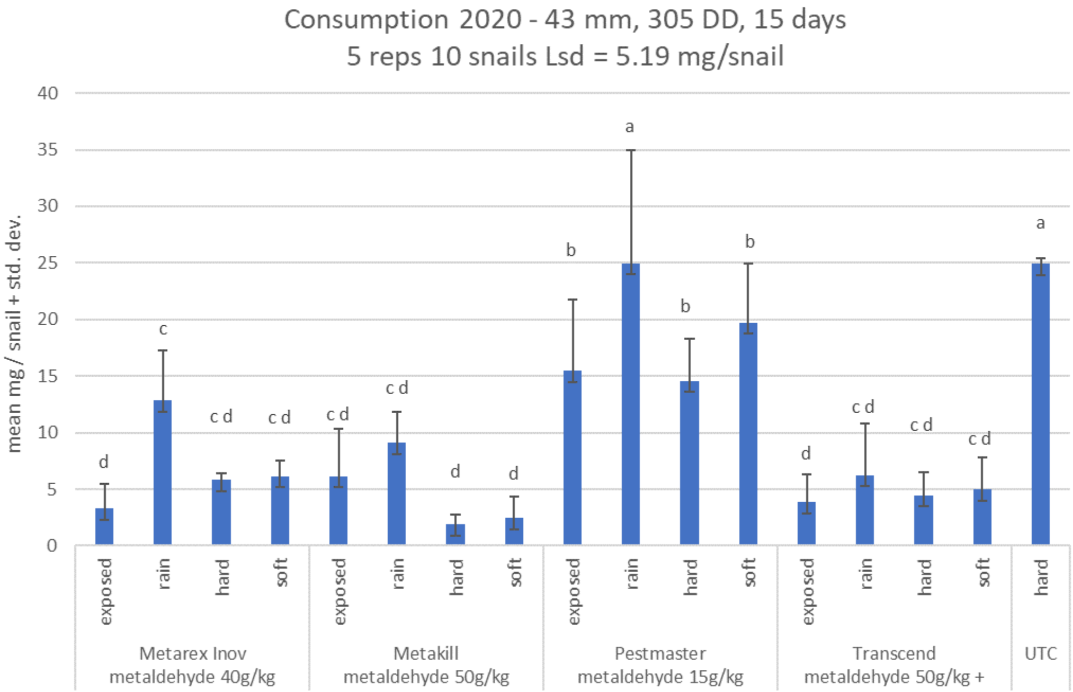
Consumption between treatment groups was significantly different for both assays (1st $F_{16,68}$ = 17.1; $P < 0.001$: 2nd $F_{16,68}$ = 93.9; $P < 0.001$). Significantly (LSD $P < 0.05$) greater consumption of all softened products was observed in the 2nd assay (Fig 2d). These results suggest some products when applied may require some moisture for them to soften somewhat to increase bait consumption.

a)



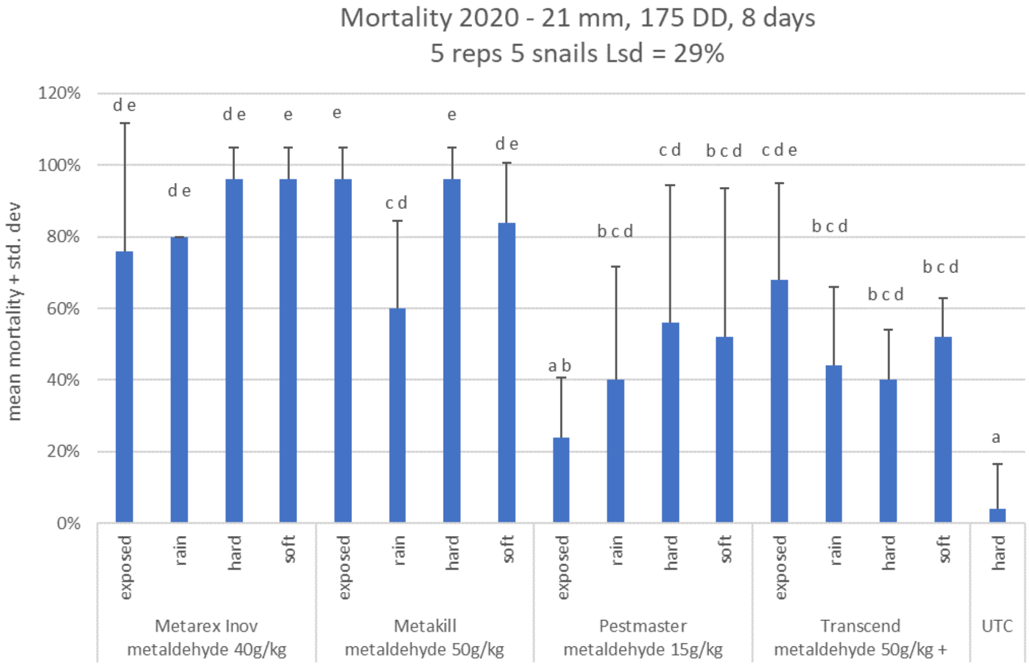
Mortality 2020 - 43 mm, 305 DD, 15 days
5 reps 10 snails Lsd = 12%
mean mortality + std. dev
70%
60%
50%
40%
30%
20%
10%
0%
b
b
a
a
b
b
b
b
b
b
b
b
b
b
b
b
b
exposed
rain
hard
soft
exposed
rain
hard
soft
exposed
rain
hard
soft
exposed
rain
hard
soft
hard
Metarex Inov
metaldehyde 40g/kg
Metakill
metaldehyde 50g/kg
Pestmaster
metaldehyde 15g/kg
Transcend
metaldehyde 50g/kg +
UTC

b)



Consumption 2020 - 43 mm, 305 DD, 15 days
5 reps 10 snails Lsd = 5.19 mg/snail
mean mg / snail + std. dev.
40
35
30
25
20
15
10
5
0
d
c
c d
c d
c d
c d
d
d
b
a
b
b
d
c d
c d
c d
a
exposed
rain
hard
soft
exposed
rain
hard
soft
exposed
rain
hard
soft
exposed
rain
hard
soft
hard
Metarex Inov
metaldehyde 40g/kg
Metakill
metaldehyde 50g/kg
Pestmaster
metaldehyde 15g/kg
Transcend
metaldehyde 50g/kg +
UTC

c)



d)

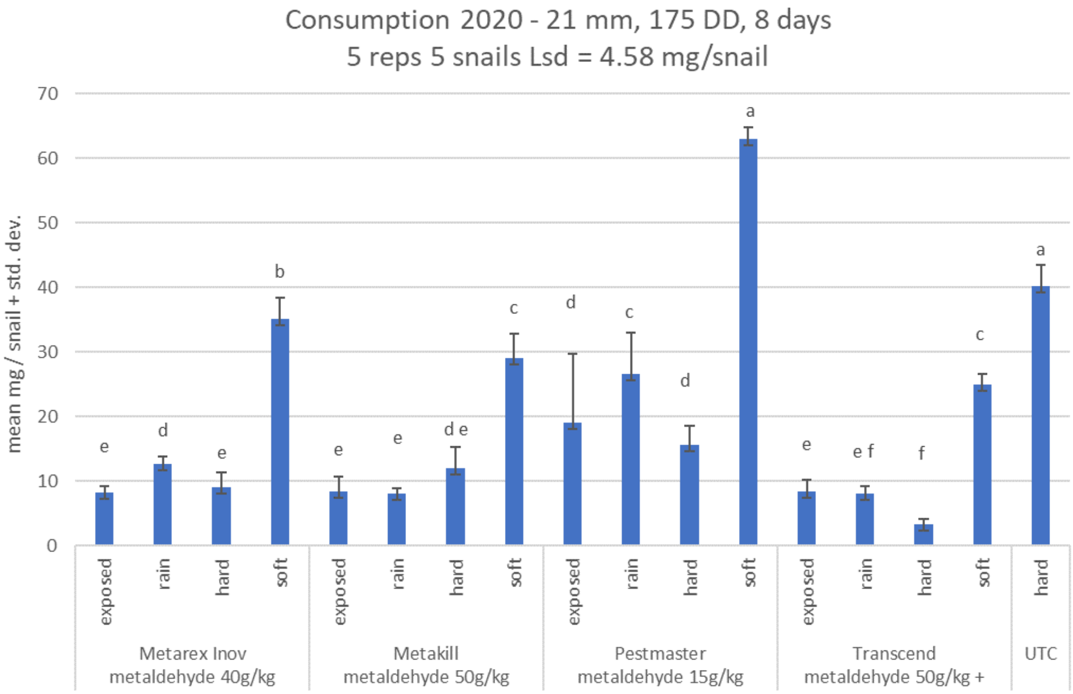


Figure 2. Results from bioassays testing four different slug and snail bait products efficacy after being exposed on wet soil to rainfall (rain) or without rainfall (exposed) and pellets from storage that were either soaked for 2 hours (soft) or not (hard). Data is presented separately as exposure, population of snails used, mortality and consumption results were all different. a) 1st assay mortality, b) 1st assay consumption, c) 2nd assay mortality d) 2nd assay consumption. Different superscript letters indicate a significant (LSD *P* < 0.05) different between groups.

Conclusions

Multiple factors, such as rainfall, soil moisture, and temperature, not only influence individual pest activity but also product performance in the field. The interaction between environment, target and product dictates the success of baiting to limit crop losses. Physical integrity of slug and snail baits, referred to as rain-fastness, is not associated to efficacy.

Treat one-off trial data on slug and snail bait efficacy data with caution, as individual results can be extremely variable and dependent on target pest individuals' activity / state. Comparisons of product data requires updating as manufacturers continue to improve the delivery of molluscicides.

Having a persistent bait that individual pests will consume to receive a lethal dose allows for application before individuals are active. This timing often coincides with rainfall. Bran-based products, which have low initial loadings of active ingredient, need to be reapplied after heavy rainfall. Modern long-window products continue to be effective for up to a month after application and rainfall. However, some products achieve rain-fastness by including glue in the pellet matrix, which can reduce palatability.

Combining what is known about the factors that improve bait efficacy, such as attractiveness, palatability, ballistics, persistence, has led to the delivery of some products that deliver faster and more efficient mortality. The continued improvement of delivery technologies has seen less of the active ingredients applied; hence lower environmental loadings, yet better crop protection and slug control; leading to better return on growers' investment in slug bait.

How will the latest products affect management strategies and packages?

Conclusions from laboratory assays indicate there is an interaction between bait hardness to achieve rain-fastness, concentration of metaldehyde in individual baits, pellet composition and rainfall that influences the amount of active consumed, hence target mortality. Field results from small plot trials in canola comparing products support these laboratory findings. That is, small hard pellets only focused on delivering an increased number of pellet points increase the chance of delivering a sub-lethal dose. This is due to decreased palatability, especially in dry conditions, and increased chance of active leaching in wet conditions and an increase in product consumed. By applying larger baits with enhanced attractiveness, the chance of encounter is maintained while maintaining delivery of a lethal dose across a range of environmental conditions.

Product choice when applying early in the season; when conditions are dry; may warrant a softer bran-based short-window product, whereas once soil moisture has increased that not only favours slug activity but ensures long-window products are palatable, hence these would be a better option. These long window-baits, having a greater loading of the active ingredient metaldehyde also ensure enough active is available for consumption. Hard glue-based pellets are best applied before substantial rainfall. Although not recommended due to settling and different ballistic characteristics of different pellet size and density, mixing short- and long-window products for application after seeding does occur with successful protection of seedlings from slugs achieved.

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Using zinc phosphide to control wild house mice

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Keywords

background food, LD_{50}, zinc phosphide

GRDC code

CSP1804-012RTX

Take home messages

- Mice are not as sensitive to zinc phosphide (ZnP) as was first reported in studies in the 1980s
- 2mg of ZnP is required on each grain to deliver a lethal dose to a 15g mouse
- Grain bait mixed at 50g ZnP/kg wheat is significantly more effective than bait mixed at the previously registered rate of 25g ZnP/kg wheat
- Reducing background food could be critical to achieving effective bait uptake
- Timely application of ZnP grain bait at the prescribed rate is vital for reducing the impact that mice have on crops at sowing
- Strategic use of bait is more effective than frequent use of bait.

Background

The content of this paper relates primarily to the GRDC investment, *Determining the effectiveness of zinc phosphide rodenticide bait in the presence of alternative food supply*. Growers were reporting concerns regarding the effectiveness of commercially prepared zinc phosphide (ZnP) wheat-based baits. In response, we conducted three experiments to examine the efficacy of ZnP bait. The initial experiment set out to identify a more attractive bait substrate, but the results of this work identified unexpected questions regarding the sensitivity of mice to ZnP. The second experiment re-assessed the acute oral toxicity of ZnP for wild house mice. The results of this work showed a significant difference between the previously reported LD_{50} of 32.68mg ZnP/kg body weight and our re-calculated LD_{50} of 72–75mg ZnP/kg body weight. We then quantified the efficacy of the higher lethal dose (~2mg ZnP per grain) compared to the registered rate (~1mg ZnP per grain) in a field trial. The results suggest that a kill rate of >80% could be achieved 90% of the time for the higher rate compared to the registered rate for which an 80% kill rate would be observed only 20% of the time. These results are helping to inform how and when growers and agronomists manage mice in cropping systems in Australia.

Experiment 1 - Effects of background food on alternative grain uptake and zinc phosphide efficacy in wild house mice.

The initial trial to determine what was driving the reduced efficacy of the bait sought to test potential new bait substrates that might be more attractive to mice.

Experiment 1a - Two choice grain preference

Mice were held on a background food type (barley, lentils or wheat) and then offered the choice of an alternative grain type (malt barley, durum wheat or lentils) for five nights. Mice displayed a strong preference towards cereal grains, with a slight preference towards malt barley.

Experiment 1b - Toxic bait take against different background grains

Mice were held on a background food type (lentils, barley or wheat) then offered ZnP-baited grain (25g ZnP/kg grain) for three consecutive nights. Mice consumed toxic bait grains regardless of bait substrate although background food type had a strong influence on the amount of toxic bait consumed. Most of the mice in this experiment consumed what was considered to be a lethal dose, however the mortality rate was significantly lower than expected (Table 1) (Henry et al. 2022). Furthermore, animals that consumed toxic grains and didn't die, stopped eating toxic grains (that is, became averse).

Table 1. Percentage mortality from ZnP bait (25g ZnP/kg grain) and the average number of toxic grains consumed for each background food type on night one of the study (Henry et al. 2022).

Background food	n	Mortality (%)	Toxic grains eaten (av.)
Lentils	30	86	7.3 ± 2.5
Barley	30	53	4.5 ± 2.9
Wheat	30	47	2.1 ± 1.6

Bait substrate key results

Mortality was not as high as expected in mice that consumed toxic grains. The development of aversion was rapid although its duration is unknown. These results identified questions relating to the sensitivity of mice to ZnP (Henry et al. 2022). Had we been selecting for mice that were less sensitive to ZnP through frequent application of bait over a 20-year period? Or were mice just less sensitive to ZnP than had been reported in the past?

Experiment 2 - Acute oral toxicity of zinc phosphide: an assessment for wild house mice (*Mus musculus*)

This experiment re-assessed the acute oral toxicity of ZnP for wild house mice using an oral gavage technique, where known doses of ZnP were delivered directly into the stomachs of mice. The responses of three different groups of mice were assessed and compared: (1) wild mice from an area where ZnP had been spread frequently (exposed), (2) wild mice from an area where ZnP had never been used (naïve), and (3) laboratory mice (Swiss outbred). The proportion of mice that died at each dose was used to calculate a dose-response curve for each of the groups of mice (Figure 1) (Hinds et al. 2022).

Acute oral toxicity key results

The results showed no significant differences in the sensitivity of any of the groups of mice to ZnP, indicating that there has been no selection for tolerant mice in areas where mice had frequent exposure to ZnP. However, there was a significant difference between the previously reported LD_{50} of 32.68mg ZnP/kg body weight (Li and Marsh 1988) and our re-calculated LD_{50} of 72–75mg ZnP/kg body weight. These results mean that 2mg of ZnP/grain is needed instead of 1mg of ZnP/grain to kill a 15g mouse (Hinds et al. 2022).

Lab – Swiss outbred

LD_{50} = 79.18 ± 6.24mg ZnP/kg

Naïve wild mice

LD_{50} = 72.11 ± 9.09mg ZnP/kg

Exposed wild mice

LD_{50} = 75.22 ± 4.39mg ZnP/kg

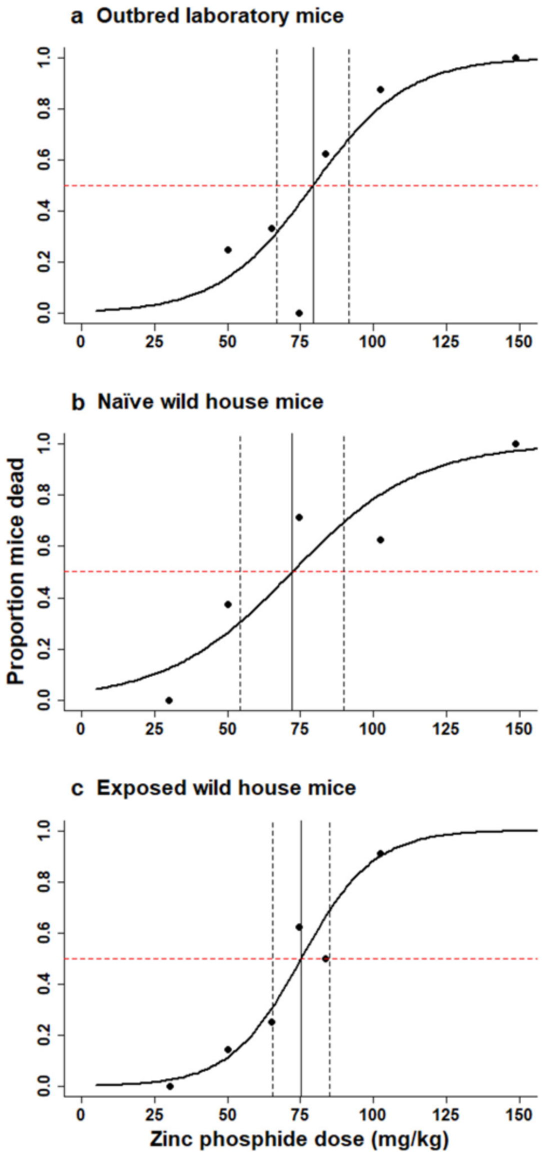

Figure 1. Proportion of mice dying after oral gavage with different ZnP concentrations (mg ZnP/kg body weight). Calculated dose response curves for (a) outbred laboratory mice, (b) naïve wild house mice, and (c) exposed wild house mice. Horizontal dashed line represents 50% mortality; vertical solid line equates to LD_{50} value; vertical dashed lines represent standard error for the LD_{50} estimate. N>four animals per test dose, with a mix of males and females (Hinds et al. 2022).

Experiment 3 - Improved house mouse control in the field with a higher dose zinc phosphide bait.

This experiment addressed the efficacy of the two different bait types, ZnP25 (25g ZnP/kg bait, ~1mg ZnP/grain) applied at 1kg bait/ha and the new formulation, ZnP50 (50g ZnP/kg bait, ~2mg ZnP/grain), applied at 1kg bait/ha.

Nine sites were selected on farms in the area surrounding Parkes in central NSW, three un-baited control sites, three sites baited with ZnP25 (25g ZnP/kg bait), and three sites baited with ZnP50 (50g ZnP/kg bait). All sites were trapped prior to baiting to establish population sizes and then again after baiting to determine changes in population.

Field trial key results

Baiting with ZnP50 led to a median reduction in mouse numbers of >85%. Modelling showed that under similar circumstances, using the ZnP50 formulation should deliver >80% reduction in population size most (>90%) of the time. In contrast, the current registered bait (ZnP25) achieved approximately 70% reduction in population size, but with more variable results. We would be confident of getting an 80% reduction in population size only 20% of the time if using the currently registered ZnP25 bait under similar field conditions (Figure 2) (Ruscoe et al. 2022).

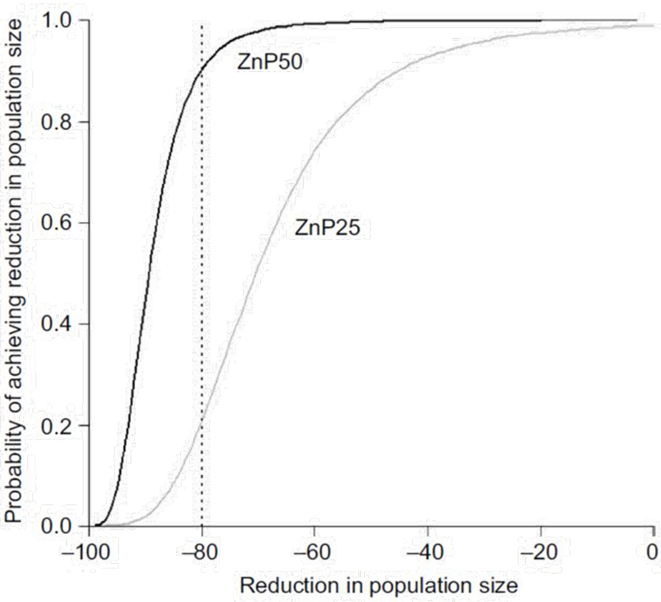

Figure 2. The probability of achieving a certain reduction in population size or better by using the ZnP50 bait (solid black line) and the ZnP25 bait (solid grey line). The dotted vertical line shows that there is a ~90% chance of getting a >80% reduction in population size by using ZnP50, but only a 20% chance of achieving that outcome by using ZnP25 (Ruscoe et al. 2022).

Conclusion

- Mice are not as sensitive to ZnP as was first reported in studies in the 1980s.
- 2mg of ZnP is required on each grain to deliver a lethal dose to a 15g mouse.
- ZnP grain bait mixed at 50g ZnP/kg wheat is significantly more effective than bait mixed at the previously registered rate of 25g ZnP/kg wheat.

Future research

Substantial grain loss, pre- and post-harvest is common in zero and no-till cropping systems. In 2022, it was estimated that $300 million worth of grain (GRDC project code GGA2110-001SAX) was left on the ground post-harvest in WA alone and reports of losses of 1t/ha are not uncommon (pers. comm). Bait spread at 1kg/ha equates to approximately three toxic grains per square metre. If there have been losses of 1t/ha, equivalent to about 2200 grains per square metre, finding a toxic grain becomes a game of hide and seek for mice (Figure 3). Understanding the role that background food plays in the uptake of ZnP bait will be critical to achieving effective mouse control.

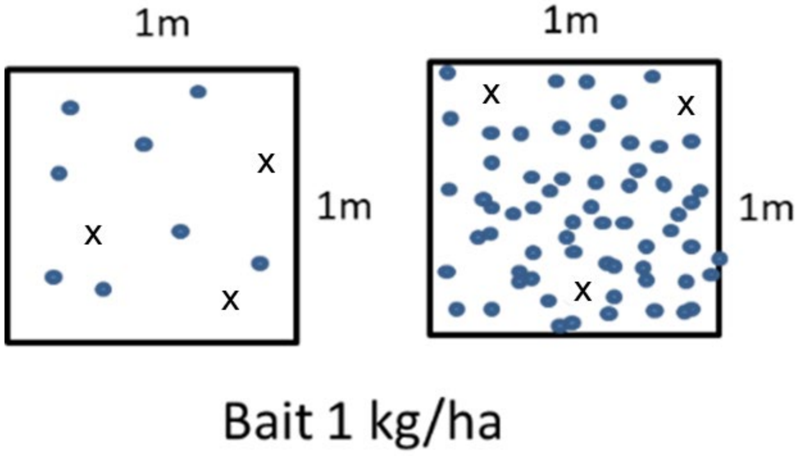

Figure 3. Representation of detectability of toxic grains at different levels of background food. The dots represent grains and crosses represent toxic grains.

Acknowledgements

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Rust in 2023 and beyond – pathotypes and varieties and strategies for durable deployment of new genes for resistance

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Take home messages

- Stripe rust in particular is likely to be important again in 2023; monitor for the presence of the green bridge, and if present, make sure it is destroyed at least 4 weeks before crops are sown, either by heavy grazing or herbicides
- The structure of stripe rust populations in eastern Australia has become more complex in recent years. This has changed the stripe rust response; for example, of many varieties of common wheat, durum wheat and triticale, stressing the need for careful varietal selection and preparedness given the heightened threat of rust in 2023
- There have now been five documented incursions of stripe rust since it was first detected in Australia in 1979 (Ding et al. 2021). Three of these appear to have originated from Europe (1979, 2017 and 2018) and one North America (2002). These incursions have cost the industry hundreds of millions of dollars; for example, it was estimated that between $40-$90 million was spent on fungicides annually in 2003, 2004 and 2005 following the second incursion in 2002 (Wellings, 2007). The critical importance of thoroughly laundering clothing and personal effects after interstate or overseas travel cannot be emphasised enough
- The variability of rusts and their rapid spread across the Australian continent reinforces the importance of regular and nationally coordinated monitoring of these pathogens. All stakeholders are encouraged to monitor crops, barley grass and wild oat for rust throughout 2023, and to forward freshly collected samples in paper only to the Australian Cereal Rust Survey, at University of Sydney, Australian Rust Survey, Reply Paid 88076, Narellan NSW 2567.

Wheat stripe rust pathotype update

Cereal rust pathotypes (aka races, strains) are isolates of rust that differ in ability to overcome the resistance genes in cereal varieties. They are identified by using a field-collected sample of rust to infect a set of cereal varieties (‘differentials’), each carrying a known resistance gene, and determining which resistance genes are overcome and which are not. This process takes about 3 weeks. Given favourable conditions for rust development, the pathotype/s present is a major determinant of how varieties perform and whether or not yield loss will occur.

Knowing what pathotypes are present, their distribution and impact on cultivars is the foundation of all rust control. This information is used to:

- monitor the effectiveness of resistance genes in cereal varieties

- interpret and determine varietal rust response
- provide new or relevant rust pathotypes for breeding and research
- understand how new pathotypes develop
- understand pathogenic and genetic variability, and the evolutionary potential of rust pathogen populations.

Epidemics of wheat stripe rust in eastern Australia in 2020 and 2021 were caused almost entirely by two pathotypes that found their way into Australia, from probably Europe/South America, in 2017 and 2018. These two pathotypes belong to two genetic groups, defined by internationally accepted Multi Locus Genotypes ('MLGs') based on DNA fingerprinting markers: PstS10 (pathotype 239 E237 A- 17+ 33+; '239'; 2017); PstS13 (pathotype 198 E16 A+ J+ T+ 17+; '198'; 2018). In 2022, these two pathotypes, along with a third pathotype of unknown MLG (pathotype 238 E191 A+ 17+ 33+; '238') that was first detected in 2021, were responsible for the extensive and damaging stripe rust epidemic experienced.

Figure 1 depicts the relative frequencies of all wheat stripe rust pathotypes detected annually since 2016, including the two previously detected MLG pathotype groups PstS0 (first detected in 1979, originating from Europe) and PstS1 (first detected in 2002, originating from North America; aka the 'WA' pathotype group). Of note in 2022 was the rapid increase in frequency of pathotype '238' (PstS?) after its initial detection in 2021, and reductions in the frequencies of pathotypes belonging to the other four MLGs. Our greenhouse tests have not detected any virulence advantage of pathotype 238 over the other groups, meaning that its increase in frequency in 2022 is likely due to increased 'aggressiveness' – for example, faster growing, producing more spores.

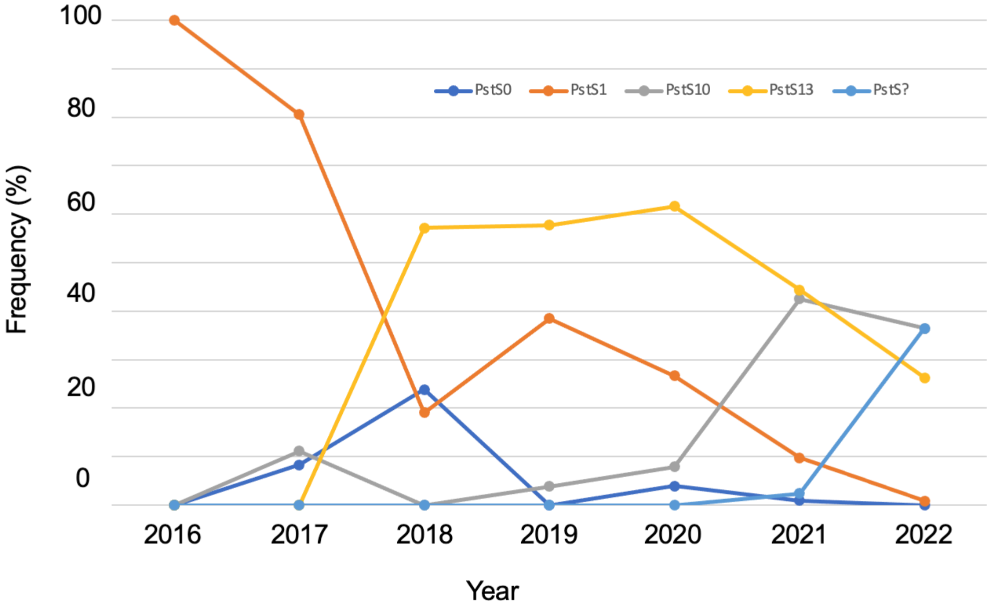

Figure 1. Frequency (%) of four internationally accepted DNA fingerprint MLG groups (PstS0, PstS1, PstS10, PstS13) of wheat stripe rust pathotypes, and a fifth as yet undefined group (PstS?) in eastern Australia, 2016 through 2022.

The expression of adult plant resistance (APR)

Seasonal conditions not only affect the stripe rust pathogen, they also affect crop development and expression of resistance genes in different wheat varieties. Most varieties rely on adult plant resistance (APR) genes for protection from stripe rust, which as the name implies, become active as the plant ages. Consequently, all varieties, unless rated resistant (R), are susceptible as seedlings and move towards increasing resistance as they develop and APR genes become active.

Much remains to be known about the expression of APR. The growth stage at which APR becomes active differs between wheat varieties and relates to their resistance rating. An MR variety would generally have APR active by GS 30–GS 32 (early stem elongation), MR-MS by GS 37–GS 39 (flag leaf emergence), MS by GS 49–GS 60 (awn peep-start of flowering) and MSS by GS 61–GS 75 (flowering to mid-milk). Varieties rated S or worse have relatively weak levels of resistance that are generally of limited value in disease management. Note that a variety can have a higher or lower resistance rating to individual pathotypes (aka strains) of the pathogen, depending on its resistance genes and the corresponding virulence of different stripe rust pathotypes.

Mild temperatures during 2021 and 2022 that extended well into spring slowed crop development, which consequently delayed the expression of APR genes whilst also favouring multiple cycles of stripe rust infections. This extended the time between growth stages and affected management strategies, which in more susceptible varieties is based around early protection with fungicides until APR within a variety is reliably expressed.

Higher levels of nitrogen nutrition can also delay crop maturity and expression of APR genes within varieties whilst also being more conducive to stripe rust infection (thicker canopy and leaf nitrate food source for pathogen). Differences in nitrogen nutrition can relate to rotation history (pulse vs cereal/canola in previous season) and rate and timing of fertiliser application (pre-sowing, at sowing or in-crop). However, under higher levels of N nutrition, the resistance level of a variety only ever drops by one category; it does not for instance make a MR/MS variety an S. Under high levels of N nutrition, growers need to manage a variety as one category lower in resistance (that is, manage a MR/MS as an MS).

Fungicide insensitivity/resistance in rust

The use of fungicides in Australian broadacre farming since the early 1980s has resulted in the emergence of fungal pathogen isolates with insensitivity to them, especially DMI fungicides. This has been well documented in, for example, septoria tritici blotch, wheat powdery mildew, barley powdery mildew, and net form of net blotch, and in blackleg in canola.

Cases of fungicide insensitivity in rust pathogens are fortunately much less common. Apart from reports from Brazil of a decline in the field performance of DMIs against the Asian soybean rust pathogen, few if any agronomically important cases of fungicide insensitivity in a rust pathogen are known.

We tested more than 800 rust isolates of wheat (stem rust, leaf rust, stripe rust), barley (leaf rust) and oat (crown rust, stem rust) for sensitivity to the DMI fungicide tebuconazole under controlled conditions. Importantly, these tests revealed insensitivity in isolates of the leaf rust pathogens of barley (*Puccinia hordei*) and wheat (*Puccinia triticina*) collected in 2021 to not only tebuconazole, but also prothioconazole, propiconazole and triadimenol. While tebuconazole is not registered for the control of leaf rust in barley, it is registered for scaled and mildew control in barley (maximum rate 290 mL/ha) and for rust diseases in wheat and oat (maximum rate 290 mL/ha).

More extensive testing using standard historical isolates of both rust pathogens from our rust collection revealed that in *P. hordei*, insensitivity occurs in a clonal lineage of pathotypes that trace back to an exotic incursion into WA that was first detected in 2001. All isolates within this lineage that we tested, including the original 2001 isolate, were insensitive to tebuconazole at rates of more than six times the maximum rate of 290mL/ha recommended for rust control in wheat and oat. Insensitive isolates are common in all Australian barley growing regions.

Within the wheat leaf rust pathogen *P. triticina*, insensitivity to the four DMI fungicides was identified in a single pathotype, namely 93-3,4,7,10,12 +Lr37 which could grow and sporulate on leaves treated with rates of tebuconazole up to 25 times the recommended high field application of 290 mL/ha. This pathotype was first detected in southern NSW in October 2020 and is considered to be of exotic origin. It was isolated again in 2021 and 2022, and although it increased in frequency and has spread to Victoria and Queensland, it remains at low levels in the overall *P. triticina* population.

Our work appears to be the first documented case of insensitivity to a fungicide in a cereal attacking rust pathogen. Further in-field testing of these findings needs to be undertaken and at this stage there have been no known in-field failures of fungicides associated with cereal rust insensitivity. However, it reminds us of the remarkable abilities of these pathogens to change and adapt to circumvent the strategies used to control them, be they genetic resistance or agrochemicals.

Broader threats posed by cereal rust pathogens

Ongoing frequent changes in cereal rust pathogens, well documented by our rust surveillance over the past 10 years, have presented new challenges to resistance breeding and in crop rust control. These have included:

- loss of important resistance genes in wheat, barley, oat and triticale, due to local mutations (for example, *Rph3* and *Rph7* in barley, *Yr27* in wheat, *Pc91* in oat)
- more frequent east-to-west spread of new rust pathotypes within Australia, resulting in new virulences in the west that have rendered varieties susceptible (for example, *Lr13*, *Lr27+31*)
- introductions of exotic wheat leaf rust pathotypes in 2014 (from North America) and 2020 (source currently unknown)
- introductions of two exotic wheat stripe rust pathotypes in 2017 (Europe) and 2018 (Europe or South America)
- local emergence of two genetically divergent stripe rust isolates in 2021, one that infects wheat and one with increased virulence on barley
- emergence and spread of fungicide insensitivity in the leaf rust pathogens of barley (national) and wheat (eastern Australia).

These new rusts have reduced profitability for growers of wheat (bread and durum), barley, oat and triticale. The loss of genetic resistance has also impacted breeding programs, slowing genetic gain with an anticipated knock-on effect to grower profitability in the years ahead. Combined, they highlight the need for ongoing RD&E to ensure effective and timely industry-wide rust protection.

Strategies for durable deployment of new genes for resistance

The term durable resistance is sometimes mistakenly equated to enduring rust control in agriculture. Clearly, growing only varieties that carry high levels of durable resistance at a large scale would be expected to provide enduring rust control across agro-ecological zones, continents and possibly beyond. However, it is important to appreciate that resistance that has proven durable may not remain effective forever, stressing the importance of genetic diversity in the resistances deployed.

The durability of resistance genes when deployed over large areas is complex, being determined not just by the ability of the pathogen to acquire matching virulence, but also other traits in the pathogen and host that can impact on overall disease epidemiology. For example, on the pathogen side, our long term surveys of pathogenicity of cereal rust pathogens in Australia have provided many examples where certain pathogen genotypes seem to have greater fitness, which is independent of virulence for resistance genes (such as the recent example of wheat stripe rust pathotype '238'). On the host side, a change to growing early maturing wheat varieties developed by William Farrer in Australia had a huge impact in reducing losses to stem rust through 'disease escape'. Both of these factors can influence the overall size of the pathogen population, and in so doing, affect the timing of epidemic onset, disease pressure on varieties carrying incomplete levels of resistance, and how frequently virulent mutant pathotypes emerge.

In view of the complexity of host:pathogen interactions, genetic diversity of resistance must be seen as a key ingredient in large scale sustained control of plant diseases. It has been argued that even where specific or major resistance genes are used, genetic diversity can be used as insurance against lack of durability and hence, as a means of reducing genetic vulnerability. Above all, responsible use of resistance genes, which depends upon an understanding of the resistance genes present in varieties and breeding populations, and monitoring pathogen populations with respect to deployed resistances, are crucial in ensuring that the genetic bases of resistances are not narrowed.

Conclusion

The confirmation of two further incursions of the wheat stripe rust pathogen brings to four the number documented since this disease was first detected in Australia in 1979. The evidence available implicates Europe as the source of three of these incursions (1979, 2017 and 2018) and North America as the source of the other one (2002). In addition to the two exotic incursions of the wheat leaf rust pathogen detected in 2014 and 2020, this continues the trend that has emerged from our long-term pathogenicity surveys of cereal rusts of an increasing frequency of exotic incursions with time, presumably associated with increased international movement of people and inadvertent transport of rust spores on contaminated clothing. Exotic wheat rust incursions have cost the industry hundreds of millions of dollars. The importance of thoroughly laundering clothing and personal effects after interstate or overseas travel cannot be emphasised enough.

Stripe rust was very common and damaging in wheat crops in eastern Australia during the 2022 season, and there were many situations in which fungicides were used to control the disease. This was in part due to the occurrence of pathotype 198 E16 A+ J+ T+ 17+. The amount of stripe rust that developed was, however, nowhere near that caused by this pathotype in Argentina in 2016/17 and 2017/18. The much lower impact of pathotype 198 in Australia compared to its impact in Argentina and Europe is a clear endorsement of the value of genetic resistance in controlling rust diseases in cereals, and of the efforts of all stakeholders in using genetics as the foundation of rust control here in Australia.

The latest responses of Australian wheat and triticale cultivars to the pathotypes reported here, based on detailed greenhouse and field testing, are provided in our Cereal Rust Report (Volume 19 Issue 1, released August 2022), which can be downloaded from our website.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. The national rust pathotype surveillance program, conducted by staff at the University of Sydney, involves active participation by many people including state-based regional cereal pathologists, scientists in universities and in the private sector, grain growers, and their critical contributions are gratefully acknowledged.

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Wellings CR (2007) *Puccinia striiformis* f. sp. *tritici* in Australia: a review of the incursion, evolution and adaptation of stripe rust in the period 1979-2006. *Australian Journal of Agricultural Research* **58**: 567-575.

Useful resources

Cereal disease guide (https://agriculture.vic.gov.au/biosecurity/plant-diseases/grain-pulses-and-cereal-diseases/cereal-disease-guide)

Cereal seed treatments 2021 (https://www.pir.sa.gov.au/__data/assets/pdf_file/0005/237920/Cereal_Seed_Treatments_2021.pdf)

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

McIntosh RA, Wellings CR, Park RF (1995). 'Wheat rusts: an atlas of resistance genes.' (CSIRO Publishing: Melbourne) (https://bgri.cornell.edu/wp-content/uploads/2021/01/wheat_rust_atlas_full.pdf)

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2023: A TESTING year for cereal disease management!

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Keywords

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

GRDC codes

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

Take home message

- The 2022 season was very conducive to a range of cereal leaf diseases and Fusarium head blight (FHB) during flowering and grain fill
- However, this exceptional season for cereal diseases needs to be kept in perspective
- Leaf disease pressure, especially stripe rust, will likely be high again in 2023 requiring management early in the season, but plans need to be responsive to spring conditions
- Seed retained from any crop where FHB or white grains were evident in 2022 must be tested for Fusarium infection levels as it negatively impacts on germination and vigour
- Widespread FHB in 2022 is the Fusarium crown rot (FCR) fungus letting you know that it has not gone away with wetter and milder spring conditions the last few seasons
- Do you know your FCR risk in paddocks planned for cereals in 2023, especially if sowing durum?
- Help is available with testing and stay abreast of cereal disease management communications throughout the season, as 2023 is likely to be another dynamic year.

Introduction

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

So, if 2022 taught us nothing else, it is that we cannot control the weather. However, nothing has changed and in 2023 growers need to have extra focus on 'controlling the controllable'. The 2022 season needs to be kept in perspective, as it was the year for leaf diseases and by default returns from multiple fungicide applications in susceptible varieties. However, what are the chances of still lighting the inside wood fire in November 2023?

2022 – What a season!

2022 was wet! Records were broken and flooding was widespread in some areas. Frequent rainfall is very conducive to the development of leaf diseases such as stripe rust, as causal pathogens require periods of leaf wetness or high humidity for spore germination and initial infection. However, just as a significant contributing factor to the prevalence of cereal leaf diseases was the spring (Sep-Nov) temperatures in 2022, even compared with 2020, which remained mild (Figure 1).

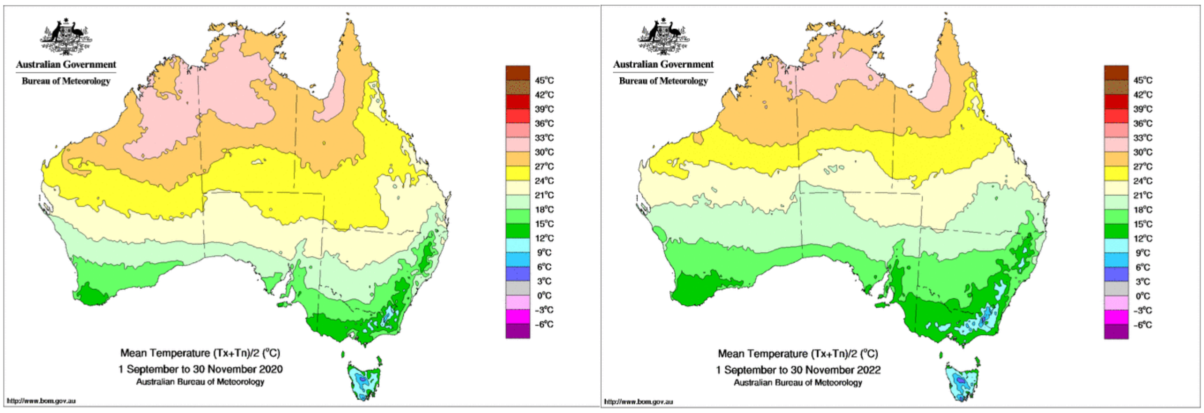

Figure 1. Mean daily temperature for spring (Sep-Nov) in 2020 (left) compared with 2022 (right).

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

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

Disease	**Optimum temperature range**	**Latent period (opt. temp)**
Stripe rust	12-20°C	10-14 days
Septoria tritici blotch	15-20°C	21-28 days
Wheat powdery mildew	15-22°C	7 days
Leaf rust	15-25°C	7-10 days
Yellow leaf spot	15-28°C	4-7 days
Fusarium head blight	20-30°C	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 phenology 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 was also on a rapid cycle time under these temperatures. Hence, underlying infections can be in their latent period and also beyond the curative activity (~1/2 of cycle time with stripe rust) when foliar fungicides are applied. This can result in pustules appearing on leaves 5 or more days after fungicide application. The fungicide has not failed, rather the infection was already present but hidden within leaves and was too advanced at the time of application to be taken out by the limited curative activity of fungicides. At optimum temperatures, stripe rust has a 10-day cycle time in an S rated variety, whereas it is a 14-day cycle in a MRMS variety. Disease cycles quicker in more susceptible varieties! Reliance on fungicides for management made susceptible (S) wheat varieties critically reliant on correct timing of fungicide application. Frequent rainfall in 2022 caused plenty of logistical issues with timely foliar fungicide applications related to paddock accessibility by ground rig and/or delay in aerial applications. The associated yield penalty was significantly higher in more stripe rust susceptible varieties due to the shorter disease cycle time. There were plenty of reports of 10-day delays in fungicide applications around flag leaf emergence (GS39) due to uncontrollable logistics that saw considerable development of stripe rust, particularly in S varieties. Yield loss at harvest has been estimated at around 30-50% due to this 10-day delay. This simply does not happen in more resistant varieties, where there is more flexibility in in-crop management, because the disease is not on speed dial when climatic conditions are optimal. The 2022 season has certainly challenged the risk vs reward of growing susceptible varieties – the management of which does not fit logistically within all growers' systems.

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

Can we really grow susceptible varieties in the longer term?

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

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

Keep the 2022 season in perspective

The 2022 season was the year for fungicides, especially in more susceptible varieties and with the mix of various diseases that occurred. The prolonged mild conditions also extended the length of grain filling so there was a benefit of retaining green leaf area through this period in 2022. Remember, fungicides do NOT increase yield, they simply protect yield potential (i.e., stops disease from killing green leaf area). As highlighted above, disease is very dependent on individual seasonal conditions, so the same returns are not guaranteed from fungicide use in 2023. What's your disease management plan if spring returns to closer to normal temperatures and rainfall? There is no talk of La Niña again in 2023 and seasonal outlook must be part of disease management planning. Early leaf disease pressure is likely to be high again in 2023, given elevated inoculum levels from 2022 and decent levels of stored soil moisture. Manage early leaf disease pressure in 2023 then adapt management to spring conditions. The most effective fungicide can often be 2-3 weeks of warmer and dry weather in spring.

Where has Fusarium crown rot gone?

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

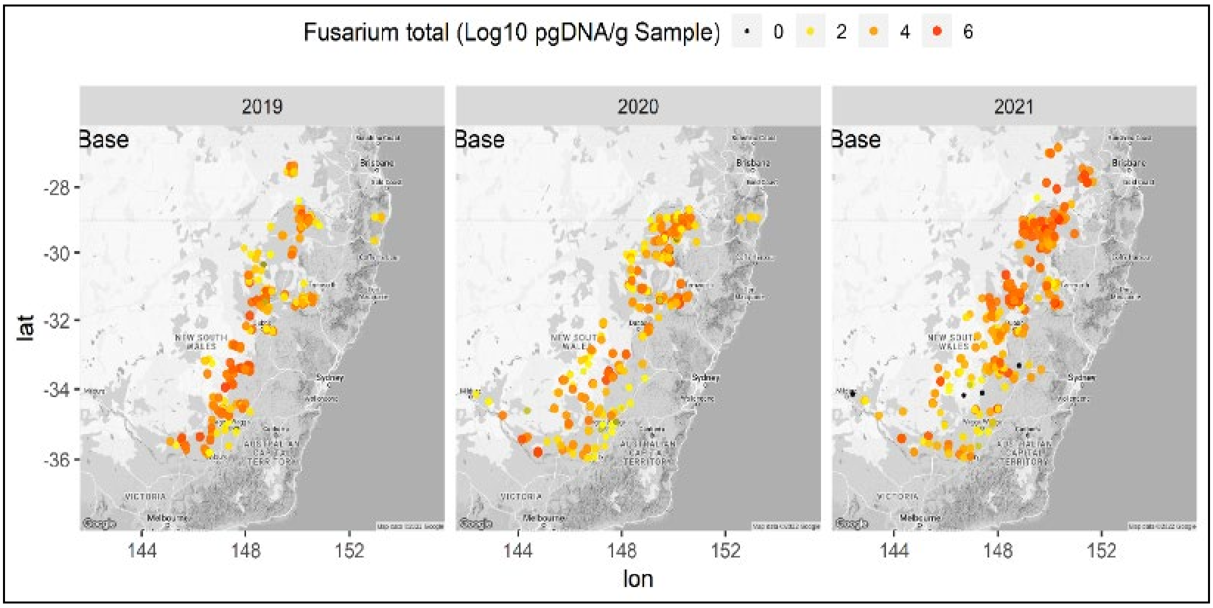

Figure 2. Levels of Fusarium crown rot within base of randomly surveyed winter cereal crops (2019 to 2021) as assessed using quantitative PCR of pathogen DNA levels – BLG208 and BLG207. Map from collaborative surveys conducted with Dr Andrew Milgate and Brad Baxter, NSW DPI Wagga Wagga.

Fusarium head blight (FHB) which caused premature partial bleaching of heads and white or pink grains was very widespread at varying levels across eastern Australia in 2022 along with white grain disorder in some regions (see separate FHB/white grain paper). Current testing of 218 head or grain samples indicates that ~79% of the FHB which occurred across NSW and southern Qld in 2022 was related to tiller bases infected with FCR. That is, Fusarium infection of wheat and durum crops in 2022 expressed as FHB due to the wetter/milder conditions during flowering and grain fill. This basal Fusarium infection would have expressed as whiteheads if crops had been temperature and/or moisture stressed during this period in 2022. This was a massive warning sign. Do not ignore it. TEST, TEST, TEST!

Why is testing so important in 2023?

FHB was widespread in 2022 with implications for seed retained from infected crops. Fusarium grain infection reduces germination and causes seedling blight (death) in plants arising from infected grain. The fungus replaces the contents of infected seed with its own mycelium, so while seed treatments can help reduce the level of seedling blight, they cannot restore the quality of heavily infected seed sources. Sowing Fusarium infected seed also introduces FCR into paddocks. The level of pink or white grains in grain is likely an underrepresentation of the true level of Fusarium grain infection, as later infections (i.e. high humidity) during grain fill, can allow some fungal spread into formed grains which appear normal. Sourcing quality seed for sowing in 2023 is potentially a big issue. Do not assume, even if you have never tested seed before or thought things were fine with seed after 2021 which was also wet. The difference was the widespread levels of FHB in 2022. If you had any level of FHB in crops retained for sowing seed or noticed white or pink grain at harvest, then get a commercial germination and vigour test or send a sample to NSW DPI for 'free' Fusarium testing (see FHB paper) well in advance of sowing. Do not let 2023 be 'the year of the re-sow'.

Testing of any paddock planned for a cereal-on-cereal rotation needs to be assessed for FCR risk using either PreDicta® B Sampling_protocol_PreDicta_B_Northern_regions.pdf (pir.sa.gov.au) or NSW DPI/LLS stubble plating (sampling bags available from LLS offices across NSW or contact author) prior to sowing in 2023. This is imperative in any paddock where FHB was noticed in 2022, as there is a high (79%) probability that the infection came from FCR in the base of plants. Yes, testing is painful and no doubt that some will just play the numbers from current testing of 2022 cereal crop infection levels across central/northern NSW. Of the 158 cereal stubbles assessed from the 2022 harvest so far, 34% had low (<10%), 27% moderate (11-25%), 20% high (26-50%) and 19% very high (>50%) FCR infection. However, FCR risk is very much dependent on the individual paddock, so is more like sending your neighbour for a prostate test to see if you will be okay! Trust me, testing cereal stubble and seed is less painful.

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

If medium to high FCR risk then:

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

If still considering a winter cereal;

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

Summary

Cereal disease management is heavily dependent on climatic conditions between and within seasons. Therefore, the situation can be quite dynamic, including the unpredictable distribution of different stripe rust pathotypes across regions. Arm yourself with the best information available including the latest varietal disease resistance ratings. Ensure you are sowing the best seed available based on testing. Do your own if you do not want to send samples away, simply count three lots of 100 random seeds and sow in separate spaced rows in the garden and see what comes up. Seed quality cannot be assured after the exceptional conditions in 2022, potentially seed retained from 2021 may be of better quality for planting in 2023. You don't know if you don't test. Do not do a whole paddock experiment to find out.

FCR risk is at record highs across much of the northern grain region. Widespread FHB in 2022 was predominantly the FCR fungus letting you know that it has not gone away with wetter and milder spring conditions the last few seasons. Do not ignore the signs. Do you know your FCR risk in paddocks planned for cereals in 2023, especially if sowing durum? We cannot keep banking on wet and mild spring conditions as our main FCR management strategy.

Keep abreast of in-season GRDC and NSW DPI communications which address the dynamics of cereal disease management throughout the 2023 season.

Further resources

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

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

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Fusarium head blight and white grain issues in 2022 wheat and durum crops

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Keywords

Fusarium head blight, Fusarium crown rot, white grain disorder, grain quality

GRDC codes

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

Take home message

- Detection of Fusarium head blight (FHB) was widespread across eastern Australia in 2022
- White grain disorder (WGD, Eutiarosporella formerly Botryosphaeria) was also confirmed in some areas (mainly southern Qld)
- FHB and WGD can be confused with melanism (false black chaff) and stripe rust head infections. Use NSW DPI pathologists for correct identification
- FHB infection is a function of prolonged high humidity (>80%) during flowering and early grain fill
- FHB causes yield loss (up to 100%) but also potentially downgrading of grain due to production of mycotoxins in affected white or pink grains (deoxynivalenol, DON mainly) which can affect end use depending on the level of infection
- Retaining grain from FHB or WGD affected crops negatively impacts suitability for sowing so grain infection levels should be tested.

Where did it come from?

If caused by *Fusarium pseudograminearum,* then the Fusarium head blight likely came from basal infection of tillers from Fusarium crown rot. Rain splash transports spores on lower nodes into heads. If caused by *Fusarium graminearum*, then it likely came from air borne spores produced on maize or sorghum stubble or some grass weeds known to be hosts. It can also host on wheat and barley. However, climatic conditions during flowering through to soft dough are a key factor in disease development. Frequent rainfall, high humidity, and/or heavy dews or fogs that coincide with flowering and early grain fill periods favour infection and development of FHB and WGD. The most favourable conditions for FHB infection are prolonged periods (36-72 hours) of moisture (>80% humidity) and warm temperatures (20-30°C). However, infection does occur at cooler temperatures when high moisture persists for longer than 72 hours.

The abundance of inoculum and weather conditions during flowering determines the severity of FHB. The longer the wheat head stays wet during flowering and early grain development, the greater the chance of infection and increased severity. Early infections may produce spores that are responsible for secondary infections under optimum conditions for disease development, especially if the crop has uneven flowering due to late tillers or a prolonged flowering period due to cooler temperatures or phenology.

There is no information on the relative resistance of Australian wheat varieties to FHB with the exception that all durum varieties are very susceptible. The level of FHB infection is heavily related to climatic conditions during flowering with minor differences in flowering time potentially giving dramatic differences in the level of infection.

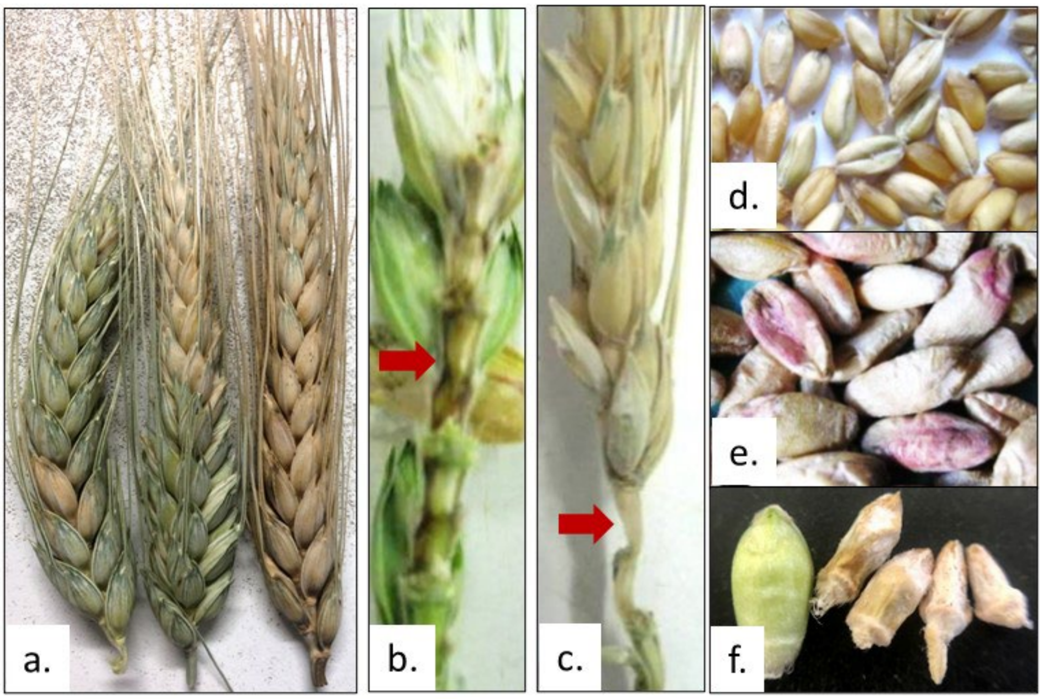

Figure 1. Correct diagnosis of Fusarium head blight and white grain disorder.

- **a.** FHB and WGD both cause partial bleaching or total bleaching of heads.
- **b.** If FHB is present, then the stem in the head (rachis) will be brown at the point where bleached spikelets attached.
- **c.** If WGD the rachis will be white where bleached spikelets attach.
- **d.** Both FHB and WGD cause production of white grains.
- **e.** If there is any pink coloration of grain, then this is diagnostic of FHB.
- **f.** Depending on infection timing, infected grains are often pinched and lighter and hence the majority blow out the back of the header at harvest. Try increasing header fan speed in infected paddocks or paddocks to be retained for seed. However, this only works if infection was early in the flowering/grain fill period and resulted in pinched grains.

Why is species identification important?

Knowing the Fusarium species of FHB or whether it is WGD is important to determining likely inoculum source and management going forward. FHB caused by *Fusarium graminearum* (*Fg*) likely produces larger quantities of more toxic forms of mycotoxins (15ADON and nivalenol) based on Australian studies in 2010 and 2016. FHB caused by *Fusarium pseudograminearum* (*Fp*) likely produces lower quantities of a less toxic form of DON (3ADON). WGD caused by *Eutiarosporella* spp. (*Eut*) produces no known mycotoxins (Simpfendorfer et al. 2017).

Species identification using quantitative PCR of 218 head or grain samples from 2022 submitted from across NSW and southern Qld shows FHB caused by *Fp* as the dominant issue (60% *Fp* only) followed by FHB caused by *Fg* (5% *Fg* only) and WGD caused by *Eut* (5% *Eut* only). Mixed infections occurred within some cereal crops with *Fp* + *Eut* (19%) most common followed by *Fp* + *Fg* (11%), *Fg* + *Eut* (1%) and *Fp* + *Fg* + *Eut* (1%).

Caution feeding infected grain to livestock

Take care when feeding *Fusarium* infected grain to stock. There are no specific Australian stock feed guidelines for mycotoxins. The US Food and Drug Administration (FDA) have guidelines that state: for the main DON toxin, advisory levels for food products consumed by humans is 1 part per million (ppm); 10 ppm for ruminating beef and feedlot cattle older than 4 months (cannot exceed 50% of diet); 10 ppm for poultry (cannot exceed 50% of diet); 5 ppm for swine (cannot exceed 20% of diet); and 5 ppm for all other animals (cannot exceed 40% of diet)(US Food and Drug Administration 2010).

Are there issues if retaining grain for sowing?

Absolutely because Fusarium and Eutiarosporella infection both reduce germination and can cause early seedling death (blight). Fusarium infected grain can also introduce Fusarium crown rot into clean paddocks through seed infection. The level of infection can be higher than the visual level of white or pink grains, as later infections may not discolour the seed. Up to 70% Fusarium grain infection has been measured in one durum wheat crop sent in from near Hillston from the 2022 harvest. So far, grain infection levels are generally much higher in seed retained from durum crops compared with bread wheat, highlighting their increased susceptibility to FHB. However, 20-30% Fusarium grain infection has been measured in a number of bread wheat seed sources retained from the 2022 harvest.

There are registered fungicide seed treatments to reduce the extent of seedling blight when sowing Fusarium infected grain. However, once infection levels get over 5% its best to try and find a cleaner seed source, if possible, as higher infection levels are also often linked to poor seedling vigour. Grading out lighter seed prior to sowing can also help as this will remove obvious severely infected grains.

Fungicide seed treatments will not eliminate Fusarium crown rot infections associated with sowing into infected cereal stubble or grass weed residues in a paddock and have no effect on FHB later in the season.

Could I have sprayed to stop it?

The only registered fungicide product to control FHB is Prosaro® 420 SC, which needs to be applied to protect the flowers at heading, follow label instructions. Research has shown that spraying at flowering (GS61) was more effective and had more yield benefit than spraying seven days before flowering. The anthers (flowers) are the primary infection site for *FHB*, so spraying before flowering provides reduced protection of these plant structures.

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

Prosaro® 420 SC is only usually applied to durum wheat (very susceptible to FHB) in parts of northern NSW which have dealt with FHB since 1999. Application to bread wheats has never previously been deemed economical but infection levels in many bread wheat crops in 2022 have challenged this thinking. Note, in north America strobilurin fungicides 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).

Harvest considerations

Harvest order or separation – Infection levels vary from paddock to paddock. Ideally, each paddock's grain should be binned separately to optimise market opportunities. Based on assessments of FHB just after flowering, the harvesting of heavily infected paddocks or sections of paddocks may be abandoned or sold directly for feed. Alternatively, more heavily infected sections of a paddock may be harvested separately from the rest of the crop. Levels of FHB may also alter the priority in which individual paddocks are harvested. FHB damaged grain must also be stored properly to prevent further disease development. Grain infected with FHB with a moisture content greater than 13% should be dried to stop further mould and mycotoxin development.

Header set-up – Adjust header openings and wind so that shrivelled, light weight, infected grain is removed along with the stubble. This technique will also reduce the level of mycotoxins, if present, in the harvested grain and is one reason why high concentrations of toxins usually do not end up in harvested grain and eventually the milled product. However, this will not remove all infected seed, since some FHB infection occurs late in development of the grain, and these infected seeds may still be plump. This technique is also only an option when the rest of the grain is of good quality. In paddocks severely affected by leaf diseases (e.g., yellow spot), which are also favoured by warm moist conditions, separating shrivelled grain caused by leaf disease and FHB is not possible during the harvesting process.

Mixing with uninfected sections or paddocks – Sections of a paddock with low levels of FHB infection could be harvested separately and blended with uninfected grain from the rest of the crop to reduce infected seed below receival limits. Equally, grain from an uninfected paddock can be mixed with seed from an infected paddock if the combined grain remains below quality limits set at the receival point. This practice may be too risky if trying to mix grain harvested from a paddock heavily infected with FHB. A combination of gravity grading followed by blending with uninfected grain may be required under moderate disease levels.

Gravity grading – This technique can be used to remove a large proportion of the light weight, pinched, chalky white and/or pink FHB infected grain before delivery to the silo to hopefully limit downgrading or allow delivery. This technique may also reduce the level of Fusarium grain infection if retaining seed for sowing. This technique is probably not viable under severe infection from FHB when most of the grain is diseased.

Human safety precautions – FHB damaged crops can be harvested and handled safely, provided normal precautions are taken to avoid exposure to grain dust. Grain dust is a hazardous substance, regardless of whether the Fusarium fungus is present. Various fungi and moulds in the dust can cause allergic reactions and lung irritation, and prolonged exposure can lead to serious breathing problems. Growers should take all the same precautions they would if handling mouldy grain. These precautions include using masks, goggles and protective clothing.

Summary

The 2022 season with prolonged high humidity (>80%) during flowering and grain fill was extremely conducive to FHB and WGD infection and development. Extended cool conditions which prolonged the flowering period were also likely a big factor in the increased prevalence of FHB and WGD this season.

If FHB is the result of basal infection of Fusarium crown rot, then the underlying issue needs to be rectified through an integrated disease management plan including crop rotation. Determining the cause of FHB or WGD is important when providing appropriate future management advice. In the majority of situations tested so far it was the FCR fungus (*Fp*) reminding us that it does not go away in wet years. If grain fill conditions had been hot and dry what would the level of whitehead expression and yield loss from FCR been in your crop?

Acknowledgements

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Testing of grain infection levels

Send 200-250 g seed in plastic double zip lock bags with variety and location to
Steven Simpfendorfer at Tamworth laboratories (above). No charge as funded by GRDC project.

Pre-sowing paddock FCR/FHB risk

PREDICTA®B soil/stubble testing available through SARDI.
Sampling_protocol_PreDicta_B_Northern_regions.pdf (pir.sa.gov.au)

Or alternatively contact Steven Simpfendorfer or your Local Land Services office about stubble testing.

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Rust sentinel sites in Central NSW - what did we learn in 2022?

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Notes

Understanding the physiology of wheat yield response to the interaction between temperature, nitrogen, and water

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Keywords

wheat, nitrogen, grain number, critical period, phenology, water

GRDC code

DAS00166_BA

Take home messages

1. Australia's agriculture is low input-low output by global standards; under-fertilisation causes soil mining
2. The critical developmental period for wheat yield spans from late stem elongation to 1 week after flowering
3. Yield response to nitrogen depends on three traits: duration of the critical period, growth rate during the critical period, and partitioning of photosynthate to spikes
4. Yield response to nitrogen is correlated with plant water status at stem elongation in May-sown crops
5. A positive yield response to nitrogen fertilisation is more likely with mean temperature during the critical period below 13 °C

Points 2 and 3 apply irrespective of soil, climate, and management; 4 and 5 apply to SA and need assessment elsewhere.

Introduction

"It depends…" is a common and justified answer to many agronomic questions. What's the expected response of wheat yield to nitrogen fertilisation? It depends on stored soil mineral nitrogen, organic matter and mineralisation, seasonal rainfall and stored soil moisture, sowing date and variety, temperature, other nutrients... "It depends" reflects the complexity of biological systems at the core of agriculture, but it does not mean we lack solid foundations to understand and manage crops. Here we focus on physiological principles to help understand and manage the water-dependent and temperature-dependent yield response to nitrogen. But first, let's have a quick look at Australian agriculture in a global context.

Australian agriculture in a global context

Esteban Jobbágy and colleagues (Jobbágy and Sala, 2014) looked at nutrient balances in agriculture with a focus on industries, across countries. They found nutrient balance (i.e., the difference between fertiliser input and nutrient exported in produce, kg nutrient per ha) correlated closely with gross income ($ per ha). Fruit and vegetables, the most profitable industry, features the largest excess of nutrients. Globally, grains are closer to neutral. The insight is clear, more profitable industries use more inputs, but hides large variation between countries. In a complementary study, Jobbágy and colleagues looked at countries across industries (Figure 1). Australia's agriculture stands out as a frugal, low input-low output. In contrast China, USA, and France feature subsidised, opulent systems with heavy use of fertiliser. Hence, the notion that we need to produce more with less is justified in opulent systems, where excess reactive nitrogen can cause environmental problems, but needs more careful consideration in Australia where under-fertilisation causes soil mining (Angus and Grace, 2017) and pervasively limits yields. A finer analysis would likely show variation within Australia, with over-fertilisation more likely in high-rainfall environments. Rob Norton (2016) calculated a negative N balance of 16 kg N/ha and a positive P balance of 6.2 kg P/ha across Australian agricultural industries over the period 2002-03 to 2011-12.

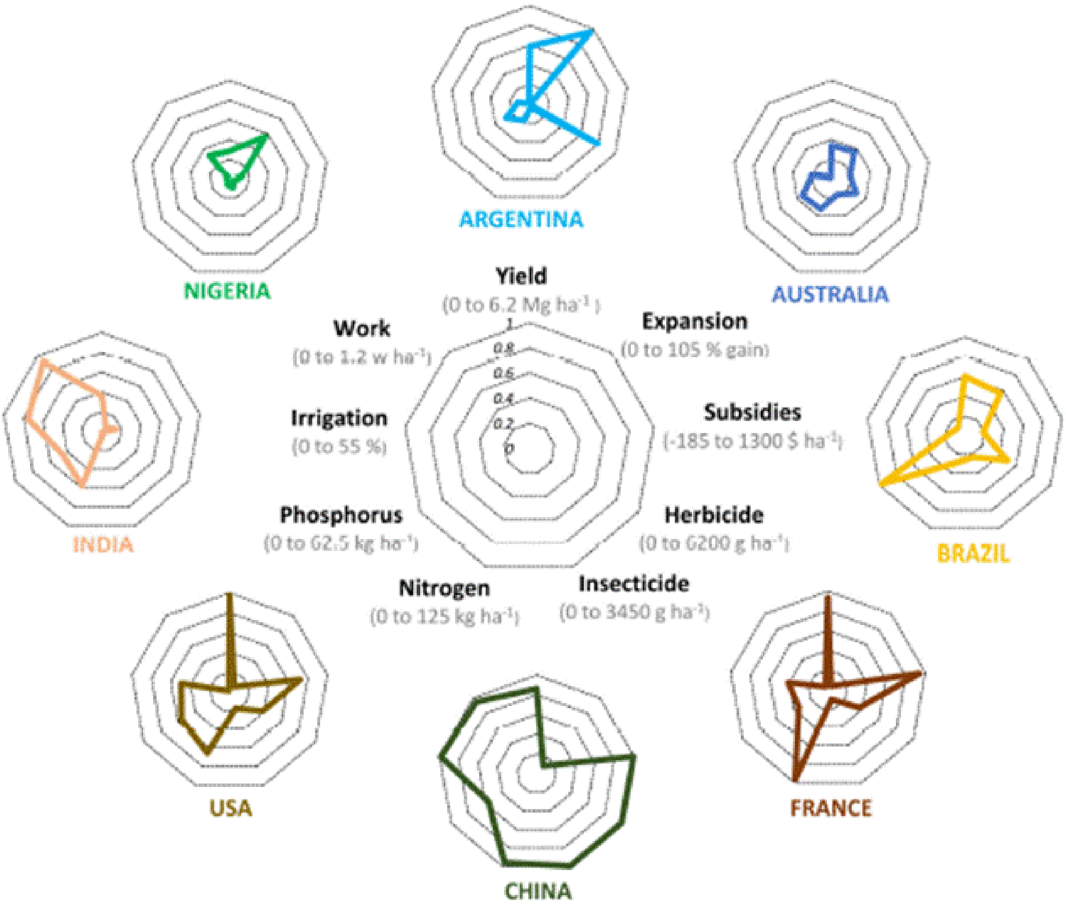

Figure 1. Australia's agriculture is low input-low output compared with high-input high-ouptut agriculture in USA, France, and China. Diagrams for each country show, clockwise: yield, expansion (land clearing), government subsidies, and inputs including herbicide, insecticide, nitrogen, phosphorus, irrigation and work. The central radar shows the units for each scale. Source: Novelli et al. (2023).

Grain yield depends on grain number; grain weight is secondary

Yield is the product of grains per m^2 and average grain weight. Relatively small variation in yield (5-10%) can be related to either grains per m^2 or grain weight. Large variation in yield (50% or more) is necessarily associated with grain number (Figure 2). This relates to the universal principle that crops accommodate environmental variation by adjusting grain number. This principle is as strong as it gets. It applies to all cereals, pulses, and oil-seed crops, irrespective of soil, climate, and management. Of course, we don't want screenings, and grain size is an important quality attribute, but we should not be distracted from the main game – to get the numbers (Figure 2).

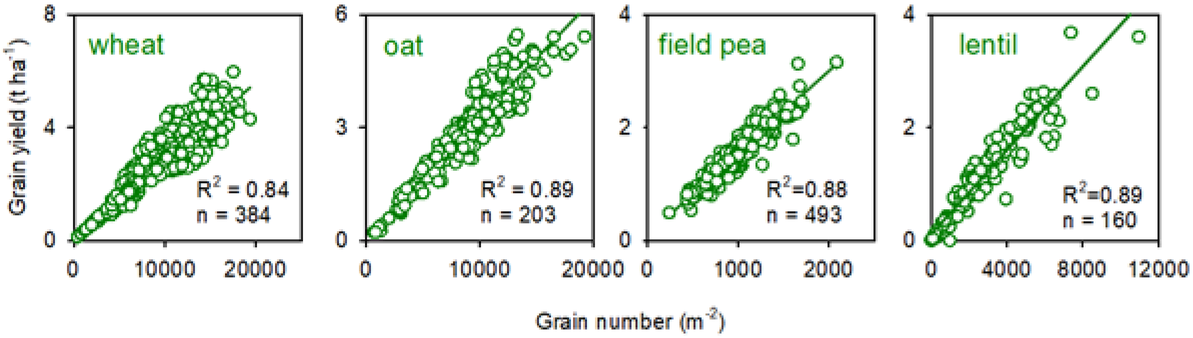

Figure 2. Crop yield is primarily related to grain number. Source: Sadras (2021).

Grain number is defined in a crop-specific critical period

Grain number in cereals is defined in a critical developmental period from late stem elongation to 10 days after flowering, with a most sensitive stage about 2-3 weeks before flowering (Figure 3). In pulses and canola, the most critical period is pod set (Figure 3). The critical period does not depend on soil, climate, or management. We found the same critical period for locally adapted Australian oat varieties in a 3.2 t/ha environment in SA, and locally adapted Chilean varieties in a 7.5 t/ha environment in southern Chile.

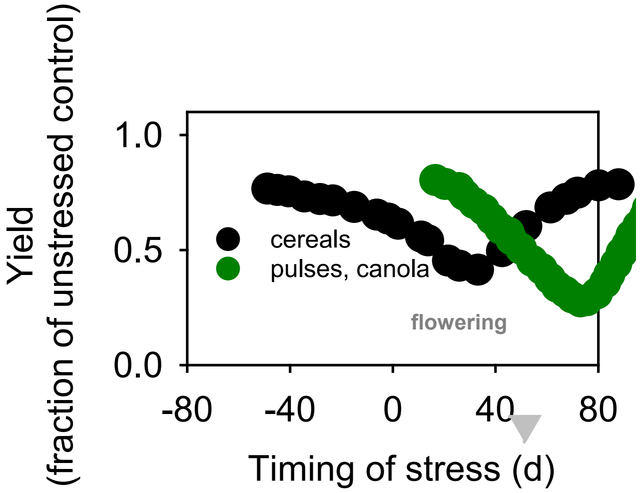

Figure 3. Yield and grain number are sensitive to stress in species-specific critical windows. Source: Sadras and Dreccer (2015).

Management should primarily focus on the critical period

Because yield is a primary function of grain number, and grain number is determined in a species-specific critical window, management should aim at:

- a high growth rate in the critical period,
- a long critical period, and
- avoiding stress (drought, heat, frost, nitrogen deficiency) in the critical period.

Plenty of experimental and modelling work focuses on matching variety-sowing date for stress avoidance. Figure 4 illustrates the relationship between yield and grain number of wheat at

Roseworthy in South Australia, and the relationship between grain number and crop growth rate in the critical period.

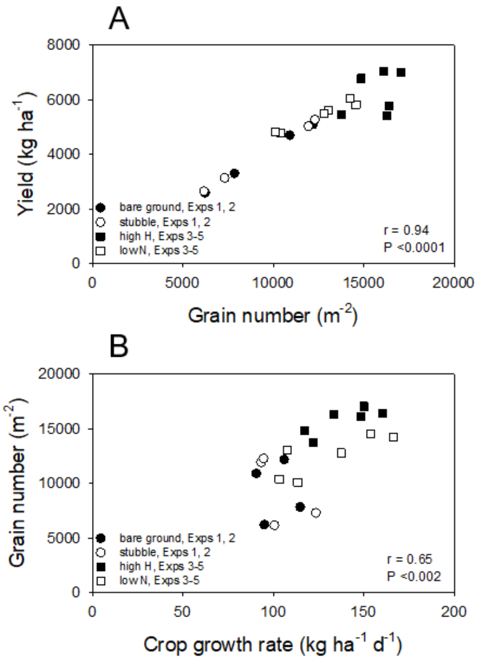

Figure 4. Relations between (A) yield and grain number and (B) grain number and growth rate in the critical period of wheat crops at Roseworthy, SA. Source: Sadras (2012).

Water-dependent response to nitrogen

Carbon isotope composition is a measure of crop water status that has been widely used in plant breeding but less so in agronomic applications. In contrast to other measurements such as thermal-based indices that depend on growing conditions (e.g., radiation, wind), carbon isotope composition integrates plant water status from sowing to time of sampling and is independent of conditions at sampling time. Carbon isotope composition at flowering accounted for about half the variation in yield in a set of 1518 wheat crops in a yield range from 700 to 10,000 kg/ha with growing season rainfall from 118 to 351 mm, plant available water at sowing from almost 0 to 161 mm, soil nitrogen at sowing from 34 to 375 kg/ha, six current varieties and 13 historic varieties (Figure 5). This relationship is forensic; it explains part of the variation in yield but is too late for in-season interventions. The next question is whether carbon isotope composition could be used for top-dressing decisions We found yield still correlates with carbon isotope composition at stem elongation, and carbon isotope composition at stem elongation predicts yield response to nitrogen in crops sown in early to mid-May, but not for later sowings in SA (Figure 6).

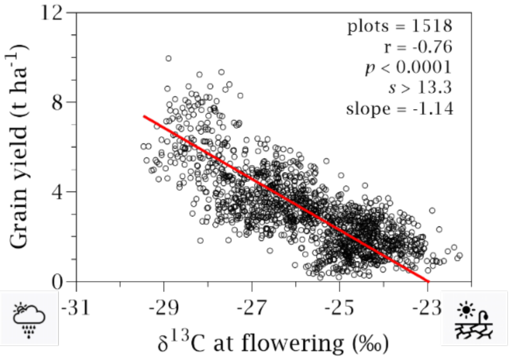

Figure 5. Relation between wheat yield and carbon isotope composition, a measure of crop water status, at flowering. Source: Cossani and Sadras (2022) ($^{o}/_{oo}$ = per thousand).

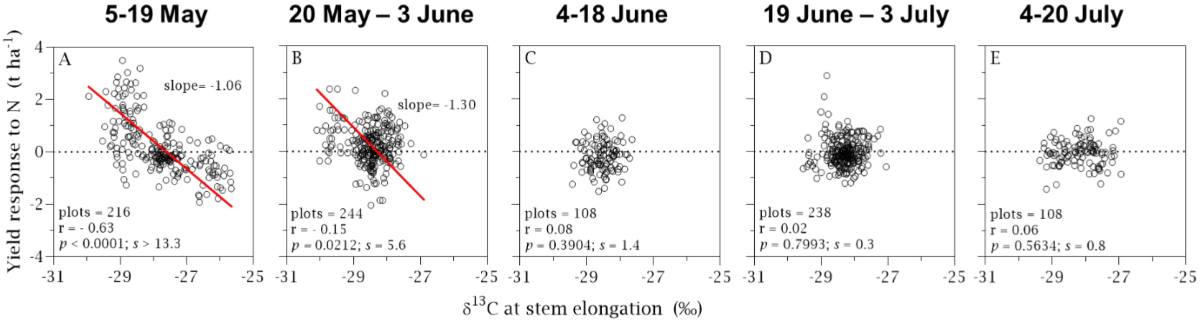

Figure 6. Relation between wheat yield response to nitrogen and carbon isotope composition, a measure of crop water status, at stem elongation for five sowing windows in SA. Response to nitrogen is 100 (YN-Y0)/Y0, where Y is yield and subscripts indicate fertilised (N, 50 to 200 kg/ha), and unfertilised controls (0). Source: Cossani and Sadras (2022) ($^{o}/_{oo}$ = per thousand).

The relationships between yield and carbon isotope composition *do* depend on other factors such as rainfall regime. We have developed cost-effective, high throughput methods to measure carbon isotope composition in wheat samples, with the potential to be scaled to paddock scale to aid nitrogen management spatially.

Temperature-dependent response to nitrogen

We advanced a framework to interpret the interaction between nitrogen and temperature that is based on three principles (Sadras et al., 2022):

1. yield response to nitrogen fertiliser is primarily related to grain number per m^2
2. grain number is a function of three traits: the duration of the critical period, growth rate during the critical period, and partitioning to grain
3. all three traits vary non-linearly with temperature.

The implication is that 'high' nitrogen supply may be positive, neutral, or negative for yield under 'high' temperature, depending on the part of the response curve captured experimentally. For wheat in SA ranging from failed crop to 6 t/ha, yield increased with duration of the critical period and declined with increasing temperature in the critical period at 0.5 t per °C (Figure 7). Yield response to nitrogen shifted from positive to negative at mean temperature ~ 13 °C (Figure 8). Yield declined at 6% per °C with 200 kg N/ha, 5% per °C with 100 kg N/ha and 2% per °C with 50 kg N/ha.

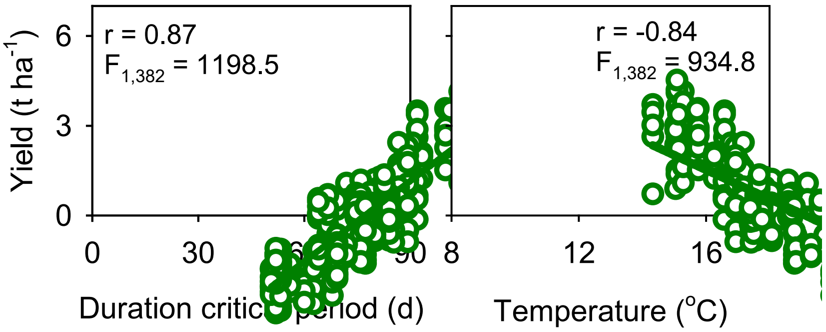

Figure 7. Wheat yield as a function of the duration of the critical period, and average temperature during the critical period. Source: Sadras et al. (2022).

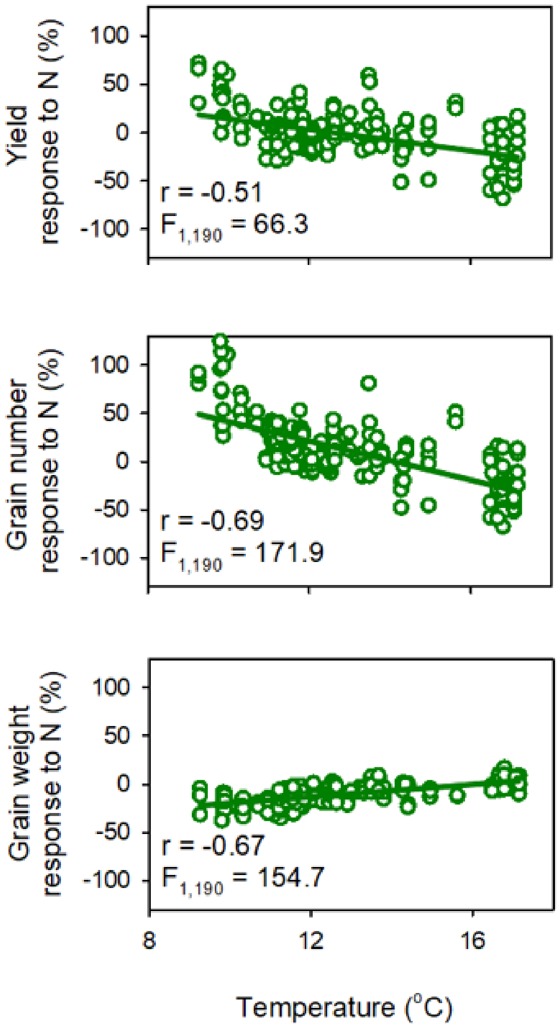

Figure 8. Response of yield and yield components to nitrogen as a function of mean temperature in the critical period. Source: Sadras et al. (2022).

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Optimising control of annual ryegrass

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Key words

annual ryegrass, wild oats, post-emergent herbicides, resistance, glyphosate, group 1, group 2, pre-emergent herbicides, dormancy

GRDC code

UCS2008-001RTX

Take home message

- Resistance to the Group 1 and Group 2 post-emergent herbicides in annual ryegrass is widespread and 23% of samples of annual ryegrass from NSW are resistant to glyphosate (group 9)
- There is more resistance in wild oats to the Group 1 herbicide Topik® compared to Axial®. Resistance testing can help decision making with Group 1 herbicides
- Resistance to pre-emergent herbicides in annual ryegrass remains at low frequencies, enabling their use in annual ryegrass control programs
- Continuous cropping is selecting for increased dormancy in annual ryegrass populations. Crop competition coupled with effective pre-emergent herbicide strategies can be used to reduce the impact of late emerging annual ryegrass

Resistance to herbicides in annual ryegrass in NSW

In 2020/2021 a survey of resistant weeds was conducted across the grain growing regions of Australia. This survey collected more than 1300 annual ryegrass samples that were then tested for resistance to common post-emergent and pre-emergent herbicides. In annual ryegrass, resistance to the Group 1 herbicide Axial® (pinoxaden + cloquintocet-mexyl) was high across all states and 73% of samples collected in NSW were resistant to this herbicide (Table 1). The frequency of resistance present to the Group 1 herbicide clethodim was lower, with only 17% of samples collected in NSW resistant. Likewise, resistance to the Group 2 herbicides was high with 86% of samples collected in NSW resistant to Hussar® (iodosulfuron-methyl-sodium + mefenpyr-diethyl) and 67% resistant to Intervix® (imazamox + imazapyr). Resistance to glyphosate (Group 9) is increasing in annual ryegrass and 23% of samples collected in NSW were resistant to this herbicide. No resistance to paraquat (Group 22) was detected in the survey.

Table 1. Extent of resistance in annual ryegrass to various post-emergent herbicides from random samples collected in 2020/2021 across Australia. Resistance is defined as 20% survival or greater.

State (Samples tested)	Resistant samples (%) (resistant ≥20% survival in pot trial)					
	Axial 100 300 mL ha^{-1}	Clethodim (240g/L) 500 mL ha^{-1}	Hussar OD 100 mL ha^{-1}	Intervix 750 mL ha^{-1}	Glyphosate (540g/L) 1.5 L ha^{-1}	Paraquat (250g/L) 1.2 L ha^{-1}
National (1,354)	71	23	91	79	16	0
NSW (317)	73	17	86	67	23	0
Victoria (183)	73	10	95	86	22	0
Tasmania (21)	86	52	71	57	0	0
SA (279)	66	14	85	68	14	0
WA (554)	71	35	98	92	12	0

In contrast to the post-emergent herbicides, resistance to the pre-emergent herbicides was less frequent (Table 2). Resistance was identified to trifluralin (Group 3) and Boxer Gold® (prosulfocarb + s-metolachlor; Group 15), but not to Sakura® (pyroxasulfone; Group 15), Rustler® (propyzamide; Group 3), Luximax® (cinmethylin; Group 30) or Overwatch® (bixlozone; Group 13). Therefore, pre-emergent herbicides are still likely to be effective for annual ryegrass control, where post-emergent herbicides are increasingly likely to fail. However, just because the survey failed to identify resistance to some herbicides does not mean resistance is not present.

Table 2. Extent of resistance in annual ryegrass to various pre-emergent herbicides from random samples collected in 2020/2021 across Australia. Resistance is defined as 20% survival or greater.

State (Samples tested)	Resistant samples (%) (resistant ≥20% survival in pot trial)					
	Trifluralin 1.5 L ha^{-1}	Boxer Gold 2.5 L ha^{-1}	Sakura 118 g ha^{-1}	Rustler 1 L ha^{-1}	Luximax 0.5 L ha^{-1}	Overwatch 1.25 L ha^{-1}
National (1,354)	12	2	0	0	0	0
NSW (317)	0	1	0	0	0	0
Victoria (183)	21	9	0	0	0	0
Tasmania (21)	0	0	0	0	0	0
SA (279)	38	1	0	0	0	0
WA (554)	4	2	0	0	0	0

Resistance to herbicides in wild oats in NSW

The same survey collected just under 600 wild oat samples that were tested for resistance to the Group 1 herbicides Topik® (clodinafop-propargyl + cloquintocet-mexyl) and Axial. About 40% of the samples tested were from NSW. Resistance to Topik was identified in 27% of samples from NSW (Table 3). Resistance to Axial was less common in wild oats and present in only 16% of samples from NSW. NSW had a higher frequency of resistance in wild oats compared to other states.

While often resistance results in cross resistance to other herbicides in the same mode of action, there are cases where one or more herbicides from that mode of action may still be effective against the resistant population. This can provide a useful short-term option for management of resistant populations. As these patterns of resistance are unpredictable, it is important to conduct resistance testing to ensure susceptibility of the population.

Table 3. Extent of resistance in wild oats to the Group 1 herbicides Topik and Axial from random samples collected in 2020/2021 across Australia. Resistance is defined as 20% survival or greater. Some wild oat samples collected had insufficient germination to test with Axial.

State	Topik 65 mL ha^{-1}		Axial 100 200 mL ha^{-1}	
	Samples tested	Resistance (%)	Samples tested	Resistance (%)
National	582	16	295	8
Queensland	61	20	40	8
NSW	232	27	125	16
Victoria	72	15	54	0
Tasmania	4	0	0	-
SA	63	6	10	0
WA	150	4	84	0

Changes in annual ryegrass emergence patterns

The adaptability of annual ryegrass is a major reason it is the most important weed of grain cropping in Australia. In addition to evolution of resistance to herbicides, annual ryegrass can also evolve other traits that allow it to avoid control tactics. One of these traits is increased seed dormancy. There is evidence that populations of annual ryegrass have changed their emergence pattern where more of the population emerges later in the season. This allows some of the population to avoid control by knockdown and pre-emergent herbicides.

We have established that there is heritable variation for dormancy within annual ryegrass populations. In these studies, the early emerging and late emerging proportions of populations were separated and crossed among themselves. The progeny of these two sub-populations had different emergence patterns (Figure 1). There is about a 3-week difference in emergence between the two sub-populations.

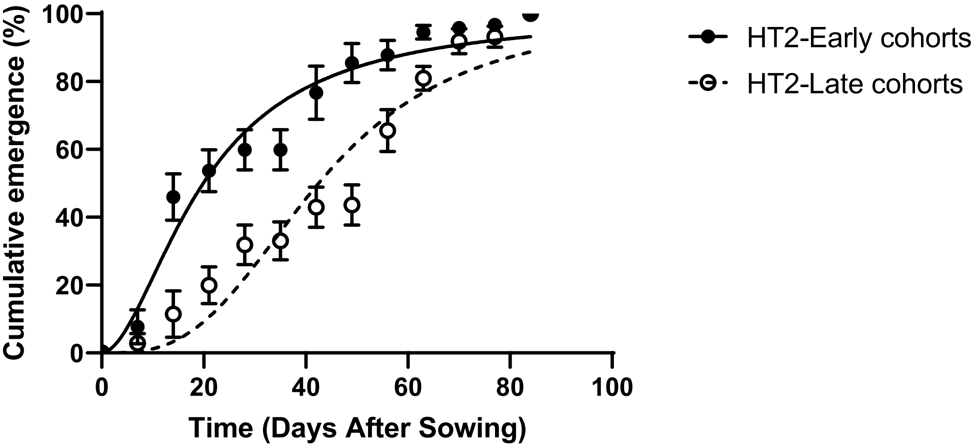

Figure 1. Cumulative emergence of seeds of early and late cohorts selected from an annual ryegrass population.

This pattern of delayed emergence has previously been identified in brome grass and barley grass populations in southern Australia. It is likely that more dormant populations of other grass weeds, such as wild oats, could also be selected in continuous cropping fields.

Delayed emergence will make annual ryegrass more difficult to control, particularly as reliance on knockdown and pre-emergent herbicides for control of annual ryegrass control is high. Management strategies will need to adapt. Previously we have shown that the combination of crop competition with effective pre-emergent herbicides is one tactic that can limit the impact of late emerging annual ryegrass. The use of pre-emergent herbicide mixtures and sequences to provide longer control of emerging annual ryegrass is another tactic that can be used to help combat later emergence. Stopping seed set of surviving annual ryegrass plants through crop-topping and harvest weed seed control is also valuable to combat increased seed dormancy of populations.

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Intercropping and companion cropping of high value cash crops (wheat and chickpeas) in central NSW – how did they perform?

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Key words

companion cropping, intercropping, wheat, chickpea, pulse crops

GRDC code

BLG126

Take home message

- Intercropping increased productivity (yield), and on average required 14% (and up to 42%) less land than monoculture crops to grow the same amount of grain
- Wheat had a competitive advantage over chickpea, and therefore the chickpea proportion (plant population) needs to be at least 50% of the total intercrop mix
- No productivity gains were observed between sowing species in alternating rows verses mixed within the rows. However, alternate rows showed a small grain yield increase to the chickpea component
- Termination of the wheat or chickpea component within the companion mix reduced productivity by 63% and 10%, respectively
- Soil nitrogen benefit of ~73 kg N/ha was derived from the chickpea monoculture compared to the wheat monoculture. Residual N increased (by up to 40 kg N/ha) as the chickpea proportion increased from 25% to 75% of the total intercrop mix
- Crop stubble type and configuration had no effect on soil water accumulation over the fallow period due to a wet summer/autumn fallow period in 2022
- Compared to wheat monoculture, the intercrop treatments had a ~50% reduction in profitability in year 1, however showed a ~12% increase in the following winter cash crop (canola)
- Cost associated with separating the wheat and chickpea within an intercrop mix will be a potential barrier for adoption (up to $95 per tonne).

Introduction

Intercropping is where two or more species are sown and harvested together with the objective of harvesting grain of both species, whilst companion cropping is where two or more species are sown together with the objective of harvesting grain from a single species, while the other species is terminated using herbicides. Claimed benefits include N-fixation, reduced disease, improved nutrient uptake, weed suppression, soil structure benefits and mycorrhiza hosting (Fletcher, et al 2020). Neither of these techniques (intercropping/companion cropping) are common practice in large-scale rainfed cropping systems across Australia, however they have been used for centuries throughout the world on a smaller scale. Over recent years there has been increased global interest in these approaches as sustainable farming systems and greater productivity from a unit of farmland are sought.

The land equivalent ratio (LER) is a concept in agriculture that describes the relative land area required under sole cropping (monoculture) to produce the same yield as under intercropping. An LER greater than 1.0 (or 100%) indicates that production is higher in the intercropping system compared to monoculture. For example, a LER of 1.25 (or 125%) indicates that two monocrops planted in equal proportion would require 25% more land to produce the equivalent yield achieved by intercropping the two crops. Studies from overseas and limited work in Australia have shown that LER of greater than 1 (or 100%) are achievable for intercropping systems involving both monocot and dicot species.

There has been little research on the role and benefits of intercropping and companion cropping in large scale cropping systems, and the necessity for further research has been highlighted by recent studies (Fletcher, et al 2016, 2020). The review by Fletcher et al (2016) highlighted the lack of information available to Australian grain growers and identified areas for future research – genotypic adaptation for intercrop/companion species, rotational benefits, yield variability between companion species and regional adaptation and management complexity versus productivity.

This project evaluated the role of companion and intercropping using chickpea and wheat in central NSW. The project looked at land equivalent ratio and gross margin return to growers, but also investigated the role of companion/intercrops to increase residual stubble cover to increase summer fallow efficiency when compared to fallows managed after chickpea crops.

The project was set up to answer the following research questions in central NSW farming systems:

1. Can grain yield, grain quality and profitability be improved by growing a pulse (chickpea) and cereal (wheat) crop together? Should either species be terminated or is there net benefit in harvesting both?
2. What is the impact of soil water use efficiency in-crop and soil water storage (residual soil water at harvest and subsequent fallow efficiency) for the following crop after companion/intercrops of wheat and chickpea?
3. Is there an optimum plant density for each species, and should the proportion change if the aim is to maximise grain yield and/or improve fallow efficiency/groundcover post-harvest?
4. Should crop species be separated and sown in alternate drill rows, or mixed within the one drill row?
5. What is the legacy effect on the soil nitrogen balance and grain yield in subsequent crops following an intercrop/companion cropping system using wheat and chickpea?

Table 1. Site details for Canowindra & Condobolin experiments

Details	**Canowindra (Central East NSW)**	**Condobolin (Central West NSW)**
Sow date	25-May, 2021	21-May, 2021
Soil type	Chromosol	Chromosol
Plot seeder details	Excel single disc with rubber firming wheel and scalloped closing plate at 25cm row spacing	
Chickpea - Target density (Drummond)	45 plants m^2	35 plants m^2
Wheat - Target density (Vixen)	140 plants m^2	120 plants m^2
Previous crop (2020)	Wheat	Wheat
Fallow rainfall (Nov20–Mar21)	238mm (+83^a)	374mm (+255^a)
Growing season rainfall (Apr21–Oct21)	378mm (+39^a)	248mm (+13^a)
Fallow rainfall (Nov21 – Mar 22)	523mm (+177^a)	546mm (+286^a)
Mineral N (0–120cm)	230 kgN/ha	114 kgN/ha
Colwell P (0–10cm)	34 mg/kg	25 mg/kg

a = +/- from the long-term average

Table 2. Treatments applied at Canowindra & Condobolin experiments

Trt no	Treatments
1	Chickpea monoculture
2	Wheat monoculture
3	Intercropped – wheat/chickpea at 75/25[ab] species composition
4	Intercropped – wheat/chickpea at 50/50[ab] species composition
5	Intercropped – wheat/chickpea at 25/75[ab] species composition
6	Intercropped – wheat/chickpea at 50/50[b] in alternate rows
7	High nitrogen treatment (Decile 7) Wheat monoculture
8	High nitrogen treatment (Decile 7) Intercropped – wheat/chickpea at 50/50[ab]
9	Companion crop – wheat/chickpea at 50/50[ab], with chickpea sprayed out at GS60
10	Companion crop – wheat/chickpea at 50/50[ab], with wheat sprayed out at GS49
11	Cover crop[c] post chickpea monoculture

a = Species mixed (% of targeted plant population/m^2 for each crop type) within row
b = Seeding rate % calculated for best practice at each location
c = Hybrid forage sorghum sown (Condobolin 7/12/21 & Canowindra 23/12/21) at 10kg/ha & terminated 45 days after sowing

Legacy benefits (yield and profit) to the following winter cash crop (2022) were measured via sowing canola (45Y93CL) at 3kg/ha with a single disc plot seeder over the previous 2021 companion treatments. Canowindra was sown on 25 April, and Condobolin on 6 May with 50kg/ha of MAP fertiliser applied with the seed and no additional nitrogen fertiliser.

Results & discussion

Seasonal conditions and plant establishment

The 2021 season could be described as a relatively soft season with above average rainfall at both sites. Canowindra received 193 mm above the long-term average of 599 mm, whilst Condobolin received 371 mm above the long-term average of 431 mm. The 2021/2022 summer period (Nov–May) was extremely wet at both sites, with 176 mm above the long-term average of 346 mm at Canowindra, and 276 mm above the long-term average of 260 mm at Condobolin. The wet summer negated any soil water legacy benefits across the various stubble type configurations.

Plant density achieved for the wheat monoculture was 139 plants m^2 at Canowindra (target 140 plants m^2) and 108 plants m^2 for Condobolin (target 120 plants m^2). Chickpea monoculture was 44 plants m^2 and 33 plants m^2 at Canowindra (target 45 plants m^2) and Condobolin (target 35 plants m^2), respectively. Refer to Appendix Table 1 and Table 2 for plant density results across the various ratio treatments within the companion mixes.

Productivity (grain yield)

The Canowindra site achieved an average wheat yield of 6.84 t/ha (ranged from 1.61–9.29 t/ha) and 1.11 t/ha (ranged from 0.01–1.90 t/ha) for chickpeas. Condobolin wheat yields were less, with an average of 5.02 t/ha (ranged from 0.09–7.26 t/ha) and 0.97 t/ha (ranged from 0.07–2.58 t/ha) for chickpeas. Refer to Appendix table 1 and 2 for grain yield and quality results.

Table 3 illustrates grain yield at Canowindra and Condobolin as a percentage of the monoculture controls. Grain yield for each species was higher when sown as a monoculture compared to the intercrop/companion mixes, with a 5–9% yield benefit with additional N to the wheat monoculture treatment.

The land equivalent ratio (LER) identified that intercrop mixes (Treatments 3, 4 and 5) required on average 14% less land to grow the same amount of grain as a monoculture. LER (%) ranged from 78% to 142% and tended to be higher (~30%) at the Canowindra site (HRZ) compared to Condobolin (LRZ). Wheat out-competed chickpea for light and resources, and the plant density/proportion needed to contain at least 50% chickpea for any productivity benefit to be realised. For example, when wheat dominated the mix (W75%_C25%) the chickpea component yielded 8–19% of the chickpea monoculture compared to 42–78% in the W25%_C75% mix. Sowing species in alternate rows helped reduce the competitive advantage of wheat (by providing space) and further increased chickpea yield by ~12%, but this increase in chickpea yield came at the expense of wheat yield (~18% reduction). Therefore, there was no LER benefit by sowing in alternating rows verses mixed within row.

Termination of wheat or chickpea within the companion mix reduced productivity and highlighted again the competitive advantage of wheat over chickpeas. For example, terminating wheat at GS55 produced a 63% grain yield reduction in chickpea, and terminating chickpea at GS60 produced a ~10% grain yield reduction in wheat (compared to monoculture treatments).

Table 3. Productivity of intercrop and companion treatments at Condobolin and Canowindra expressed as yield (t/ha), percentage of monoculture control and LER (%) in 2021.

Trt no	Treatment	Canowindra HRZ site [b]			Condobolin LRZ site[c]			Combined site average LER (%)
		Wheat	Chickpea	LER (%)	Wheat	Chickpea	LER (%)	
1 & 2	Monoculture	8.82 t/ha	1.90 t/ha	100%	6.69 t/ha	2.58 t/ha	100%	100%
3	Wheat75_Chick25	89%	19%	109%	70%	8%	78%	93%
4	Wheat50_Chick50	84%	54%	138%	81%	18%	99%	119%
5	Wheat25_Chick75	64%	78%	142%	73%	42%	115%	129%
6	Wheat 50_Chick 50_alternate rows	60%	65%	125%	69%	31%	99%	112%
7	Wheat100_plusN	105%	–	–	109%	–	–	–
8	Wheat50_Chick50_plusN	86%	47%	133%	86%	31%	117%	125%
9	Wheat50_Chick50_Csprayout[a]	91%	1%[a]	–	86%	3%[a]	–	–
10	Wheat 50_Chick50_Wsprayout[a]	18%[a]	60%	–	1%[a]	13%	–	–
11	Covercrop_Chick100	–	99%	–	–	93%	–	–

a = Spray-out treatment not 100% effective, with seasonal conditions that favoured crop regrowth

b = Refer to Appendix Table 1 for plant establishment, biomass, harvest index, grain yield and grain quality results.

c = Refer to Appendix Table 2 for plant establishment, biomass, harvest index, grain yield and grain quality results.

Legacy effects (water, nitrogen and following canola crop) post intercrop/companion

Stubble type configurations had no effect on soil water accumulation over the summer fallow period due to above average summer rainfall at both trial site locations (Site details in Table 1).

Averaged across both sites, there was a nitrogen legacy benefit of ~73 kgN/ha derived from the chickpea monoculture compared to wheat monoculture. Soil nitrogen increased by up to 40 kgN/ha when the chickpea proportion/density increased from 25% to 75%. Growing a summer cover crop post chickpeas reduced mineral N by ~82 kgN/ha.

On average, canola grain yield increased by 12% following the chickpea monoculture compared to wheat monoculture. As the proportion of chickpea raised from 25%, 50% to 75% the grain yield of canola was 98%, 108% to 113%, respectively of the yield after wheat monoculture. Interestingly, the chickpea and wheat spray-out treatment (companion treatments) increased yield by 5% and 8%, respectively.

Table 4. Legacy effects derived post intercrop and companion treatments for mineral nitrogen (kgN/ha), plant available water (PAW mm) (measured May 2022) and subsequent canola grain yield (t/ha) and oil (%) in 2022.

Treatment	**Mineral N^{ab} (kgN/ha)**		**PAW^{ac} (mm)**		**Canola-Canowindra**			**Canola-Condobolin**		
	Canowindra	**Condobolin**	**Canowindra**	**Condobolin**	**Yield (t/ha)**		**Oil%**	**Yield (t/ha)**		**Oil%**
Chick_100	266	203	120	105	4.26	109%	42.9	3.33	114%	44.8
Wheat_100	183	141	121	127	3.90	100%	44.6	2.91	100%	45.2
Wheat75_Chick25	183	98	112	145	3.99	102%	44.3	2.73	94%	45.0
Wheat50_Chick50	176	134	122	134	4.29	110%	44.0	3.08	106%	44.7
Wheat25_Chick75	213	151	115	127	4.33	111%	44.0	3.36	116%	44.5
Wheat 50_Chick 50_alternate rows	199	149	102	113	4.16	107%	44.0	3.11	107%	44.6
Wheat100_plusN	186	172	127	129	4.06	104%	43.9	3.12	107%	44.9
Wheat50_Chick50 _plusN	220	175	115	128	4.30	110%	44.3	3.44	118%	44.3
Wheat50_Chick50_ Csprayout	202	146	118	115	4.20	108%	44.3	2.97	102%	45.1
Wheat 50_Chick50 _Wsprayout	247	149	118	123	4.40	113%	43.8	3.01	104%	44.3
Covercrop_chick100	181	125	115	141	4.13	106%	43.3	2.60	89%	44.9
P Value	*0.091*	*0.083*	*0.997*	*0.475*	*0.136*		*0.003*	*0.019*		*0.023*
L.S.D 5%	*62*	*58*	*46*	*33*	*0.34*		*0.71*	*0.46*		*0.53*

a= Mineral N and PAW (mm) measured in May 2022 via 5 soil cores bulked together per plot
b= Mineral N depths include 0–10cm, 10–30cm, 30–60cm and 60–90cm
c= PAW depths include 0–10cm, 10–30cm, 30–60cm, 60–90cm and 90–120cm.

Profitability

Year one (intercrop and companion treatments)

Averaged across both sites, treatment gross margins ranged from $-237/ha to $1737/ha. The wheat monoculture was $1622/ha and chickpea monoculture much lower at $425/ha. The addition of nitrogen to the wheat monoculture treatment was the most profitable (6% higher than wheat monoculture) at $1737/ha, and the least profitable was the wheat spray-out companion treatment ($-237/ha). Whilst the intercropped treatments performed well from a productivity perspective, there was a ~50% reduction in profitability compared to the wheat monoculture due to price received for each crop, and additional expenses associated with seed separation.

A commercial quote to separate the wheat from chickpea was $95/t, as two passes would be required. First pass would separate wheat from chickpeas but likely leave white heads and trash from the wheat in the chickpeas ($35/t), and the second pass would involve cleaning the chickpeas with high wind speed and the use of a gravity table ($60/t). Therefore, a 5 t/ha yielding crop mix would cost $475/ha to separate the two species.

Table 5. Gross margin ($/ha) of the intercrop and companion treatments over 2021 and 2022. Percentages are % gross margins relative to the 'Wheat_100 treatment'

Treatment	2021 - Intercrop/Companion crop						2022 - Legacy canola crop						Average over 2 years	
	Condobolin		Canowindra		Combined AVG		Condobolin		Canowindra		Combined AVG			
Chick_100	$623	44%	$228	13%	$425	26%	$1,691	118%	$2,237	108%	$1,964	112%	$2,390	71%
Wheat_100	$1,421	100%	$1,822	100%	$1,622	100%	$1,437	100%	$2,076	100%	$1,756	100%	$3,378	100%
Wheat75_Chick25	$427	30%	$1,074	59%	$750	46%	$1,317	92%	$2,122	102%	$1,720	98%	$2,470	73%
Wheat50_Chick50	$646	45%	$1,211	66%	$929	57%	$1,530	106%	$2,302	111%	$1,916	109%	$2,845	84%
Wheat25_Chick75	$756	53%	$833	46%	$794	49%	$1,700	118%	$2,328	112%	$2,014	115%	$2,809	83%
Wheat 50_Chick 50_alternate rows	$609	43%	$858	47%	$733	45%	$1,546	108%	$2,219	107%	$1,883	107%	$2,616	77%
Wheat100_plusN	$1,407	99%	$2,066	113%	$1,737	107%	$1,561	109%	$2,151	104%	$1,856	106%	$3,593	106%
Wheat50_Chick50_ plusN	$650	46%	$1,013	56%	$832	51%	$1,744	121%	$2,321	112%	$2,033	116%	$2,864	85%
Wheat50_Chick50_ Csprayout	$546	38%	$947	52%	$747	46%	$1,472	102%	$2,257	109%	$1,865	106%	$2,611	77%
Wheat 50_Chick50_Wsprayout	-$426	-30%	-$49	-3%	-$237	-15%	$1,475	103%	$2,364	114%	$1,919	109%	$1,682	50%
Covercrop_chick100	$453	32%	$129	7%	$291	18%	$1,232	86%	$2,172	105%	$1,702	97%	$1,993	59%
Min	*-$426*		*-$49*		*-$237*		*$1,232*		*$2,076*		*$1,702*		*$1,682*	
Mean	*$647*		*$921*		*$784*		*$1,519*		*$2,232*		*$1,875*		*$2,659*	
Max	*$1,421*		*$2,066*		*$1,737*		*$1,744*		*$2,364*		*$2,033*		*$3,593*	

*Refer to appendix Table 3 and 4 regarding input costs and prices

Year two (legacy crop – canola)

Averaged across both sites, gross margins ranged from $1702 to $2033/ha. The chickpea monoculture and intercropped treatments with greater than 50% chickpeas had between a 9–15% increase in gross margin over the wheat monoculture. The W50_C50_plusN had the highest gross margin at $2033/ha.

The wheat monoculture and wheat plus N were the highest gross margin treatments over this two-year study. Interestingly, intercropped treatments with a proportion ≥50 % chickpea had a higher gross margin than chickpea monoculture, however it's likely that the chickpea monoculture might provide longer legacy benefits.

Comments and observations about managing intercrop/companion

Intercropping is highly reliant on pre-emergent herbicide chemistry for successful weed control. Based on current pesticide registrations, in-crop herbicide options are often limited (or non-existent) and growers need to be familiar with label requirements and withholding periods prior to selecting the species crop mix. Crop safety with pre-emergent herbicides is often higher in a knife point press wheel system compared to disc seeders, and some labels do not include registration that allows use in disc seeding systems.

Harvest management and desiccation timing can be difficult for a wheat/chickpea intercrop mix, particularly with late season rainfall as chickpea are indeterminate and wheat more determinate in their flowering pattern. Desiccation timing may need to be compromised, and preference towards the species of greater economic value should be considered (seasonally specific).

Chickpeas grown as a companion or intercrop (with wheat) tend to grow taller, branch less, have fewer pods per plant and an increased height to 'lowest' pod, compared to chickpea grown in a monoculture. Therefore, harvest height will be slightly higher.

Despite prophylactic fungicide application, Ascochyta blight was visually present within the chickpea monoculture at Canowindra but absent within a companion/intercrop mix. It is assumed that the wheat stubble reduced rain splash spread of inoculum into the upper canopy.

Chickpea spray-out treatment was scheduled to occur at peak biomass (GS65), however in reality the chickpeas needed to be terminated at GS60 due to label restrictions and crop safety for the wheat cash crop. For example, the last chance to terminate chickpeas is either awn peep or wait until after the dough stage of wheat.

A Group 1 grass selective herbicide was applied to the wheat spray-out treatment at GS49, however it took 3–4 weeks for visual signs of a 'kill' on the wheat. Water and nutrients would have translocated during the 3–4 week lag phase.

Unless grading/separation occurs at harvest (which adds complexity) there would also need to be adequate storage facilities on-farm for the mixed grain.

Summary

These results suggest that intercropping systems for growing high value cash crops (wheat and chickpeas) in central NSW may have productivity benefits, but profitability was severely reduced due to the costs associated with seed grading/separation and price received for each grain type. Cost of seed separation will be a major barrier to adoption if not addressed.

Intercropping is a much more complex farming system with high reliance on pre-emergent herbicides for successful weed control (little to no in-crop herbicide options), and harvest management/desiccation timing can be problematic due to managing a combination of indeterminate (chickpea) and determinate (wheat) maturity plant types.

Intercropping did improve overall productivity, with an average 12% (and up to 40%) less land required than monoculture crops to grow the same amount of grain. Sowing the correct plant density ratio for each species was important to ensure that one species did not dominate and 'choke out' the remaining species. In these two experiments, wheat was more competitive than chickpea and the proportion of chickpea needed to be at least 50% of the intercrop mix for benefits to be realised. Another option to reduce the competitive advantage of wheat was to sow each species in alternating rows, however whilst this improved the chickpea yield (at the expense of wheat yield) it reduced overall productivity (LER%).

Compared to the wheat monoculture, the companion cropping concept of terminating either the wheat or chickpea resulted in less production and profitability over this two-year study. Terminating the wheat caused major yield penalties to the chickpeas, whilst terminating the chickpeas had much less effect on wheat yield. Neither companion treatments were as profitable as the wheat monoculture.

These results highlight the residual benefits (largely N & disease) of having pulse crops within the farming system, and intercropping could be a tool to make the 'pulse crop' more profitable for that season whilst also providing elevated levels of ground cover to help drive fallow efficiency. However further research is required to evaluate if a pulse monoculture has longer lasting benefits compared to an intercrop. Grain prices for pulse crops are renowned for being highly variable, and intercropping might take away some of the price risk volatility as the wheat component will be the main income driver of the intercrop.

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Appendix Table 1. Plant establishment, biomass, grain yield, harvest index (HI) and grain quality (protein and test weight minimum (TWT)) from intercrop/companion treatment at Canowindra - 2021

Treatment name	Establishment		Wheat					Chickpea		
	Wheat plants m^2	Chickpea plants m^2	Biomass (t/ha)	Yield (t/ha)	HI (%)	Protein (%)	TWT (Kg/hL)	Biomass (t/ha)	Yield (t/ha)	HI (%)
Chick_100	–	44	–	–	–	–	–	10.6	1.90	22%
Wheat_100	139	–	14.1	8.82	42%	11.4	73.8	–	–	–
Wheat75_Chick25	99	10	13.1	7.89	44%	11.6	74.5	2.9	0.37	28%
Wheat50_Chick50	74	23	12.5	7.43	47%	11.5	73.1	3.0	1.03	28%
Wheat25_Chick75	36	33	9.5	5.65	47%	11.9	70.4	5.2	1.49	30%
Wheat 50_Chick 50_alternate rows	69	24	10.1	5.30	48%	11.9	72.2	4.8	1.23	29%
Wheat100_plusN	132	–	16.4	9.29	49%	11.7	74.4	–	–	–
Wheat50_Chick50_plusN	66	23	13.5	7.56	48%	11.8	73.7	2.6	0.89	30%
Wheat50_Chick50_Csprayout	76	18	13.7	8.05	47%	11.6	74.4	0.2	0.01	–
Wheat 50_Chick50_Wsprayout	70	21	8.6	1.61	20%	19.0	63.9	3.6	1.15	30%
Covercrop_chick100	–	43	–	–	–	–	–	10.4	1.89	24%
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.102
l.s.d 5%	13	5	1.8	0.65	4.5%	0.5	2.8	2.09	0.37	6.3%

* Chickpea yield was lower at Canowindra compared to Condobolin, presumably due to incidence of Ascochyta blight and cooler temperatures (i.e., pod set requires daily mean temperatures >15°C)

Appendix Table 2. Plant establishment, biomass, grain yield, harvest index (HI) and grain quality (protein and test weight minimum (TWT) from intercrop/companion treatment at Condobolin -2021

Treatment name	Establishment		Wheat					Chickpea		
	Wheat plants m^2	Chickpea plants m^2	Biomass (t/ha)	Yield (t/ha)	HI (%)	Protein (%)	TWT (Kg/hL)	Biomass (t/ha)	Yield (t/ha)	HI (%)
Chick_100	–	33	–	–	–	–	–	6.71	2.58	51%
Wheat_100	108	–	11.78	6.69	49%	9.1	78.8	–	–	–
Wheat75_Chick25	81	8	9.88	4.70	49%	9.3	79.6	0.47	0.20	50%
Wheat50_Chick50	55	15	9.00	5.44	50%	9.5	80.1	1.01	0.46	46%
Wheat25_Chick75	29	24	8.43	4.87	51%	9.8	79.9	1.80	1.09	45%
Wheat 50_Chick 50_alternate rows	53	15	8.66	4.60	52%	9.7	80.3	1.00	0.79	49%
Wheat100_plusN	108	–	11.62	7.26	51%	9.7	79.4	–	–	–
Wheat50_Chick50_plusN	59	16	9.65	5.72	52%	10.1	80.7	0.97	0.81	45%
Wheat50_Chick50_Csprayout	51	15	10.10	5.77	51%	9.5	80.2	0.19	0.07	–
Wheat 50_Chick50_Wsprayout	55	15	5.35	0.09	3%	–	–	1.05	0.34	37%
Covercrop_chick100	–	32	–	–	–	–	–	6.35	2.41	51%
P value	<0.001	<0.001	<0.001	<0.001	0.049	<0.001	<0.001	<0.001	<0.001	0.005
l.s.d 5%	8	4	1.4	0.65	2.2%	0.3	0.5	0.92	0.55	6%

Appendix Table 3. Input costs, grain prices and assumptions used for Canowindra gross margins

Treatment	Intercrop/companion - input costs ($/ha) and grain price ($/T)					Canola legacy crop input cost & price		
	Variable costs	Wheat Grade	Wheat price	Chickpea grade	Chickpea price	Variable costs	Canola grade	Canola price
Chick_100	$ 724	–	–	CHKP1	$ 500	$ 634	CAN	$ 665
Wheat_100	$ 808	AGP1	$ 298	–	–	$ 619	CAN	$ 665
Wheat75_Chick25	$ 1,713	AUH2	$ 330	CHKP1	$ 500	$ 623	CAN	$ 665
Wheat50_Chick50	$ 1,758	AUH2	$ 330	CHKP1	$ 500	$ 636	CAN	$ 665
Wheat25_Chick75	$ 1,598	AGP1	$ 298	CHKP1	$ 500	$ 638	CAN	$ 665
Intercrop_W50_C50	$ 1,509	AUH2	$ 330	CHKP1	$ 500	$ 630	CAN	$ 665
Wheat100_plusN	$ 1,003	AUH2	$ 330	–	–	$ 626	CAN	$ 665
Wheat50_Chick50_plusN	$ 1,928	AUH2	$ 330	CHKP1	$ 500	$ 637	CAN	$ 665
Wheat50_chick50_Csprayout	$ 1,715	AUH2	$ 330	CHKP1	$ 500	$ 632	CAN	$ 665
Chick50_wheat50_Wsprayout	$ 1,024	FED1	$ 250	CHKP1	$ 500	$ 641	CAN	$ 665
Covercrop_chick100	$ 817	–	–	CHKP1	$ 500	$ 628	CAN	$ 665

*Grain prices adjusted according to receival grade and price derived from AWB Parkes

*Variable costs adjusted to suit various treatments but derived from 2022 GRDC Farm gross margin and enterprise planning guide.

*$95/T seed grading/separation costs included in various intercrop treatments

Appendix Table 4. Input costs, grain prices and assumptions used for Condobolin gross margin

Treatment	Intercrop/companion - input costs ($/ha) and grain price ($/T)					Canola legacy crop input cost & price		
	Variable costs	Wheat Grade	Wheat price	Chickpea grade	Chickpea price	Variable costs	Canola grade	Canola price
Chick_100	$ 667			CHKP1	$ 500	$ 564	CAN	$ 650
Wheat_100	$ 686	ASW1	$ 315			$ 545	CAN	$ 650
Wheat75_Chick25	$ 1,154	ASW1	$ 315	CHKP1	$ 500	$ 537	CAN	$ 650
Wheat50_Chick50	$ 1,298	ASW1	$ 315	CHKP1	$ 500	$ 553	CAN	$ 650
Wheat25_Chick75	$ 1,324	ASW1	$ 315	CHKP1	$ 500	$ 565	CAN	$ 650
Intercrop_W50_C50	$ 1,235	ASW1	$ 315	CHKP1	$ 500	$ 554	CAN	$ 650
Wheat100_plusN	$ 880	ASW1	$ 315			$ 555	CAN	$ 650
Wheat50_Chick50_plusN	$ 1,557	ASW1	$ 315	CHKP1	$ 500	$ 569	CAN	$ 650
Wheat50_chick50_Csprayout	$ 1,306	ASW1	$ 315	CHKP1	$ 500	$ 548	CAN	$ 650
Chick50_wheat50_Wsprayout	$ 596			CHKP1	$ 500	$ 549	CAN	$ 650
Covercrop_chick100	$ 752			CHKP1	$ 500	$ 531	CAN	$ 650

*Grain prices adjusted according to receival grade and price derived from AWB Parkes

*Variable costs adjusted to suit various treatments but derived from 2022 GRDC Farm gross margin and enterprise planning guide.

*$95/T seed grading/separation costs included in various companion treatments