SA CROP TECHNOLOGY CENTRE

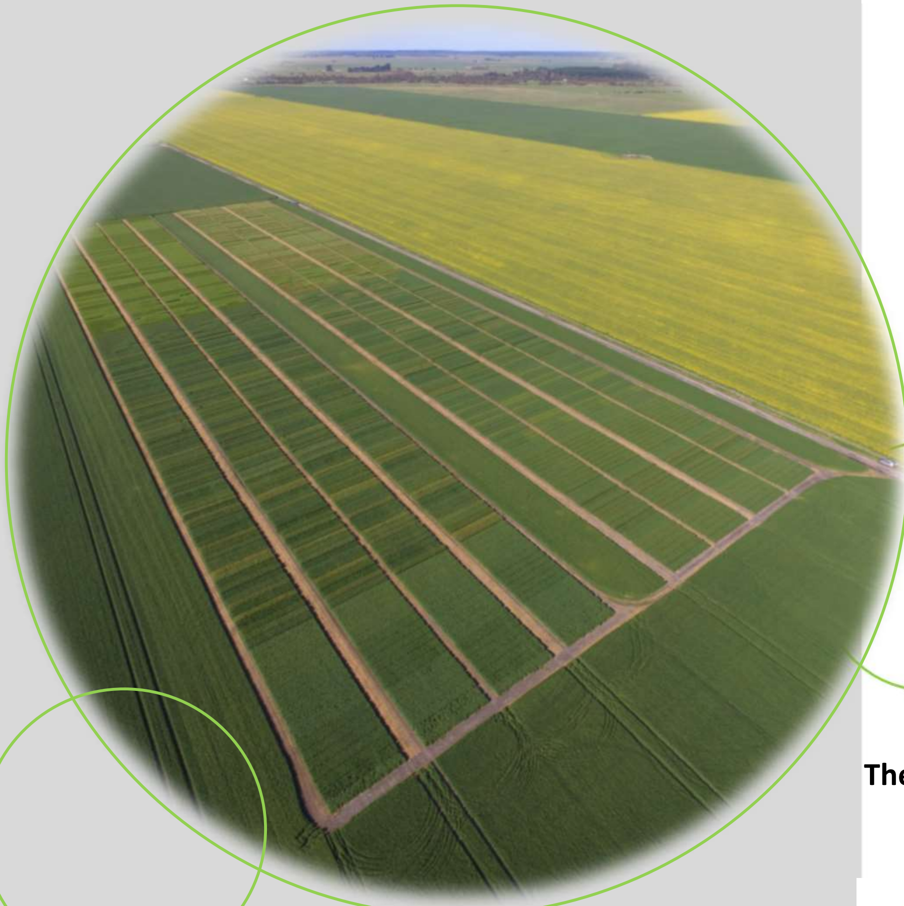
FAR AUSTRALIA

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

FIELD DAY

INCREASING PRODUCTIVITY & PROFITABILITY IN THE HRZ OF SA

Thursday 19th October 2023



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SOWING THE SEED FOR A BRIGHTER FUTURE

SA CROP TECHNOLOGY CENTRE

SA Crop Technology Centre Annual Field Day

Featuring the GRDC's:

Hyper Yielding Crops & Pulse Agronomy project

Thursday 19th October 2023 at 9.00am

MILLICENT, SA GPS -37.514572, 140.245477

Showcasing: Crop management to achieve maximum yields in SA

What have we learnt so far from HYC in wheat, barley and canola?

Coffee at 9.00am followed by Canola and Pulse session: 9.30am

Directions: GPS -37.514572, 140.245477

Signposted off Main Rd 300 Rd

Canola site kindly hosted by James & Chris Gilbertson

Pulses site kindly hosted by Andrew & Megan Skeer

Speakers: Dr Steve Marcroft (Marcroft Grains Pathology), Rohan Brill (Brill Ag) and Nick Poole (FAR Australia)

KEYNOTE SPEAKER

DR STEVE MARCROFT

Dr Marcroft has been working on diseases of canola for the past 25 years and has developed many of the cultural practices currently used in Australia to minimise the impact of blackleg. Steve leads the field-based components of the research carried out by Marcroft Grains Pathology in collaboration with the University of Melbourne.

Kindly sponsored by: RAGT

Main field day

Directions: GPS -37.529752, 140.253641

Signposted off Banya Road

(Site kindly hosted by Andrew & Megan Skeer)

12.30pm - 1.15pm

Lunch & Opening Address

Lunch kindly sponsored by: westernAG

Dr Courtney Peirce, GRDC Manager Sustainable Cropping Systems (South) and Nick Poole, FAR Australia

1.30pm - 4.30pm

In-field technical sessions - cereals

Dr John Kirkegaard (CSIRO) Nick Poole, Max Bloomfield, Daniel Bosveld (FAR Australia), Jen Lillecrapp (Mackillop Farm Management Group)

4.30pm

Close and refreshments

(kindly hosted by Brett & Mel Gilbertson)

Post event refreshments kindly sponsored by: Nutrien Ag Solutions

For more information and to register your attendance click here

HYC 2023 Field Day Millicent

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We trust that you will enjoy your day with us at the SA Crop Technology Centre Field Day. Your health and safety is paramount, therefore whilst on the property we ask that you both read and follow this information notice.

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- All visitors are requested to follow instructions from FAR Australia staff at all times.
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- All visitors are requested to report any hazards noted directly to a member of FAR Australia staff.

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SMOKING

- There is No Smoking permitted inside any marquee or gazebo.

Thank you for your cooperation, enjoy your day.

INCREASING PRODUCTIVITY AND PROFITABILITY IN SA HRZ

FEATURING THE GRDC'S NATIONAL HYPER YIELDING CROPS (HYC) PROJECT

On behalf of our investor, the **Grains Research & Development Corporation** along with the HYC project collaborators, I am delighted to welcome you to our 2023 SA Crop Technology Centre Field Day featuring Hyper Yielding Crops (HYC).

Hyper Yielding Crops is a national project led by Field Applied Research (FAR) Australia. Over the past three years, the HYC project has aimed to push the economically attainable yield boundaries of wheat, barley and canola. As well as the five research centres across the HRZ's of Australia, the project has been successful in engaging with growers to scale up the results and create a community network with the aim of lifting productivity.

To make the programme as diverse as possible I would like to thank all our speakers who have helped to put today's programme together.

I would also like to thank the GRDC for investing in this research programme. Also a big thanks to James and Chris Gilbertson along with Andrew and Megan Skeer our host farmers for their tremendous practical support given to the team, to Brett and Mel Gilbertson for providing a lunch venue, and to today's sponsors RAGT, Western Ag and Nutrien Ag Solutions.

Should you require any assistance throughout the day, please don't hesitate to contact a FAR Australia staff member. We hope you find the day informative, and as a result, take away new ideas which can be implemented into your own farming business.

Nick Poole
Managing Director
FAR Australia

Hyper Yielding Crops

Hyper Yielding Crops (HYC) has been built on the success of the GRDC's four-year Hyper Yielding Cereals Project in Tasmania which attracted a great deal of interest from mainland HRZ regions. The project demonstrated that increases in productivity could be achieved through sowing the right cultivars, at the right time and with effective implementation of appropriately tailored management strategies. The popularity of this project highlighted the need to advance a similar initiative nationally which would strive to push crop yield boundaries in high yield potential grain growing environments.

With input from national and international cereal breeders, growers, advisers and the wider industry, this project is working towards setting record yield targets as aspirational goals for growers of wheat, barley and canola.

In addition to the research centres, the project also includes a series of focus farms and innovative grower networks, which are geared to road-test the findings of experimental plot trials in paddock-scale trials. This is where in the extension phase of the project we are hoping to get you, the grower and adviser involved.

HYC project officers in each state (Jen Lillecrapp of MFMG here in SA) are working with innovative grower networks to set up paddock strip trials on growers' properties with assistance from the national extension lead Jon Midwood.

Another component of the research project is the HYC awards program. The awards aim to benchmark the yield performance of growers' wheat paddocks and, ultimately, identify the agronomic management practices that help achieve high yields in variable on-farm conditions across the country. This season, HYC project officers are seeking nominations for 50 wheat paddocks nationwide (about 10 paddocks per state) as part of the awards program.

For more details on the project contact:

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Jen Lillecrapp, SA HYC Project Officer, MFMG
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Scan the QR code for 2022 HYC project results

Emerging blackleg challenges this season

Steve Marcroft[2], Angela Van de Wouw[1], Susie Sprague[3], Andrew Ware[4], Kurt Lindbeck[5], Andrew Wherret[6], Andrea Hills[7] and Nick Perndt[2].

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[5]NSWDPI, Wagga Wagga
[6]Livingfarm
[7]DPIRD Esperance

Keywords
blackleg, canola, seed treatment, stubble management.

GRDC codes
UOM1904-004RTX, UM00051, CSP00187, MGP1905-001SAX

Take home messages

- Seedling infection levels of blackleg in 2022 were not severe, as the season prior to spring was very conducive for excellent plant growth
- Crown canker was low due to good blackleg resistant cultivars, highly effective SDHI fungicides and most crops being sown early prior to cold winter conditions
- Crown canker was more severe where water logging occurred. This was due to root tissue death which is easily colonised by fungi
- Upper canopy infection (UCI) was not severe as most crops flowered in a normal flowering window. The cool wet spring also meant that crops didn’t mature under stress and therefore plants could tolerate partial blocked vascular tissue in their stems and branches. Fungicide application at the early bloom stage was also widely adopted and highly effective
- Pod infection was in some circumstances very severe. Rainfall post flowering caused both blackleg and Alternaria infection. Mature pods were colonised by saprophytic fungi
- Disease on pods, wind, hail and delayed harvest resulted in pod shatter, which was probably the cause of most yield loss in 2022
- Blackleg management in 2023 will not be changed as a result of wet conditions in 2022. That is, high levels of infection in 2022 will not change the disease risk in 2023.

Learnings from 2022

Until October, 2022 was the perfect canola growing season in Victoria and Southern New South Wales. An early break meant crops were established early in the sowing window. Early sown crops grew quickly and became established prior to cold conditions in June.

Blackleg: crops avoided early seedling infection as they were already past the 3-leaf growth stage at the onset of winter, (blackleg is most severe between late May and mid-August). In addition, new cultivars generally have excellent blackleg resistance (blackleg ratings MR or above) and most seed was treated with a highly effective SDHI seed treatment and/or flutriafol on the fertiliser. The result was seedling blackleg infection in 2022 was generally low. However, where water logging occurred, crown canker were much more severe. Water logging caused root tissue death which is easily colonised by blackleg.

Downy mildew: downy mildew is most severe when it kills the cotyledons and 1st true leaves, robbing the crop of vital seedling vigour. Crops that are set back early, are more reliant on favourable spring growing conditions for high yield. In 2022, similar to blackleg, crops were established prior to conditions being conducive for downy mildew, therefore although downy was commonly present it was not generally severe and unlikely to cause yield losses.

White leaf spot: white leaf spot (WLS) is a very common disease, causing loss of leaf photosynthetic area. In 2022 in cooler areas with higher winter rainfall, it led to leaf area reduction. Miravis Star is registered for WLS control and was probably warranted in some southern Victorian crops.

Spring 2022 was obviously an extremely wet period and given the very high rainfall, it can be assumed that crops would be severely infected with Upper Canopy Infection (UCI) blackleg. However, July which is the key infection month for early flowering crops was not overly wet. In addition, data from CSIRO shows that UCI is expressed when crops mature under warm dry conditions. UCI causes partial blockage of the vascular tissue in the stem and branches, therefore if late spring conditions are cool and moist and this results in low levels of plant stress, then UCI is typically less expressed and causes less yield loss. By 2022, most growers had previous experience with UCI and therefore many applied fungicides in response to the very favourable canola outlook at the time. The result of a cool moist spring and fungicide protection meant was UCI was not a big issue in 2022.

Pods, late spring is where and when the season turned pear shaped, when a lot of rain fell on crops post flowering which resulted in pod infection. Pods were infected with blackleg, Alternaria and other saprophytic fungi. Blackleg and Alternaria were expected and caused significant yield loss to many crops. Yield loss is a result of infection of the seed inside the pod (causes seed to die and shrivel) and of premature pod shattering. This was made worse as most crops could not be windrowed and harvested at ideal timing as machinery could not get onto the paddock. In 2022 we also observed pods maturing (50% seed colour change) but the plants supporting the pods were still completely green. Some plants even had mature pods but were still producing new leaves! Wind and hail then arrived at the party and stole other people's beer!

In 2022 pods were also impacted by unusual symptoms. As previously stated mature pods remained on unharvested plants in some circumstances for a considerable time period. With constant rainfall, these mature pods were infected with opportunistic saprophytic fungi, causing discolouration on the pods. This was made worse in crops where plants had prematurely died due to water logging, where many dead plants were a very grey colour as they were colonised by saprophytic fungi. When harvest then did occur, high levels of mould were reported on seed. Kurt Lindbeck (NSW DPI) grew cultures from many infected seed lots, and interestingly all cultures were either blackleg or Alternaria. The saprophytic fungi were only present on the pod and did not penetrate onto the seed. The other issue in 2022 was how blackleg infected the pods. It caused normal lesions but also caused pods to turn white, starting at the peduncle and working towards the tip. Pycnidial fruiting bodies then occurred across the entire pod rather than within a round lesion as normally occurs.

a) Disease and shattered water logged plants

b) Waterlogged crown infection

c) Entire pod blackleg infection

d) Pods being colonised by various fungi as they mature

Figure 1. *Images of blackleg infection (a,b &c) and (d), a range of diseases as pods mature.*

Management decisions for 2023

Will I get an economic return from applying a fungicide to my canola crop

In recent times, new fungicide actives and new timing recommendations have resulted in large yield responses. Many agronomists have reported 20% returns, but many others have also reported no yield returns. In our trials, we've achieved up to 49% return but also zero. So how do you know where your crop will sit in 2023?

Obviously, predicting a yield return will be very accurate if you know exactly how much disease will occur, but unfortunately, the level of crop damage caused by disease is determined by a number of interconnected factors and to complicate it further, other diseases such as Sclerotinia, white leaf spot, powdery mildew and Alternaria, can also influence economic returns.

The key is to identify the risk for an individual crop and then determine the cost of application compared to the cost of potential yield loss. In most years this is relatively easy, for example, low rainfall years are low risk, whereas with a high rainfall year and high yield potential, it is very easy to gain an economic advantage from fungicide application. But it is the decile 4 to 7 years where there is lots to be gained or lost from fungicide decisions.

Blackleg crown canker

Do I need to protect seedlings?
Canola intensity in the rotation and in the landscape continues to increase. Canola intensity is a driving factor for blackleg due to this disease being stubble borne. Therefore, understanding your risk of blackleg is essential. Risk is driven by the following factors:

- Canola growing region – high canola intensity and high rainfall = high risk. 1 in 4-year rotations and 500m isolation between this year's crop and last year's stubble reduces risk. Monitor crops for both UCI and crown canker so that you know if you need to retain or change practices
- Distance to canola stubble – crops sown adjacent to one-year-old stubble will have the highest amount of disease, so maintain a 500m buffer if possible
- Cultivar resistance – cultivars rated R-MR or above have very low risk of developing crown cankers. MR will develop cankers but only if grown under high disease severity, for example canola/wheat/canola in high rainfall. See www.grdc.com.au/resources-and-publications/all-publications/publications/2020/blackleg-management-guide
- Pathogen population – if you've grown the same cultivar for a number of years and disease severity is increasing, and you sow a cultivar from the same resistance group, then you will be at a higher risk of crown cankers
- Crop germination timing – severe crown canker is most likely to develop when plants are infected during the early seedling stage (cotyledon to 4th leaf). The driving factor for seedling infection is the length of time that the plant is exposed to blackleg infection while in the seedling stage (Figure 2). Therefore, the risk of seedling infection, which leads to crown cankers, is very variable from season to season. For infection to occur, blackleg fruiting bodies on the canola stubble must be ripe and ready to release spores. Fruiting bodies typically become ripe approximately three weeks after the break of the season, when the stubble has stayed consistently moist. Spores are then released with each rainfall event. Temperature also has a large influence as it will determine the length of time that

the plant remains in the vulnerable seedling stage. Once plants progress to the 4th leaf stage, they are much less vulnerable to crown canker. Older plants will still get leaf lesions, but the pathogen is less likely to cause damaging crown cankers as the fungus cannot grow fast enough to get into the crown. Typically, plants sown early in the growing season (April) will develop quickly under warmer conditions and progress rapidly past the vulnerable seedling stage, whereas plants sown later (mid-May) will progress slowly and remain in the vulnerable seedling stage for an extended period.

Blackleg upper canopy infection fungicide application
Blackleg upper canopy infection (UCI) refers to infection of the upper stem, branches and flowers and whilst we are constantly improving our understanding regarding these new symptoms, there is still a very large knowledge gap of how individual cultivars react to UCI. Furthermore, our research shows that similar symptoms of UCI can cause very severe economic impact in one season and have no economic impact in another. As such, our recommendations for managing blackleg UCI are constantly evolving. However, we now know that early sowing, which leads to early flowering, is a major trigger for UCI (Figure 2).

What are the steps to determine a UCI spray decision

- Leaf lesions – presence of leaf lesions indicates that blackleg is present and that your cultivar does not have effective major gene resistance. No leaf lesions = no reason to spray. However if you have applied a seedling foliar fungicide, a lack of lesions may be due to that fungicide and the crop may still become susceptible to UCI at the early bloom stage.
- New leaf lesions on upper leaves as the plants are elongating – this observation is not critical but does give an indication that blackleg is active as the crop is coming into the susceptible window. However, a number of wet days at early flower will still mean high risk, even if there were no lesions on new leaves up to that point. Remember, it will take at least 14 days after rainfall to observe the lesions. More lesions = higher blackleg severity.
- Date of 1st flower and targeted date of harvest – the earlier in the season flowering occurs, the higher the risk. This date will vary for different regions. Generally, shorter season regions can more safely commence flowering at an earlier date compared to longer season regions. An earlier harvest date results in less time for the fungus to invade the vascular tissue and cause yield loss. Consequently, if you're in a long growing season rainfall region, your crop flowers in early August and is harvested in December, you are in a very high risk situation.
- Genetic resistance – this is a knowledge gap for growers. If a crop variety is susceptible it is much more likely to gain a yield response to a fungicide. At present no cultivars have a UCI blackleg rating. In 2022 the GRDC investment screened all commercial cultivars for UCI resistance. It is hoped that a UCI blackleg rating system can be developed in conjunction with seed companies.

- Yield potential – yield potential is simply an economic driver. A 1% return on a 3t/ha crop is worth more money than a 1% return on a 1t/ha crop.

How can I determine if I should have sprayed for UCI

- Check for external lesions
- Cut branches and stems to check for blackened pith, which is indicative of vascular damage and likely yield loss
- Observe darkened branches, these branches go dark after vascular damage and are indicative of yield loss
- Pod infection will cause yield loss, unfortunately there is nothing that can be done to prevent pod infection
- Leave unsprayed strips to check for yield returns.

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.

Useful resources

BlacklegCM App for iPad and android tablets
Blackleg management guide (www.grdc.com.au/resources-and-publications/all-publications/publications/2020/blackleg-management-guide)
Marcroft Grains Pathology (https://marcroftgrainspathology.com)
Australian Fungicide Extension Network (https://afren.com.au/)
NVT Australia (https://www.nvt.com.au)

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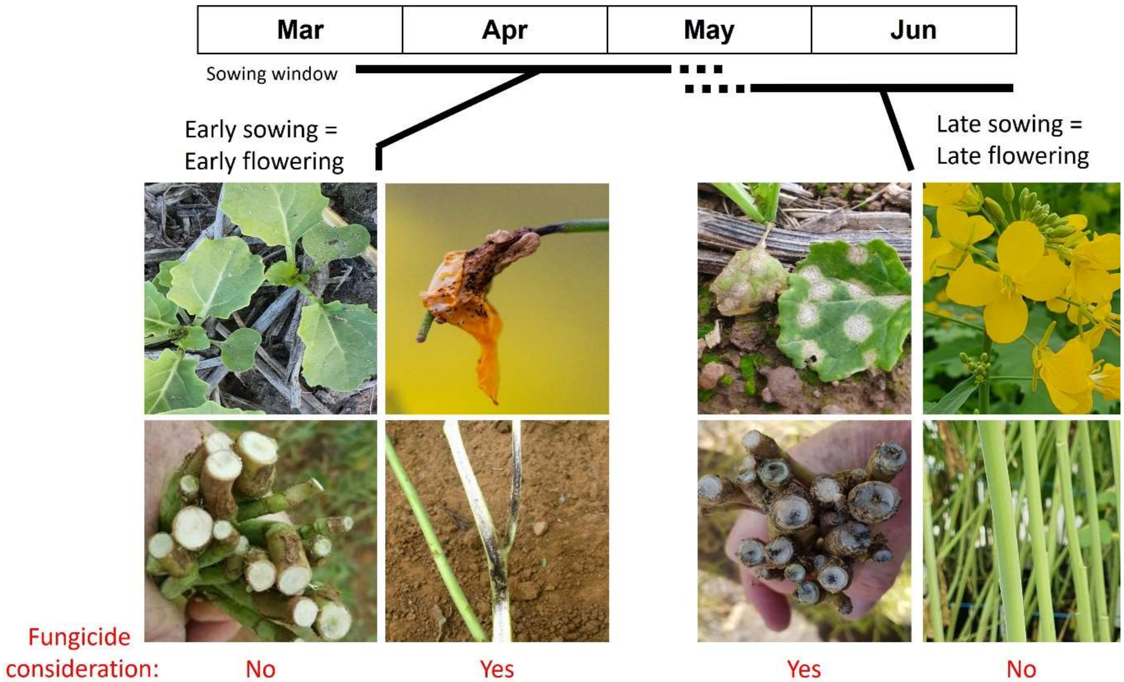

Figure 2. *Sowing time, and therefore flowering time determines whether you will be needing to control crown canker blackleg or upper canopy infection blackleg.*

Date published

February 2023

Canola Yield Potential in 2023 – How does it compare to other years?

Rohan Brill, Brill Ag

When water, nutrition, disease and pests are not an issue, crop yield potential is driven by the photothermal quotient – often referred to as the PTQ. PTQ is the ratio of the amount of light (energy) available to plants relative to the temperature level. It can be easily calculated as the sum of solar energy falling on a flat surface in one day (Solar Exposure), divided by the mean daily temperature. Very wet years are often cloudy so light availability is lower and crop yield potential is reduced. In contrast, dry years often have a high PTQ, as there is little cloud. However, in dry years, water is often limiting so a high yield potential is not going to be realised.

PTQ is most important during the crop critical period, which is the period from about 10 days after the start of flowering to close to the end of flowering. This is the period when grain number is set, which usually correlates closely with grain yield. Crop management should be focused on ensuring that the crop critical period overlaps with the period with highest resource availability, e.g., high but not excessive water supply, high PTQ (without extreme shock events) and high nutrient availability.

Table 1 shows a summary of Solar Exposure, Mean Daily Temperature and PTQ for September for Geelong and Mount Gambier. These locations were chosen as the closest Bureau of Meteorology stations to Gnarwarre and Millicent respectively. The conditions at these BOM stations will likely have been slightly different than the trial locations but the trends across seasons will be similar. At Geelong in 2023, Solar Exposure in September has been well above average, but this benefit for crops in the region has been all but cancelled out by high mean daily temperature in September, with only a slightly higher PTQ than average. The 2022 season was quite different, characterised by low Solar Exposure and mean daily temperature with a resulting PTQ just slightly below average.

The trend was similar near the SA research site as it was for Victoria. Mount Gambier September Solar exposure was well above average, but temperature was also well above average, resulting in a PTQ very close to average.

Table 1. *Solar exposure, mean daily temperature and photothermal quotient (PTQ) at two locations in 2022, 2023 and the average across seasons for these locations.*

	Solar Exposure (MJ/m^2)	*Mean Daily Temperature (°C)*	*PTQ ($MJ/m^2/Day/°C$)*
Geelong Average	13.70	12.70	1.08
Geelong 2022	12.70	11.95	1.06
Geelong 2023	15.60	14.13	1.10
Mount Gambier Average	13.90	11.10	1.24
Mount Gambier 2022	13.90	10.05	1.38
Mount Gambier 2023	16.40	13.20	1.25

2023 trial activities

A core component of research in 2023 at all HYC sites across Australia is experimenting with crop nutrition and variety choice to increase growth through the crop critical period, with the aim of increasing crop yield potential. We have included six or nine varieties combined with high and low nutrient input in a YieldMax trial with sampling conducted at the start and end of the crop critical period, as well as at crop maturity.

A trial with a more detailed focus on crop nutrition is also being run at each site. These trials examine the nitrogen response at each site with rates from nil to 300 kg N/ha. Due to its success at raising crop yield potential in trials in recent years, we are also examining further canola response to manure compared to the inorganic nutrients (nitrogen, phosphorus, potassium and sulfur) that are supplied by manure.

Overall, these trials are designed to close the gap between yield potential (as set by PTQ) and achieved yield in higher rainfall environments.

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] Bill 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*ᶲ	5	148	2.2	72.1	76
	Faba beans	*PBA Samira*ᶲ	9.4	335	4.4	171	164
	Field Pea	*PBA Wharton*ᶲ	9.9	287	3.9	146	141
	Lentils	*PBA Hallmark XT*ᶲ	6.8	129	2.6	105	24
	Lupins	*Luxor*ᶲ	5.5	188	3	174	14
	Vetch	*Timok*ᶲ	9.3	240	3.5	162	78
Buraja	*Chickpea*	*CBA Captain*ᶲ	7.1	220	2.3	74	146
	Faba beans	*PBA Samira*ᶲ	6.7	209	2.9	123	86
	Vetch	*RM4*ᶲ	4.8	187	1	51	136
Canowindra	*Chickpea*	*CBA Captain*ᶲ	8.9	247	2.2	89	158
	Faba beans	*PBA Samira*ᶲ	15	395	5.8	230	165
	Lentils	*PBA Hallmark XT*ᶲ	6.7	124	1.4	58	66
	Lupins	*Murringo*ᶲ	17.6	525	4.3	263	262
	Lupins	*PBA Bateman*ᶲ	15.6	519	3.4	179	340
Caragabal	*Chickpea*	*CBA Captain*ᶲ	9.6	278	2.1	72	206
	Faba beans	*PBA Samira*ᶲ	17.4	594	5.7	251	343
	Field Pea	*PBA Taylor*ᶲ	7	278	3.4	134	144
	Lentils	*PBA Hallmark XT*ᶲ	7.2	133	1.7	71	62
	Lupins	*PBA Bateman*ᶲ	9.7	313	2.1	112	201
	Vetch	*Timok*ᶲ	11.1	345	1.6	92	253
Ganmain	*Chickpea*	*CBA Captain*ᶲ	5	164	Not harvested due to hail		
	Faba beans	*PBA Samira*ᶲ	12	347	5.2	211	136
	Field Pea	*PBA Wharton*ᶲ	8.3	294	2.7	104	190
	Lentils	*PBA Hallmark XT*ᶲ	5.5	93	2.1	91	2
	Vetch	*Timok*ᶲ	6.6	166	2.7	127	39
Gol Gol	*Chickpea*	*CBA Captain*ᶲ	1.7	*	0.6	*	*
	Faba beans	*PBA Samira*ᶲ	1.5	*	0.5	*	*
	Field Pea	*PBA Wharton*ᶲ	2.4	*	1	*	*
	Lentils	*PBA Hallmark XT*ᶲ	1.8	*	0.6	*	*
Parkes	*Chickpea*	*CBA Captain*ᶲ	9	328	2.6	89	239
	Faba beans	*PBA Samira*ᶲ	15.1	552	6.3	282	270
	Lentils	*PBA Hallmark XT*ᶲ	3.9	88	0.7	29	59
	Lupins	*Murringo*ᶲ	3	98	0.8	47	51
	Lupins	*PBA Bateman*ᶲ	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).

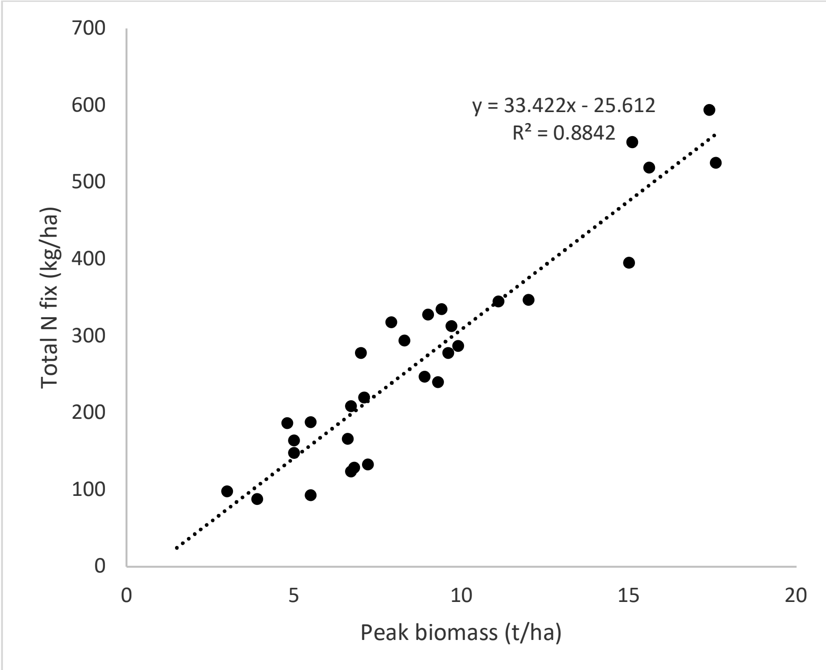

Figure 1. *Relationship between peak biomass (above ground, measured at 30-50% podding) and total N fixation in 2021. Crops included = chickpeas, faba beans, lentils, lupins, field peas and vetch.*

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*ⓓ	3.8	12.4	9.7	4.2	5.5
Faba bean	*PBA Samira*ⓓ	3.8	13.0	17.8	16.3	12.4
Field pea	*PBA Butler*ⓓ	4.8	11.3	8.7	5.6	14.8
Lentils	*PBA Hallmark*ⓓ	3.7	7.7	7.5	1.0	6.2
Lupins	*Luxor*ⓓ	5.2	15.0	*[1]	*	6.1
Lupins	*PBA Bateman*ⓓ	6.0	16.5	*[1]	9.7	8.1
Vetch	*Timok*ⓓ	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 Luxorⓓ 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*ⓓ	4.1	1.7	0.3	1.2	1.1
Faba bean	*PBA Samira*ⓓ	2.4	4.5	5.6	4.1	6.0
Field pea	*PBA Butler*ⓓ	2.7	2.2	2.9	1.6	3.7
Lentils	*PBA Hallmark*ⓓ	2.7	2.4	1.1	0.4	0.5
Lupins	*Luxor*ⓓ	4.0	5.0	*	0.2	2.1
Lupins	*PBA Bateman*ⓓ	3.6	3.8	*	0.7	2.7
Vetch	*Timok*ⓓ	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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Thanks to grower co-operators Jeff Savage (Barellan), Dennis Tomlinson (Buraja), Daybreak Farming (Caragabal), Chris Berry (Trundle), Viridis Ag (Canowindra), Angus Maurice (Wellington), Trentham Estate (Gol Gol), Nathan Border (Parkes).

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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Swan *et al* (2022), What is the N legacy following pulses for subsequent crops and what management options are important to optimise N fixation? 2022 Wagga Wagga GRDC Update.

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Biological nitrogen fixation by pulses and the contribution of legumes to following crops

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A key strategy in developing a more sustainable agriculture is to restore the functional biodiversity of the agricultural landscape. There is an increasing awareness about developing cropping systems which are less dependent on fossil fuels, which have less negative impact on the environment and with greater ability to adapt to externalities such as climate change (Jensen *et al* 2012). Cropping systems which are more complex are likely to be more resilient to externalities and may be less dependent on external inputs. Diversity in both time (rotation) and space (field size and mixed cropping) are important parts of potentially more dynamic and sustainable systems, and legumes can play a key role in providing many important benefits for future sustainable cropping systems.

Amounts of N_2 fixed by legumes

Legumes can access two sources of nitrogen (N) for growth – atmospheric N_2 fixed in symbiosis with the soil bacteria rhizobia, and soil mineral N. The amounts of N_2 fixed is usually calculated from measurements of how much shoot biomass dry matter (DM) is produced during a growing season, the N content (%N) of that biomass, and the proportion of the N derived from the atmospheric N_2 (%Ndfa). Therefore, it is not surprising that in the absence of obvious constraints to N_2 fixation the amounts fixed by experimental crops are generally closely related to legume productivity with between 15-25 kg shoot fixed N for every tonne (t) of shoot DM accumulated (Fig. 1). On average across a range of grain legumes 21 kg N is fixed per t DM under Australian growing conditions (Unkovich *et al* 2010).

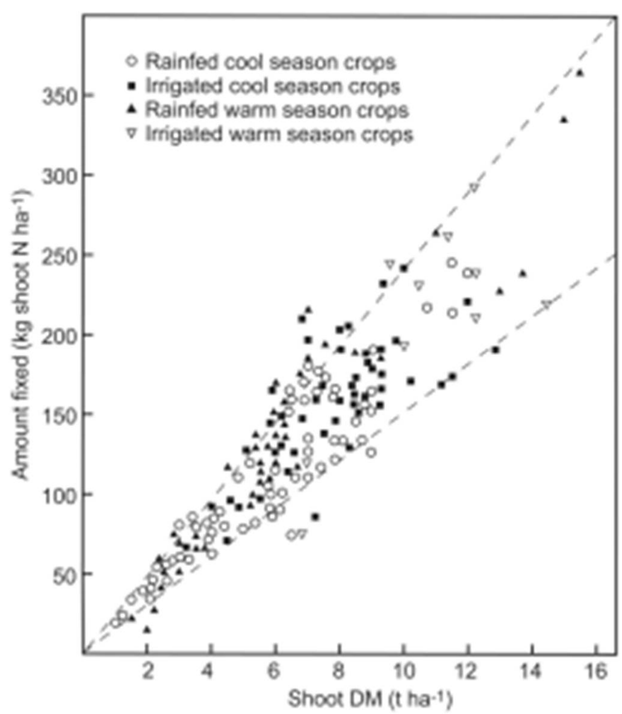

Figure 1. Experimental data demonstrating the relationship between the amounts of shoot N fixed and shoot DM production for rainfed and irrigated cool-season (e.g. lupin, faba bean, field pea) and warm-season grain legumes (e.g. soybean, mung bean). The lower and upper broken lines indicate 15 and 25 kg N fixed/t DM; respectively (Source: Peoples *et al* 2009).

While information such as depicted in Fig. 1 that has been collated from scientific trials tell us something about the potential for N_2 fixation under experimental conditions, the levels of N_2 fixation that achieved on-farm under farmer management is of more interest. Table 1 provides measures of N_2 fixation obtained from 60 different commercial rainfed pulse crops sampled at various locations in SA, Vic, and in southern, central, and northern NSW. The data in Table 1 indicate a wide range of values for %Ndfa and the amounts of shoot N fixed per ha or per t of shoot DM. On average around two-thirds of the crop N was derived from N_2 fixation, with the amount being fixed being equivalent to an average 16 kg shoot fixed N/ t shoot DM across all crops. The data also suggest that faba bean, lupin and vetch tend to fix greater amounts of N (kgN/ha) than lentil, chickpea or field pea in farmers' fields.

Table 1 Summary of on-farm determinations of N_2 fixation indicating the mean and range (shown in italics in parenthesis) of estimates for the proportion (%Ndfa) and the amounts of shoot N fixed by 60 commercial rainfed pulse crops sampled across south-eastern Australia between 2001-2017.

Legume crop	Number of farmers' crops sampled	%Ndfa	Amounts of shoot N fixed (kg N/ha)	Amounts of shoot N fixed (kgN/tDM)
Faba bean	23	68% (*42-96*)	126 (*46-306*)	17 (*10-25*)
Vetch	3	69% (*53-84*)	89 (*53-135*)	17 (*13-22*)
Lupin	14	63% (*20-82*)	83 (*20-150*)	16 (*9-21*)
Lentil	4	65% (*17-82*)	51 (*20-104*)	18 (*4-30*)
Chickpea	8	67% (*24-98*)	47 (*13-111*)	14 (*7-25*)
Field pea	8	56% (*8-85*)	46 (*12-87*)	14 (*2-20*)
Mean		65%	88	16

(Source: Unpublished data of Peoples, Swan & others)

All the pulses sampled on-farm were grown as sole crops. However, in the traditional farming systems of Asia, Africa and South America, and on many organic farms of Europe, legumes are often grown as an intercrop /companion crop with a cereal (Bedoussac *et al* 2015; Ladha *et al* 2022). Where a legume and cereal are grown together in the same field in these systems, the strong competition by cereal root systems with neighbouring legume roots for soil mineral N generally results in a higher %Ndfa for the intercropped legume compared to where it might be grown as a sole crop.

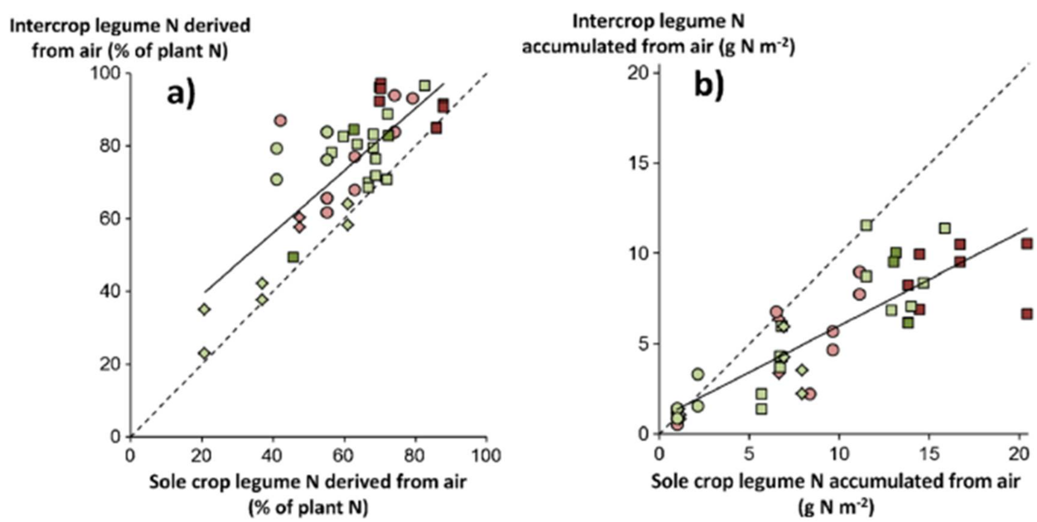

Figure 2 Comparisons of measures of (a) %Ndfa and (b) amounts of N_2 fixed by intercropped and sole cropped faba bean or field pea grown in the same experiment. Red symbols represent where legumes were grown with wheat, and green was where they were grown with barley. The different symbol shapes indicate different locations in Europe. The broken lines indicate a 1:1 relationship and the solid black lines represent the predicted trends ((a); $y=0.86x+22.00$; $r^2=0.62$***; (b); $y=0.51x+0.85$; $r^2=0.71$***; Source: Bedoussac *et al* 2015).

The magnitude of this effect can be seen in the European data presented in Fig. 2 comparing N_2 fixation by intercropped with sole crops whereby %Ndfa represented on average 73% for legume intercrops and 61 % for sole legume crops (Fig.2a). However, the quantity of N fixed by the intercropped legume will inevitably be less than in a sole legume crop because the fewer legume plants per unit area in the intercropped system compared with the sole crop results in lower biomass which is often also restricted by competition with the cereal for light (Fig. 2b).

It is important to note that the N_2 fixation values presented in Figs. 1 and 2 or in Table 1 tell only part of the story. Research has now demonstrated that a sizeable proportion of the legume total plant N can be partitioned below-ground either associated with, or derived from, the nodulated roots (Fig. 3). The information presented in Fig. 3 suggest that except for chickpea which has around half of its N below-ground because of its high nodule load, most pulse crops tend to allocate around 30-33% of the whole plant N in the nodulated roots.

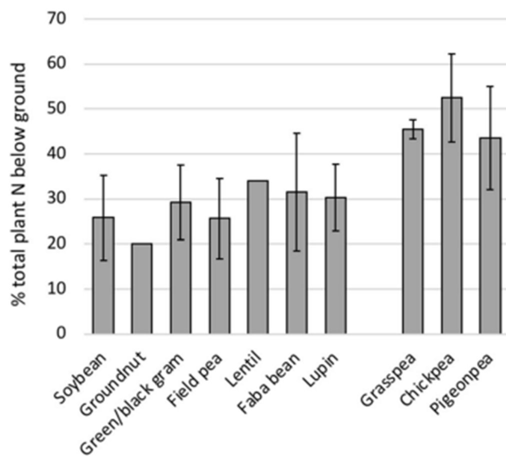

Figure 3 Examples of the allocation of N in roots, nodules and rhizodeposition (i.e. root exudates, detached root hairs, senesced roots and nodules) by various grain legumes expressed as % of total plant N (Source: Herridge *et al* 2022).

Although the below-ground pool of legume N has frequently been ignored in the past, the data in Fig. 4 collected from irrigated commercial faba bean crops clearly illustrates that shoot-based measures of N_2 fixation can greatly underestimate the total amount of N being fixed and will give a misleading view of the overall net contributions of fixed N to the N-balance of cropping systems when the amounts of fixed N are compared to the amounts of N removed in harvested grain.

One way that has been proposed to overcome the short-comings of shoot-based measures of N_2 fixation is to adjust above-ground fixation values using a "root-factor" based on data such as that depicted in Fig. 4 to provide a determination for the total plant (i.e. above-ground+below-ground; see Unkovich *et al* 2010 and Herridge *et al* 2022). For example, a root-factor for lentil which Fig.3 indicates has ~33% of its N below-ground (i.e. 67% above-ground) would be 1.5, so a shoot-based estimate of N_2 fixation would need to be multiplied by 1.5 to include the contribution of fixed N by the nodulated roots. In the case of chickpea with around 50% of total plant below-ground the root-factor would be 2, whereas for groundnut (peanut) with 20% below-ground, the root-factor would be 1.25.

An easy "rough-rule-of thumb" for growers to estimate the likely amounts of N that their own crop might have fixed is to take advantage of the observation that the harvest index (proportion of above-ground biomass partitioned in grain) of crop legumes at maturity is often 30-35%. In other words, the total above-ground DM accumulated (i.e. shoot+grain) by a pulse crop during a growing-season would approximate 3-times the grain yield (t/ha). To make the mental arithmetic a little easier, if we assume that 20 kg N was fixed per t above-ground DM and around one-third of the total crop N was below-ground (i.e. a root-factor of 1.5), the total amounts of N fixed in above- and below-ground parts could be determined using the following equation:

Total amounts N fixed = (3 x 20 x 1.5) x (grain yield)

In other words, 90 kg fixed N for every t of grain harvested.

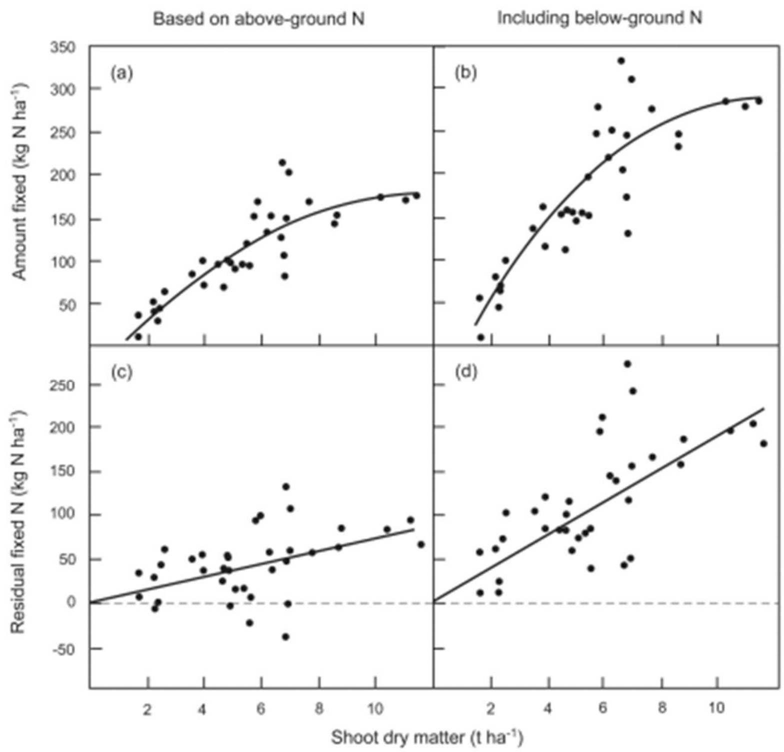

Figure 4 Data from irrigated commercial faba bean crops grown near Narrabri, NSW showing the impact of estimating N_2 fixation: (a) from shoot-based measures of crop N, or (b) by adjusting shoot values to include below-ground N, and the consequences when calculating net inputs of fixed N remaining after grain harvest (i.e. amount of N fixed – grain N removed) when either (c) ignoring or (d) including contributions of below-ground N. (Source: Peoples *et al* 2009).

Factors that limit legume N_2 fixation

Of the 60 commercial pulse crops whose measures of N_2 fixation were summarised in Table 1, a total of 12 crops (20%) had measured estimates of %Ndfa < 50% and were considered to have displayed sub-optimal levels of N_2 fixation. The main factors that contributed to poor N_2 fixation included:

Reduced legume growth

- Drought or soil constraints to root exploration (e.g. acidity, salinity or high boron) or root disease and nematode damage that restrict soil water extraction.
- Competition due to poor in-crop weed control, or carry-over of herbicide residues that retard growth.
- Limited growth potential due to nutritional deficiencies (e.g. P and/or Mo), or sowing a pulse species not adapted to the local soil pH (see Fig. 5 below).

Low %Ndfa

- Since the capacity for N_2 fixation is subject to the presence of sufficient numbers of the specific rhizobial species in the soil that can effectively nodulate the particular legume species being grown, poor nodulation can result from either a failure to inoculate when >6-years (had elapsed since the same legume species had last been grown, or the use of out-of-date or inappropriately stored inoculant.

- Acidic subsurface soil layers which can cause poor survival and persistence of rhizobia (Fig. 5).
- High soil mineral N at sowing. Soil mineral N delays nodulation and reduces the need for N_2 fixation to satisfy the crop's N requirements for growth (e.g. see Fig. 6 where %Ndfa was reduced by lower soil nitrate concentrations than faba bean). High levels typically occur when legumes were either sown after a long period of fallow (Schwenke *et al* 1998), or where there had been a failed N-fertilised crop in the previous year.

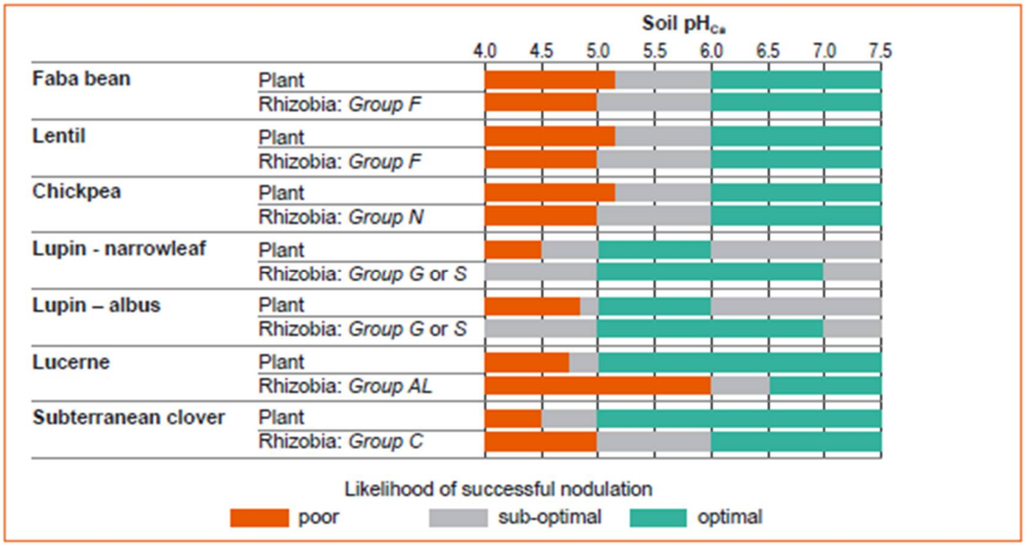

Figure 5 The tolerance of legume species and their associated rhizobia to a range of soil pH_{ca} and the likelihood of successful nodulation (poor, sub-optimal or optimal). (Source: Burns and Norton 2018).

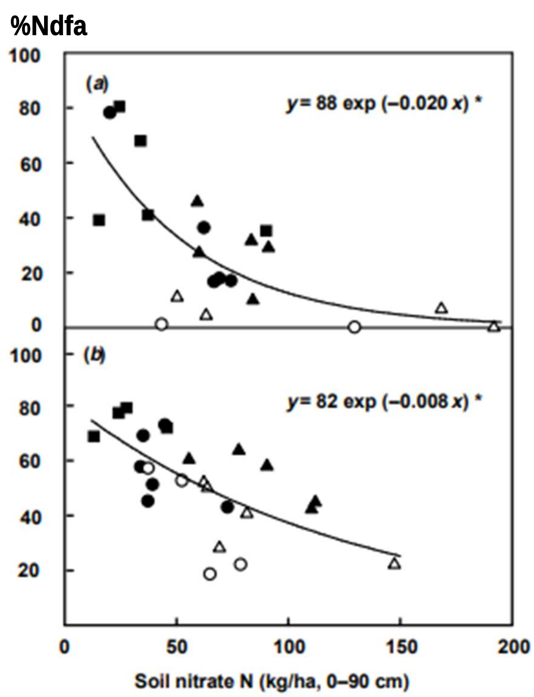

Figure 6 The relationship between soil nitrate-N measured in the root zone (0-90 cm) at sowing and plant reliance upon N_2 fixation for growth (%Ndfa) by commercial: (a) chickpea or (b) faba bean growing in northern NSW. The different symbols indicate different farm locations, the open symbols represent on-farm data collected in 1994 and closed symbols 1995. (Source: Schwenke *et al* 1998).

Additional soil mineral N after pulses

There are many Australian studies showing greater levels of soil mineral N after legumes compared to other alternative non-legume crops (e.g. Evans et al 2003; Fig.7) resulting in higher wheat grain yields when wheat is grown after a legume compared to after a non-legume (Fig. 7). Discussion below aims to explain how much additional available soil N grain-growers might expect legumes to contribute. Aspects of wheat recovery of soil mineral N will be examined the following two sections.

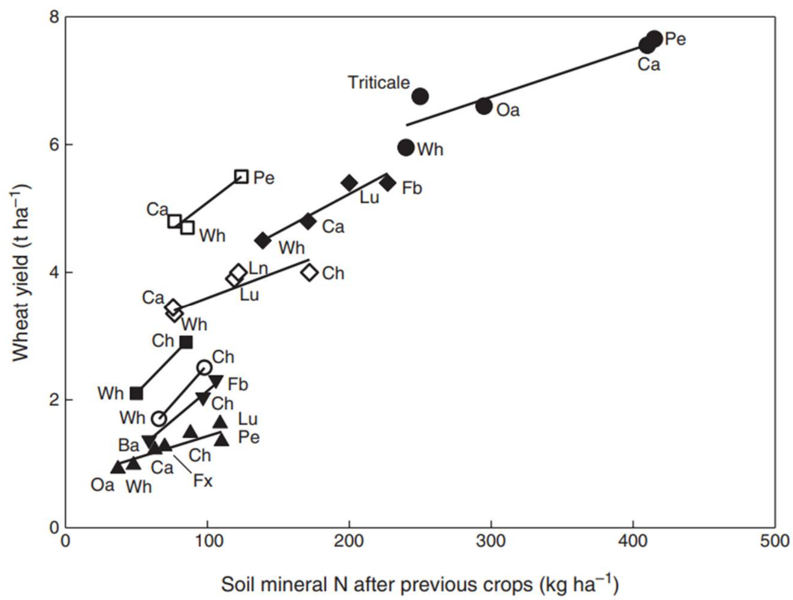

Figure 7 Relationship between residual soil mineral N (≥ 0.9m) measured after different crops and the grain yield of a following wheat crop. Each set of symbols and fitted line is from a different field experiment. The following acronyms were used to identify different crops: Wh = Wheat; Ba = Barley; Oa = Oats; Ca = Canola; Fx = Flax; Pe = Field pea; Ln = Lentil; Ch = Chickpea; Fb = Faba bean; Lu = Lupin.

Calculations of net inputs of fixed N such as those presented for faba bean in Fig. 4d are valuable for evaluating the longer-term sustainability of cropping systems but is not such a useful guide to the subsequent accumulation of soil mineral N since it is the total pool of residual organic legume N remaining in the paddock after grain harvest rather than the amount of N_2 fixed that ultimately determines the level of soil N-availability.

Decomposition of organic plant residues typically follow a characteristic pattern, with an initial rapid decline followed by a period of slow decrease. The magnitude and timing of the release of N from organic residues and accumulation as plant-available forms represents the balance between the microbial-mediated mineralisation (i.e. the release of inorganic forms of N) and immobilisation processes (i.e. microbial assimilation of inorganic N for growth) in the soil. Apart from the location of the legume residues (e.g. as standing stubble, on the soil surface, or incorporated into the soil) and climatic conditions (especially impacts on rainfall on soil moisture and temperature to stimulate microbial activity), the main factors that influence mineralisation and immobilisation relate to the chemical composition of the above- and below-ground residues; especially the N concentration and C:N ratio (for further details see Ladha *et al* 2022). These compositional features can vary across legume species and plant parts but will also be dependent upon whether the residues are young or from mature plant materials. For example, in green or "brown" manured legumes and legume cover-crops where fresh, green legume shoots are either mulched, incorporated by cultivation or killed with herbicide, the C:N ratio is commonly <20:1 which is conducive to net mineralisation (i.e. where mineralised N exceeds microbial induced immobilised of N) in the short- to medium-term. By contrast, the senesced vegetative materials of pulses remaining after grain harvest can be >30 (Peoples *et al* 2017) which can induce transient net immobilisation. However, since the C:N ratio of stubble of harvested cereal crops tend to be much greater (75-160:1), the duration of net immobilisation and N tie-up will be considerably longer. Both the higher N content and lower C:N ratios of legume residues (regardless of whether these are green or senesced materials) than the stubble of cereals and other non-legumes crops will result in greater net N mineralisation, and higher concentrations of soil mineral N (Ladha *et al* 2022).

To answer the question "*How much more soil mineral N might be expected after pulses?*" and to provide some overview of the combined effect of all the variables mentioned above, soil data collected from 15 cropping systems studies undertaken at different locations in NSW (n = 9), SA (n = 4) and Victoria (n = 2) between 1989-2016 have been collated in Table 2 (see Peoples *et al* 2017 for details). The legume crops had either been grown for grain, or "brown manured" (BM) – i.e. killed with knock-down herbicide in late-spring as a strategy to control herbicide-resistant grasses (Swan *et al* 2023).

Collectively the data from Table 2 indicated that the increased available soil N detected to the assumed average rooting depth of wheat (0-1.2m) immediately prior to sowing wheat in the first growing season following legumes compared to where either wheat, barley or canola had been grown in neighbouring plots the same experiments represented on average:
35 kg additional mineral N/ha for 1^st^-crop after pulse grain crop
60 kg additional mineral N/ha for 1^st^-crop after BM
In studies where the experimentation was continued into a second year after a legume crop significantly higher soil mineral N were still detected before sowing a second wheat crop representing on average (unpublished data):
18 kg additional mineral N/ha for 2^nd^-crop after pulse grain crop
26 *kg additional mineral N/ha for 2^nd^-crop after BM*

Table 2 Comparison of mean estimates of grain yield and total residual N remaining after pulse crops or total N inputs by brown manured (BM) legume crops, the subsequent additional soil mineral N measured in autumn the following year compared with non-legume controls and determination of the soil mineral N benefits.

Crop species & number of studies	Legume		Additional	kg soil mineral N/ha benefits		
	Grain yield (t/ha)	Total residue N (kg N/ha)	Mineral N detected (kg N/ha)	per mm fallow rainfall	per t grain yield	as a % residue N
Field pea (n=7)	2.4	140	23	0.16	14	22
Field pea BM (n=2)	-	269	52	0.10	-	20
Chickpea (n=6)	1.4	105	35	0.11	25	31
Lupin (n=6)	2.5	135	37	0.15	16	29
Lupin BM (n=1)	-	290	86	0.17	-	30
Faba bean (n=5)	3.8	180	47	0.20	19	28
Lentil/Vetch (n=2)*	1.3	96	26	0.11	14	25
Vetch BM (n=2)	-	214	50	0.15	-	23
Mean all pulse crops		134	35	0.15	18	28
Mean all BM crops	-	251	60	0.12	-	24

*Note: data from the single lentil and vetch grain crops were combined for ease of analysis.
(Source: Peoples *et al* 2017).

To provide grain-growers with some idea as to how much extra soil mineral N a legume might provide, the soil mineral N results in Table 2 have been recalculated and expressed on the basis of two parameters all growers should either know: (a) mm rainfall during the fallow period between crop harvest and sowing, and (b) pulse grain yield (t/ha). The resulting values were on average:
Additional mineral N for 1^st^-crop after a pulse (kg N/ha) = *0.15 x mm fallow rainfall*
Additional mineral N for 1^st^-crop after a BM (kg N/ha) = *0.12 x mm fallow rainfall*

Additional mineral N for 1^{st}-crop after a pulse (kg N/ha) = *18 x grain yield*
It was interesting to note that chickpea seemed to have higher rates of net mineralisation than other crops on a per t grain basis (25 compared with 14-19 kg N/t grain). This presumably reflected chickpea's greater allocation of plant N into nodules whose N-content are >6%N and so are very conducive to rapid breakdown and mineralisation.

The soil mineral N data in Table 2 have also been re-calculated as a % of the total legume N residues (i.e. the N remaining in stubble after grain harvest + estimate of N associated with nodulated roots). *The extra mineral N at the beginning of the first growing seasons after a pulse was determined to be equivalent to 28% (range 20-31% across different crops) of the total legume residue N from the preceding pulse grain crop.* This is lower than previously reported by Evans *et al* (2001) who suggested about 30% of the N in legume stubble and 20% of the N in the nodulated roots may mineralize in the year following a pulse crop but may have reflected data collected under wetter summer fallows than experienced during the experiments summarised in Table 2.

In some experiments soils were also sampled in the third cropping year. *The additional mineral N prior to sowing in the second growing season following a pulse represented 10% of the legume residual N (unpublished). In the case of the BM crops the comparable values were 24% and 11% (unpublished) of the total legume BM N in the first and second subsequent cropping years; respectively*). This compares to a typical annual net mineralisation rate from the background total soil organic N pool of 2-3%.

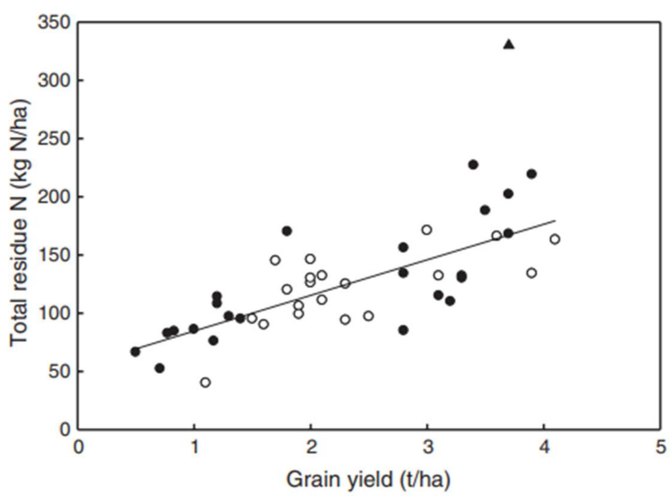

Figure 8 Relationship between legume grain yield and total legume residual N remaining after grain harvest. The open and closed symbols represent data collated from different cropping system studies. (Source: Peoples *et al* 2017).

Fig. 8 combines the information collated from the studies used to develop Table 2 with equivalent data from other studies conducted elsewhere in NSW and Vic and shows a relationship between legume grain yield and total legume residual N remaining at the end of the growing season. The line of best-fit calculated without the apparent outlier (▲) in Fig. 8 was described by (r^2 = 0.56):
Total legume residue N (kg N/ha) = *54 +(30 x legume grain yield)*
Growers could use this equation as a guide to how much organic N their pulse crop might be returning to the system and to multiply that value by 28% or 10% to provide a rough estimate of how much additional soil mineral N could become available prior to sowing the first and second crop after the pulse; respectively:
Additional soil mineral N for 1^{st}-crop after a pulse (kg N/ha) = *0.28 x [54 +(30 x pulse grain yield)]*
Additional soil mineral N for 2^{nd}-crop after a pulse (kg N/ha) = *0.10 x [54 +(30 x pulse grain yield)]*

Crop recovery of soil mineral N following pulses

All the legume treatments shown in Table 2 significantly increased ($P < 0.05$) the above-ground biomass (by 0.6–4.5 t/ha, mean 2.4 t/ha) and total N uptake (by 8–86 kg N/ha, mean 38 kg N/ha) of the following wheat crop compared to where the preceding crop had been either wheat, barley or canola. Based on the measured increases in wheat total N uptake over the two wheat cropping cycles, *the apparent recovery of N from the preceding legume grain crops and BM represented on average around 30% of the legume residue N by the first wheat crop, and 5% by the second wheat* (Peoples et al., 2017; unpublished data). These estimates are generally consistent with the earlier studies of Evans *et al* (2001) who calculated that a wheat crop recovered on average about 20% of the grain legume residue N remaining in above-ground stubble and about 10% of the N in the below-ground plant N.

A comparison of the total N uptake (i.e. shoot N + grain N + below-ground N) by the first wheat crop grown after either legumes, wheat, barley or canola with the pre-sowing measures of soil mineral N is shown in Fig. 9. The data in Fig. 9 indicate that most crops accumulated more N than was available in the soil at sowing. This highlights the importance of in-crop mineralisation of N in supporting the nutrition of wheat in grain-cropping regions of Australia.

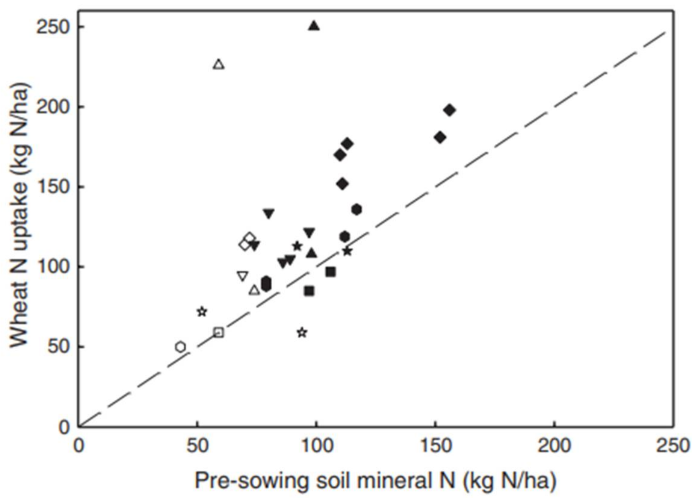

Figure 9 Relationship between pre-sowing soil mineral N and wheat total N uptake across different experiments undertaken in southern (n=3) and northern NSW (n=2) and SA (n=1). The different symbols represent data following either legumes (closed symbols) or non-legumes (open symbols) grown at different locations. The broken line represents a 1:1 relationship. (Source: Peoples *et al* 2017)

Comparing crop recoveries of legume N and fertiliser N

The effect of legumes on wheat total N uptake could only be directly compared with fertiliser N in two experiments in southern NSW. In these studies, applications of 51 kg fertiliser N/ha increased total N uptake by wheat grown after canola or wheat by 25 and 31 kg N/ha; respectively at Junee Reefs, and 75 kg fertiliser N/ha increased crop uptake by 61 kg N/ha at Wagga Wagga, NSW (Peoples *et al* 2017). This represented apparent total recoveries of fertiliser N by wheat or canola equivalent to 49–81% (mean 64%) of the fertiliser N supplied (Note: this would correspond to an average 42% recovery of fertiliser N if calculated just on an above-ground N basis). Although these determinations of recoveries of fertiliser N were somewhat higher than the apparent recoveries of legume N by wheat in the same experiments (mean recovery of 30% of total residue N from 9 legume treatments; 20% recovery if calculated on an above-ground N basis), the additional quantity of N accumulated by wheat in response to fertiliser N (25-61 kg N/ha) was lower than observed after all legume treatments (38–84 kg N/ha) at Junee Reefs and BM crops (69–86 kg N/ha) at Wagga Wagga.

That the apparent recoveries of fertiliser N were about twice that calculated for legume residual N in the same studies was not surprising given that either two-thirds (Wagga Wagga) or >90% of the fertiliser N applied (Junee Reefs) was supplied at the stem elongation immediately before a period of high plant demand when the efficiency of fertiliser N uptake would be expected to high (Crews and Peoples 2005). In comparison, only a fraction of the organic legume N was mineralised to be available for crop uptake. However, any soil mineral N generated after a legume should be just as effective in supporting wheat growth as N released from fertiliser. The organic N contributed by legumes also provided a N benefit to more than one subsequent crop and would help sustain the long-term fertility of the soil (Peoples *et al* 2017; Ladha *et al* 2022). Furthermore, the risk of losses of N from legume sources are likely to be much lower than from fertiliser which dissolves rapidly in the presence of moisture to release inorganic forms of N that are highly vulnerable to loss processes via volatile emissions, leaching or in run-off (Crews and Peoples 2005; Jensen *et al* 2012; Ladha *et al* 2022).

Other benefits derived from pulses

It is well known that wheat grain yields are usually improved by legumes. This is well illustrated by the data presented in Fig. 10 which were collated from 300 comparative field studies undertaken in Australia, Western Europe, North America, and West Asia. Analyses suggest that wheat yields are enhanced by 1.6 t/ha after lupin and 0.7 t/ha after other pulses (0.9 t/ha all pulses) to relative to wheat after wheat in the absence of N fertilizer. Even though all discussions to this point have focused on legume effects on availability of soil mineral N, the wheat yield responses shown in Fig. 10 should not be attributed only to N. For example, the breaking of pest cycles and reductions in the incidence or severity cereal leaf and root disease have often been demonstrated to be major factors contributing to yield advantages after break crops, including legumes (Kirkegaard *et al* 2008; Angus *et al* 2015).

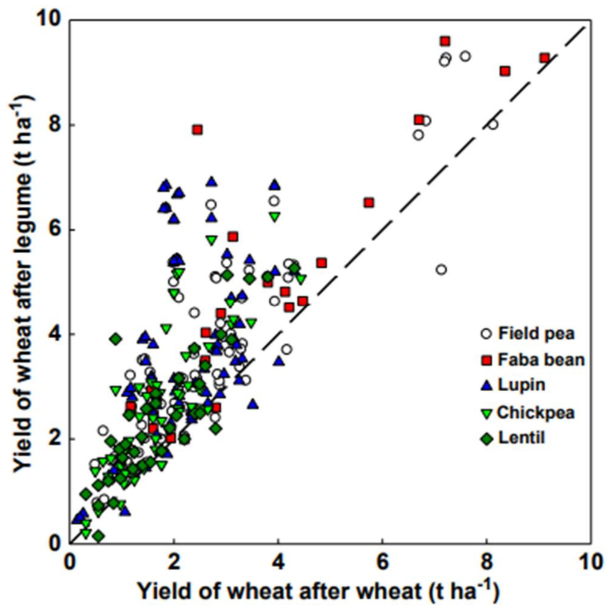

Figure 10 Grain yields of unfertilised wheat following a pulse compared to a wheat after wheat treatment grown in the same experiment. The dashed line represents equal yields. Any point above the dashed line indicates greater yield when a legume was the preceding crop. (Source: Angus *et al* 2015).

One way of estimating the relative value of the N contribution or other rotational benefits of pulses is to compare the yields of wheat growing after wheat with yield responses after legumes or an alternative break crop such as canola. When using this approach, it is assumed that both the legume and canola provide a similar disease break, but canola provides no additional N. It then concluded that: (a) increased N is the main driver of rotational benefits if grain yields wheat yields above that achieved in the wheat-wheat sequence are greater after pulses than canola, (b) "non-N-benefits" dominate when improvements in wheat yield are similar after both pulses and canola, and (c) there are no underlying nutritional or biotic constraints to wheat productivity if the wheat-wheat yields the same as pulse-wheat and canola-wheat.

Another way to distinguish between the importance of N or non-N related benefits of legumes is to compare the response curves for wheat grain yield with different rates of applied fertiliser N in pulse–wheat and wheat–wheat sequences (Chalk 1998). Where: (a) the wheat–wheat response curves converge and intersect the pulse–wheat line with increasing rates of fertiliser N such as shown in Fig. 11a, the legume benefit is largely due to increased soil N availability, (b) converging lines that do not intersect at high rates of N application indicate a combination of N and non-N benefits (e.g. Fig. 11b), and (c) yield response curves after the legume and wheat are parallel, then factors other than N are primarily involved (e.g. Fig. 11c).

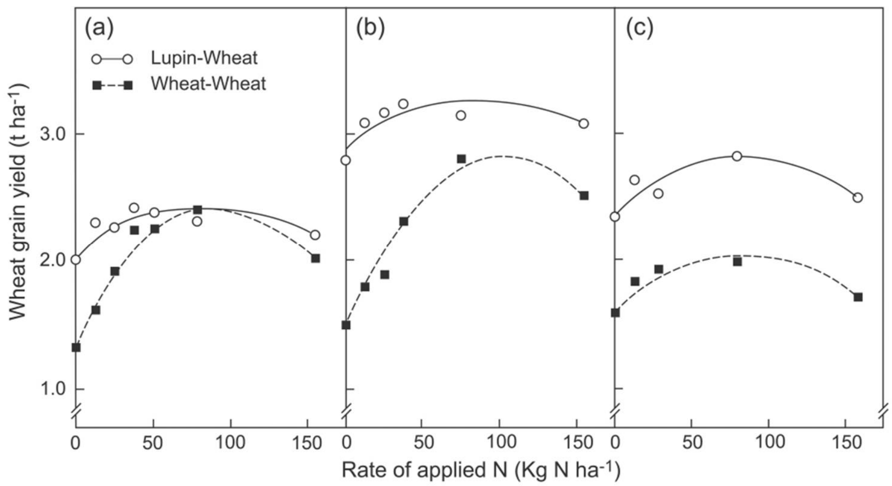

Table 11 Different grain yield responses of wheat to increasing rates of applied fertiliser N in wheat-wheat sequences (■) or lupin-wheat (○) observed in WA field experiments. (Source: Chalk 1998).

Chalk (1998) reviewed the results of 26 wheat–wheat and lupin–wheat rotations undertaken in WA and noted that the curves intersected in 5 experiments, there was incomplete convergence in 4, and curves were parallel in 12 cases, while the remaining 5 did not fit any of these three patterns due to one or other of the treatments showing either nil or negative responses to additional N. So, in 16 of the 26 comparisons (i.e. 61% of experiments) non-N-effects derived from the lupin either dominated the rotational effect or were important contributing factors in the subsequent yield improvement by wheat. Possible sources of these non-N-benefits and the broader impact of legumes on soil are discussed below.

Soil water supply and utilisation

In rainfed farming systems soil water availability is often the most important constraint to crop growth and productivity. Consequently, lower water use by legumes than other crops such as is shown for field pea in Fig. 12 could be advantageous (Kirkegaard *et al* 2008; Angus *et al* 2015). The data in Fig. 12 indicated that the amount of soil water remaining in the root zone around the time of wheat grain harvest was 75 mm less than after field peas and 150 mm less than after fallow. This residual soil water measured at maturity under the pulse can be carried over to be used by a wheat crop in the next growing season provided it is not first lost through evaporation or transpired by weeds during the fallow period between crops (Hunt *et al* 2013).

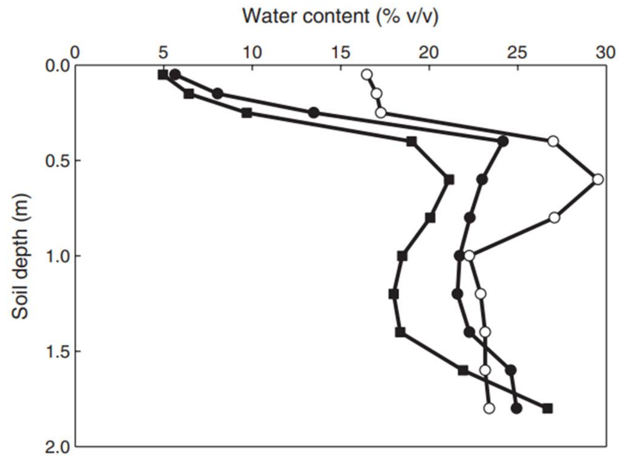

Figure 12 Soil water profiles under wheat (■), field peas (●) and bare fallow (○) sampled at the time of crop maturity in an experiment undertaken in southern NSW. (Source: Angus *et al* 2015).

However, water related improvements to wheat yield after a pulse may not always be negatively related to the extraction of soil water by the pulse. It could reflect increased extraction of soil water (and nutrients) due to a healthier, more vigorous wheat root system exploring a larger soil volume because of the reduced incidence of cereal-root pathogens due to the legume phase.

Soil biology

In addition to affecting soil borne cereal pathogens (Kirkegaard *et al* 2008), legumes appear to reduce the survival of certain species of nematodes and stimulate the activity of a plethora of soil organisms including earthworms. However, it now seems that some symbioses can also influence the composition of the microbial population in the legume's rhizosphere. It has long been known that molecular hydrogen (H_2) is an obligatory by-product of symbiotic N_2 fixation in legume nodules, with H_2 production may account for about 35% of the energy consumed in the overall nitrogenase activity (Angus *et al* 2015). In some legume systems, the rhizobial bacteria produce a hydrogenase uptake enzyme system (designated Hup+) that is able to recycle almost all of the H_2 evolved and recover most of the energy that might otherwise be lost. However, the Hup+ trait appears to be much less common than symbiotic associations that either lack the hydrogenase enzyme (Hup-) or have low Hup activity. In those systems H_2 diffuses out of the nodules into the soil. Measurements of H_2 evolution from Hup– nodules in the field suggest that >200,000 L of H_2 gas can be released into the soil by soybean fixing around 200 kg N/ha (Peoples *et al* 2008). Glasshouse comparisons of H_2 emissions from nodules from other legume species suggest that emissions from pulses may be even greater, and seem especially high from faba bean and lupin nodules (Angus *et al* 2015).

Specific microorganisms (e.g. *Actinomycetes* species) that are capable of oxidizing the H_2 diffusing from the nodule increase within microbial population in the immediate vicinity of the legume roots, so that most of the H_2 is consumed within a few cm of the nodules. (Angus *et al* 2015). There appears to be substantial consequences of this H_2-induced modification of the soil microbiota as experiments undertaken in both the glasshouse and the field have observed improvements in plant growth in soils previously exposed to H_2 regardless of whether the H_2 came from legume nodules or a gas cylinder, or whether using soil extracts or microbial isolates from H_2-teated soils (Kirkegaard *et al* 2008; Angus *et al* 2015). Whatever the factors involved in this stimulation in plant growth, field studies that have compared crop performance following soybean symbioses that either recycled (Hup+), or emitted H_2 from nodules (Hup-), have indicated that the Hup– trait significantly ($P < 0.05$) increased grain yield of a succeeding barley crop by 48% (2.9–4.3 t/ha for Hup+ and Hup− ; Dean *et al* 2006) or maize by 32% (1.43–1.89 t/ha for Hup+ and Hup− ; Peoples *et al* 2008).

Soil organic N and C

There are many reports of improvements of soil organic N and C after legumes. While measurements of incremental changes in total soil N following grain legumes are often difficult to quantify (Chalk, 1998), changes in soil organic N and C can be measured beneath long-term legume-based pastures. Growing legumes in conjunction with grasses have been demonstrated to enhance the annual rate of C accumulation compared to pure grass pastures, and the inclusion of lucerne in a crop rotation improves both the retention of soil C and its distribution down the soil profile (Jensen *et al* 2012). The regular use of vetch green manure in a cropping system has also been reported to either increase soil C sequestration or substantially slow the decline in soil organic C reserves compared to cropping without legumes (Jensen *et al* 2012). However, even though enhanced complexity of a crop rotation has been shown to favour C sequestration, the inclusion of a pulse in a cropping sequence is much less likely to significantly affect soil C reserves than a legume-based pasture or where legumes as routinely green manured.

Acknowledgements

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Further reading

For more details on research findings about legumes in wheat-based cropping systems of SE Australia:

Goward L, Swan T and Peoples M (2016). **Profitable break crop management guide**: GRDC Project CS000146 (Facilitating increased on-farm adoption of broadleaf species in crop sequences to improve grain production and profitability). Grains Research & Development Corporation, 57p. Profitablebreakcropmanagementguide.pdf (squarespace.com)

2022 MFMG Annual Trial Results Book Template

Hyper Yielding Crops – Millicent 2022
Max Bloomfield, Nick Poole, Aaron Vague, Daniel Bosveld, Darcy Warren – FAR Australia
Kenton Porker – CSIRO
Max Bloomfield – max.bloomfield@faraustralia.com.au
Project code/ID - FAR2004-002SAX
Project title - HYPER YIELDING CROPS

KEY MESSAGES

- Radiation and temperature (photothermal quotient) limited cereal yields in a wet 2022 season throughout the Limestone Coast. The highest wheat yield achieved was 8.67 t/ha and highest barley yield was 8.43 t/ha.
- Although it is not possible to quantify, wheat heads on the trial site had pinched grain indicating that despite disease management grain fill was compromised. Although there are many possible reasons including head disease, anaerobic soil conditions caused by transient water logging during grain fill cannot be ruled out.
- Disease management was critical for improving wheat yields, particularly in susceptible cultivars like RGT Accroc.
- Winter canola yields did not achieve > 5 t/ha but showed potential for grazing of early vegetative biomass. Spring canola yields were looking set to achieve up to 6 t/ha but were damaged by hail a few days prior to harvest.
- Harvesting barley on time was key to reducing head loss. There was no benefit to split Z31/Z37 PGR applications compared to full rate at Z31.

Background

Deciphering potential yield (PY) for a given location can be difficult. For example, yields in high rainfall environments are typically limited by light interception and temperature rather than water in most seasons. The photothermal quotient (PTQ, sum of daily radiation/sum of mean daily temperature in the 4 weeks prior to flowering) is typically the major constraint in the lower Limestone Coast for achieving 10 t/ha wheat yields in well managed crops. Moving into the upper Limestone Coast, increasing latitude and decreasing annual rainfall increases variation in whether PTQ or water is limiting PY. For example, climate data from Mt Gambier shows that water limited potential yield (PY_W) was <12 t/ha in only one of the last 13 years but PTQ limited potential yield (PY_{PTQ}) >10 t/ha occurred in 7 of the last 13 years when flowering between 25-31 Oct or 1-7 Nov (Table 1). Climate data from Keith suggests PY_W >10 t/ha occurred in three of the last 13 years but PY_{PTQ} was <10 t/ha in those three years (Table 2). PY_{PTQ} >10 t/ha occurred in six years but PY_W varied from ~5-8.5 t/ha in those year. This demonstrates PTQ is the main limiting factor on potential yield in the lower Limestone Coast high rainfall zone, but can also be attributed to limiting potential yield in wet years in the upper Limestone Coast medium rainfall zone. Also of note is the variation in PY_{PTQ} in varying flowering periods. For example, earlier flowering at Mt Gambier in the week of 25-31

Oct in 2021 estimated a yield reduction of ~1.4 t/ha compared to flowering in the week of 1-7 Nov.

Table 1. *Water limited and photothermal quotient (PTQ) limited yield potential, 2010 to 2022. Meteorological data from Mt Gambier Aero weather station (BoM #26021).*

Year	Water limited yield potential (t/ha)	PTQ limited yield potential 25-31 Oct# (t/ha)	PTQ limited yield potential 1-7 Nov# (t/ha)
2010	>12.5*	13.25	12.60
2011	>12.5*	10.11	9.92
2012	>12.5*	12.57	11.60
2013	>12.5*	10.00	10.65
2014	12.42	10.84	11.19
2015	10.20	9.74	9.17
2016	>12.5*	11.77	13.06
2017	>12.5*	9.37	9.80
2018	>12.5*	9.39	9.87
2019	>12.5*	10.12	10.40
2020	>12.5*	8.69	9.02
2021	>12.5*	9.83	11.21
2022	>12.5*	7.62	7.92

**Capped water limited potential yield at 550 mm growing season rainfall.*
#Dates in PTQ limited yield columns represent flowering period ranges.

Table 2. *Water limited and photothermal quotient (PTQ) limited yield potential, 2010 to 2022. Meteorological data from Keith weather station (BoM #25507).*

Year	Water limited yield potential (t/ha)	PTQ limited yield potential 1-7 Oct# (t/ha)	PTQ limited yield potential 8-14 Oct# (t/ha)
2010	8.32	10.93	11.54
2011	8.58	10.57	9.85
2012	7.02	11.00	11.95
2013	8.29	8.36	9.17
2014	5.07	10.02	10.15
2015	5.27	9.93	9.90
2016	10.62	8.08	9.18
2017	10.04	9.07	9.36
2018	7.11	10.84	10.22
2019	6.99	10.34	10.47
2020	8.19	7.83	8.07
2021	7.55	7.72	8.44
2022	10.97	6.92	7.47

Highlighted cells indicate if water or PTQ was limiting yields in each year.
#Dates in PTQ limited yield columns represent flowering period ranges. Flowering periods at Keith were estimated as optimal flowering periods for Bordertown as modelled by Flohr et al. (2017).

Activities

The GRDC Hyper Yielding Crops project runs at FAR Australia Crop Technology Centres in southern WA, lower Limestone Coast SA, SW Vic, southern NSW, and northern Tas.

The sites run multiple trials looking at various genotype (cultivar), environment (time of sowing – TOS) and/or management (e.g. simulated grazing, nutrition, plant growth regulators – PGRs, fungicide) factors to improve and tailor best agronomy of wheat, barley and canola for the high rainfall zones of Australia.

Some key trials from Millicent, SA, in 2022 are presented and discussed below.

Wheat elite screen trials
Time of sowing 1 (TOS 1) was sown on 21 Apr 2022 and harvested on 10 Jan 2023. TOS 2 was sown on 11 May 2022 and harvested on 9 Jan 2023.

TOS 1 was a factorial trial that compared nine genotypes with and without full fungicide management (see Table 3 for full fungicide treatment list). TOS 2 compared 10 genotypes with full fungicide management.

Table 3. *Fungicide and plant growth regulator application details.*

Fungicide/PGR	Rate	Application timing
Systiva (seed treatment)*	600 mL/100 kg seed	Sowing
Moddus Evo + Errex Moddus Evo + Errex	100 mL/ha + 650 mL/ha 100 mL/ha + 650 mL/ha	Z30-31 Z32-37
Prosaro	300 mL/ha	Z31
Experimental fungicide	750 mL/ha	Z39
Opus	500 mL/ha	Z59-61

*Systiva and PGRs were not applied in TOS 2 screen.

Canola winter screen trials
Two winter screen trials (ungrazed and grazed) were sown on 10 May 2022 and harvested on 12 Jan 2023. The ungrazed trial compared eight genotypes and the grazed trial compared four genotypes. Simulated grazing was done with a push mower on 9 Aug 2022 while plants were still in the vegetative phase (approx. 8 leaf stage).

Barley PGR x harvest date trials
TOS 1 was sown on 21 Apr and TOS 2 on 11 May. Winter 6 row barley Pixel was sown in TOS 1 and spring 2 row barley RGT Planet in TOS 2. TOS 1 harvest dates were 18 Dec 2022 and 9 Jan 2023. TOS 2 harvest dates were 19 Dec 2022 and 9 Jan 2023.

The trials were factorial and compared PGR treatments (Table 4) at two harvest timings (on time and delayed).

Table 4. *Plant growth regulator application details.*

PGR treatment	Rate	Application timing
Untreated	N/A	N/A
Moddus Evo	400 mL/ha	Z31
Moddus Evo Moddus Evo	200 mL/ha 200 mL/ha	Z31 Z37
Moddus Evo Ethephon 720	200 mL/ha 500 mL/ha	Z31 Z37

Results and Discussion

Hyper Yielding Crops – Wheat Elite Screen: TOS 1 and 2

Yields in the elite screen trials at both times of sowing (TOS) were considerably lower than 2021, despite the additional growing season rainfall. In TOS 1, Reflection (the top yielding cultivar in TOS 1 in 2021 at 12.74 t/ha) yielded 8.11 t/ha with a full fungicide program, while breeding lines AGTW0005 and AGFWH004818 yielded 8.33 and 8.67 t/ha, respectively, and were the only genotypes to exceed 8 t/ha (Figure 1). These three genotypes also had the best disease resistance with untreated yields 0.80 to 1.03 t/ha lower than with a full fungicide regime. Green leaf retention in the top and middle thirds of the canopy was significantly increased by fungicide applications in RGT Accroc, LRPB Beaufort, GS-18-105-W, and Stockade (previously tested as LRPB16-0598), and was significantly increased in the middle third in BigRed (Figure 2).

New white winter feed cultivar RGT Waugh (tested as SFR86-085 in previous seasons) was the highest yielding commercially available cultivar in both full fungicide (7.56 t/ha) and untreated (4.83 t/ha) treatments, although it was not statistically different to red winter feed cultivar Big Red or white milling very slow spring cultivar Stockade. Stockade was the highest yielding spring milling wheat, which is consistent with its performance in previous years when tested as a breeding line. Widely adopted in the HRZ, RGT Accroc continued its trend over the last few seasons of increasing disease susceptibility. At Millicent, RGT Accroc succumbed to Septoria tritici blotch (STB), stripe rust and leaf rust. This led to a 4.39 t/ha reduction in yield in the untreated compared to the full fungicide regime.

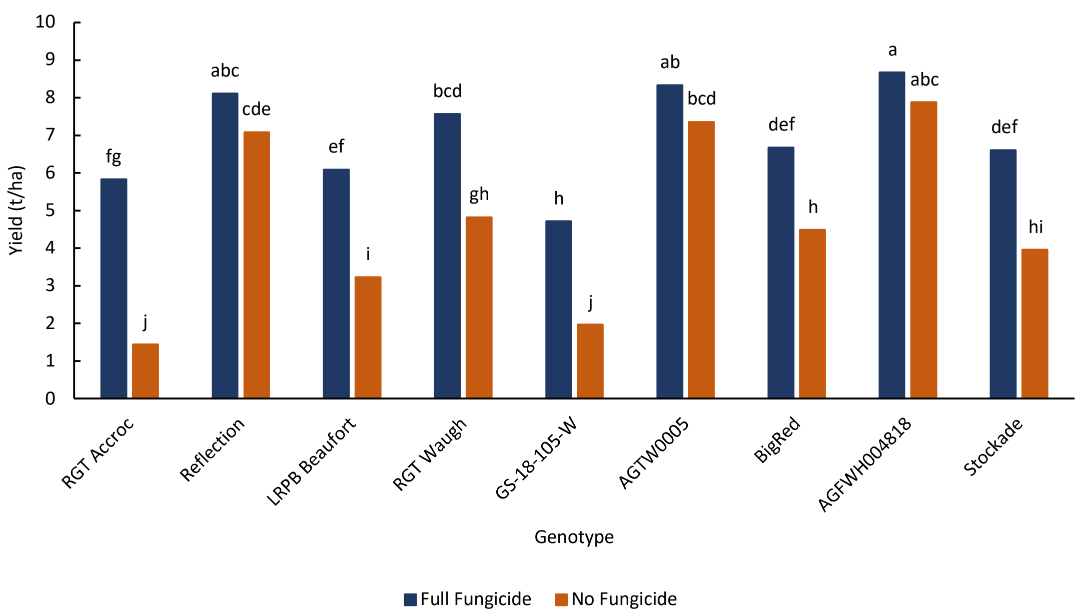

Figure 1. *Effect of genotype and fungicide management on grain yield (t/ha). Wheat elite screen TOS 1, sown 21 Apr 2022, harvested 10 Jan 2023. Letters indicate significant differences of genotype x management (p=0.05).*

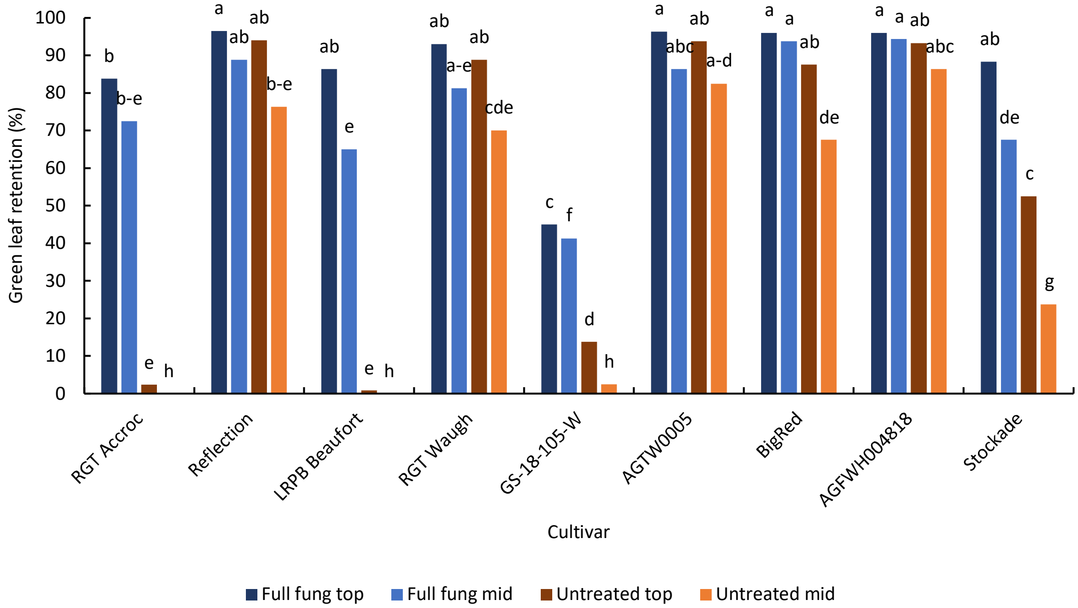

Figure 2. Effect of genotype and fungicide management on green leaf retention in the top and middle thirds of the canopy, assessed 16 Nov 2022. Wheat elite screen TOS 1, sown 21 Apr 2022. Letters indicate significant differences of genotype x management for each canopy layer (p=0.05).

The TOS 2 screen did not compare genotypes with and without fungicide. All plots were managed with a full fungicide regime developed during the early years of HYC. Red winter feed wheats Anapurna (7.20 t/ha), RGT Cesario (7.46 t/ha) and BigRed (7.17 t/ha) were the highest yielding cultivars and only ones to yield > 7 t/ha, although BigRed was not statistically different to RGT Accroc (6.71 t/ha) (Figure 3). Stockade was the highest yielding white milling wheat (6.66 t/ha), although protein content was only 12.2% (results not shown). Although not able to be statistically compared, the four common cultivars in both trials (RGT Accroc, LRPB Beaufort, BigRed and Stockade) all yielded more in TOS 2. They retained similarly high green leaf area % (Figure 4). Note that Rockstar and Scepter have quicker phenology so their green leaf area, although reduced by disease, were also lower due to maturing towards harvest quicker.

A recurring theme over several seasons and seemingly unique to the Millicent Crop Technology Centre (CTC) compared to other FAR CTCs, has been only small yield gain through to slight yield penalty sowing winter wheats early to accumulate more biomass. The only detriment to late sowing would be missing grazing opportunities. In the Germplasm x Environment x Management trial in 2022 (TOS 1; RGT Cesario, BigRed, RGT Accroc; results not shown here), there was no penalty associated with grazing (mowed at Z30, 225 kg N/ha) compared to no canopy management or PGRs applied (Moddus Evo + Errex).

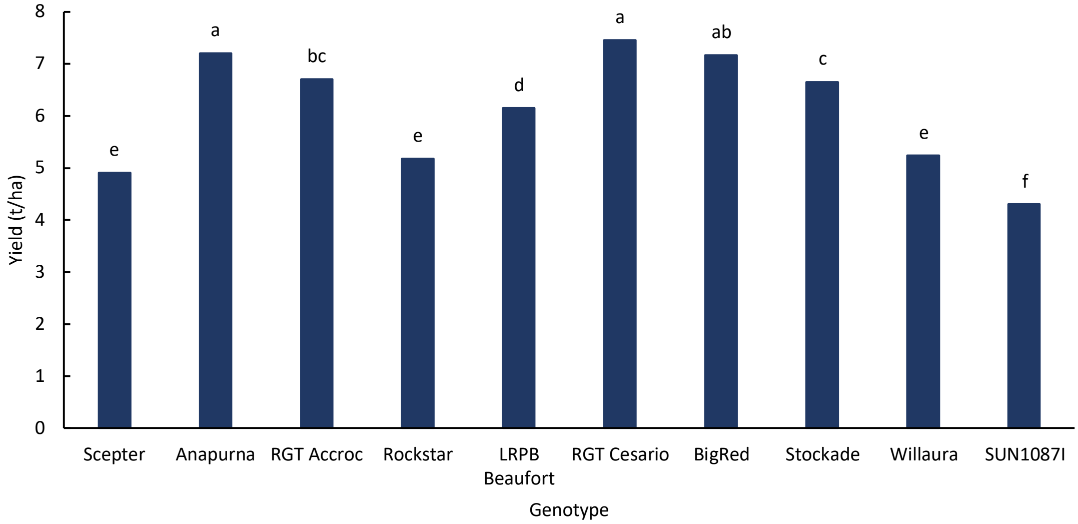

Figure 3. *Genotype grain yields (t/ha) in wheat Elite Screen TOS 2. Sown 11 May 2022, harvested 9 Jan 2023. Letters indicate significant differences of genotype (p=0.05).*

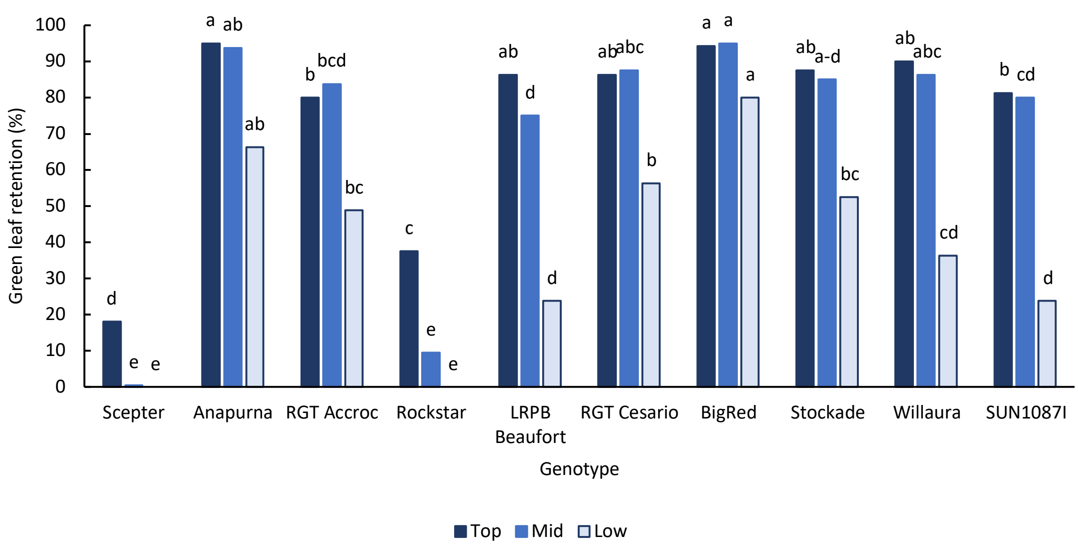

Figure 4. *Genotype green leaf retention in the top, middle and lower thirds of the canopy, assessed 22 Nov 2022. Wheat elite screen TOS 2, sown 11 May 2022. Letters indicate significant differences of genotype x management for each canopy layer (p=0.05).*

Hyper Yielding Crops – Canola Winter Screen, Grazed and Ungrazed

Hail damage three days prior to harvest of spring canola caused varying yield losses and so only winter canola results from the grazed and ungrazed screening trials will be presented here. Although the two trials cannot be statistically compared and there was no significance in yields or dry matter removed within each trial, there were still some noticeable differences (Figure 5). AGFCA014120 was the highest yielding cultivar in both the grazed (4.84 t/ha) and ungrazed (4.57 t/ha) trials, and also produced the most biomass up to the time of grazing (9 Aug). Grazing delayed flowering by 3-6 days and there were minimal to no differences in grain quality (oil and protein %, test weight; results not shown).

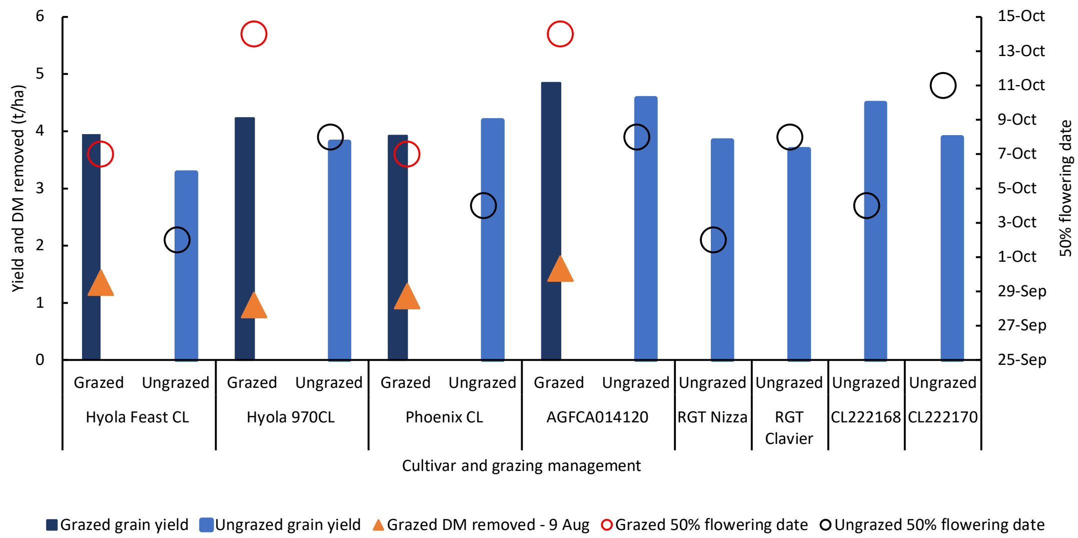

Figure 5. *Grain yields (t/ha; grazed, navy bars; ungrazed, blue bars), dry matter removed at grazing (t/ha; orange triangles; grazed 9 Aug), and date of 50% plants flowered (grazed, red open circles; ungrazed, black open circles) in canola Winter Screens. Both trials sown 10 May 2022, harvested 12 Jan 2023. All results were not significant (p=0.05) and grazed and ungrazed screens were separate trials and cannot be statistically compared.*

Hyper Yielding Crops – Barley PGR x Harvest Date: TOS 1 (Pixel, sown 21 Apr) and 2 (RGT Planet, sown 11 May)

Results from 2022 and past seasons have shown harvesting barley on time is critical to capture full yield potential and avoid head and grain losses. Results were not significant for the two-way interaction between PGR treatment and harvest timing in both TOS 1 (winter 6 row cultivar Pixel) and TOS 2 (spring 2 row cultivar RGT Planet) trials this season, however there were large differences between the mean yields for each treatment (Figure 6, Figure 7). Both cultivars at each TOS followed similar trends, showing that a single full rate application of Moddus Evo (400 mL/ha) at Z31 and timely harvesting led to highest yields. This treatment in Pixel was also the highest yielding barley treatment from any trial at the Millicent CTC and the only one to exceed 8 t/ha. Each PGR treatment in Pixel preserved a similar amount of yield (~1.4-1.6 t/ha) compared to the untreated when harvest was delayed by three weeks. Although the differences were minimal, Moddus Evo (Z31) + Ethephon (Z37) reduced yield in RGT Planet compared to the untreated at both harvest timings. Split application of Moddus Evo (200 mL/ha at Z31 and Z37) preserved the most yield in RGT Planet compared to the untreated.

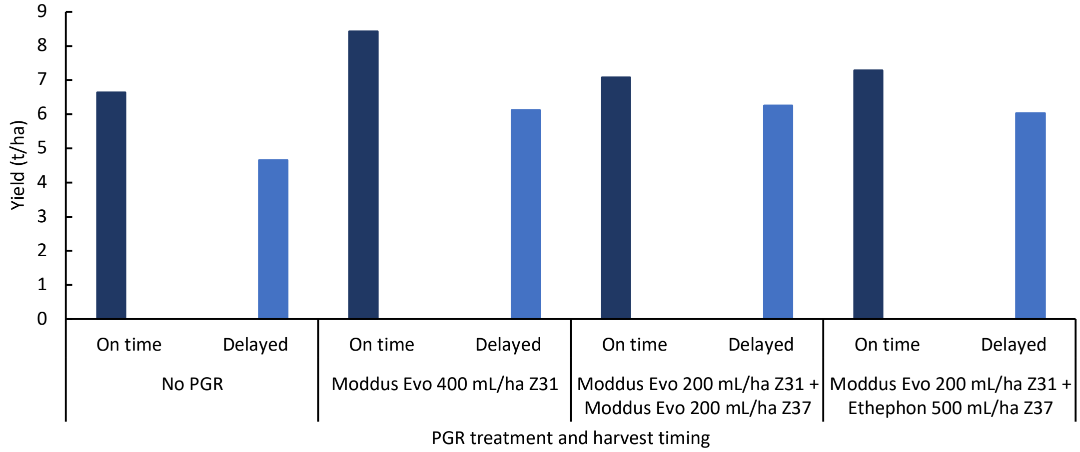

Figure 6. *Effect of PGR treatment and harvest timing on grain yield (t/ha; on time, navy bars; delayed, blue bars) on Pixel 6 row winter barley. Sown 21 Apr 2022, harvested 18 Dec 2022 (on time) and 9 Jan 2023 (delayed). No significant differences for PGR treatment x harvest timing (P val (p=0.05) = 0.056).*

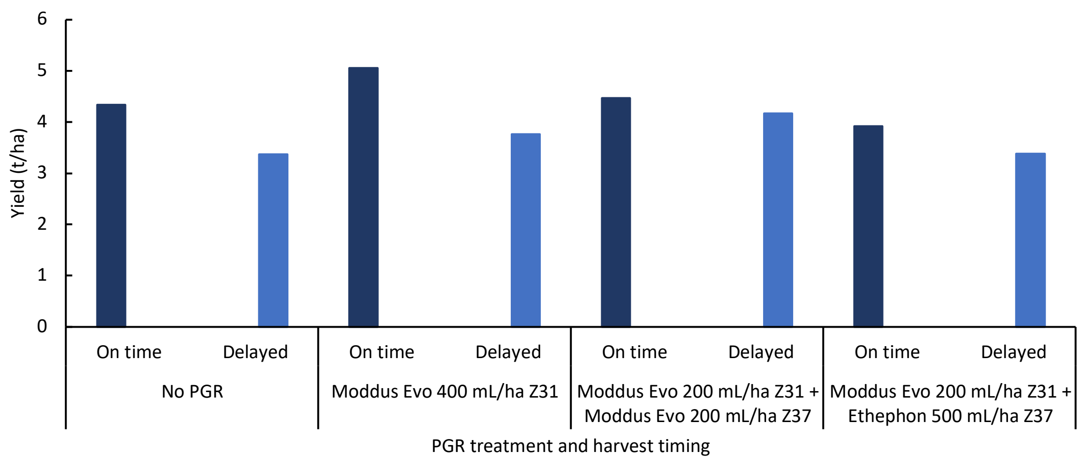

Figure 7. *Effect of PGR treatment and harvest timing on grain yield (t/ha; on time, navy bars; delayed, blue bars) on RGT Planet 2 row spring barley. Sown 11 May 2022, harvested 19 Dec 2022 (on time) and 9 Jan 2023 (delayed). No significant differences for PGR treatment x harvest timing (P val (p=0.05) = 0.106).*

Conclusions

Despite favourable spring growing season rainfall, cereal yields did not achieve the high expectations set in 2021 due to constraints from radiation and temperature during the 4 weeks prior to flowering, possible water logging due to a high water table and incomplete disease control.

Winter canola cultivars are still yet to compete with spring cultivars for yield in a grain-only system, however may present value for graze and grain.

PGR application of Moddus Evo at the full label rate (400 mL/ha) upfront at Z31 gave the highest yields in two barley cultivars at two times of sowing. However on time harvest for barley remains the key means of preventing yield losses.

FAR Australia will release a full report on all Hyper Yielding Crops trials on 4 April 2023.

References

Flohr BM, Hunt JR, Kirkegaard JA, Evans JR (2017) Water and temperature stress define the optimal flowering period for wheat in south-eastern Australia. Field Crops Research 209, 108–119.

Maximising barley yields in the SA HRZ – Millicent, SA

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Key point summary

- Lower solar radiation over spring resulted in reduced yield potentials for barley varieties in 2022 when compared to the long-term average. This is in contrast to the favourable conditions experienced in 2021 where top yields reached over 10 t/ha.
- A wetter than average spring, high inoculum in the environment and the use of susceptible varieties, meant Net Form of Net Blotch (NFNB) pressure was extremely high in 2022, particularly for late April sowings.
- The use of SDHI chemistry at the second spray timing was most effective at reducing NFNB severity on flag-1, the most important yield contributing leaf in barley.
- There was no yield difference between the single spray programs and the untreated, suggesting this level of management is not appropriate for high disease pressure environments when growing susceptible varieties.
- Applying 2-4 units of fungicide significantly improved yield compared to the untreated, but there were no significant improvements from 2 through to 4 units, regardless of seed treatment/folia spray combinations.The cheaper fungicide managements based on a single spray gave poorer screening and retention figures as well as increased brackling when assessed at crop maturity.
- New barley varieties in the pipeline are proving good candidates to be both higher yielding and more disease resistant than RGT Planet.
- Although RGT Planet still remains among the highest yielding in the Hyper Yielding Crops (HYC) screening trial, it requires a robust fungicide management program.
- Varieties such and Rosalind and Neo (tested by FAR in 2022 as IGB22102T) show much better resistance to NFNB however may need more management around Spot Form of Net Blotch (SFNB) and leaf rust, respectively.

Barley yield potential

After the record-breaking 2021 season (for HYC mainland sites) in Millicent where barley yields topped 10 t/ha, yields in 2022 fell short of repeating that feat with the top yield from each season differing by over 2 t/ha. It is now known through the work of HYC over the last three seasons that good solar radiation and cooler temperatures are essential to maximise grain number. Grain number is determined in the period approximately 3 weeks before flowering. Maximising growth of the crop in this window is associated with higher yield potential (as a result of higher grain number per head) provided the crop is not subject to other stresses such as frost, heat stress or moisture stress. In 2022 water logging during the grain fill period also provided additional stress reducing barley yield potential further.

Although temperature was close to average, solar radiation was well below the long-term average during the critical period in 2022. Varieties reaching flowering in early October e.g. May sown RGT Planet and Laureate were likely to be impacted by sharp drops in yield potential calculated by Photothermal Quotient (PTQ). Earlier flowering varieties would have been less impacted as PTQ potential yields were on average through September for wet years however this comes at a time of year when the long-term average is naturally lower. There were some peaks in PTQ potential yields for varieties towards the end of October/early November in 2022 however these still failed to raise the yield potential past the historical average, as experienced in 2021.

Disease management a major driver in barley yields

Given the wetter and warmer than average conditions experienced at the Millicent site in 2022, it's no surprise that disease was a major influence on yield. These climatic conditions coupled with high inoculum loads in the environment and the use of RGT Planet (rated SVS to NFNB) generated a 1.84 t/ha response to fungicide when tested on site (Table 1).

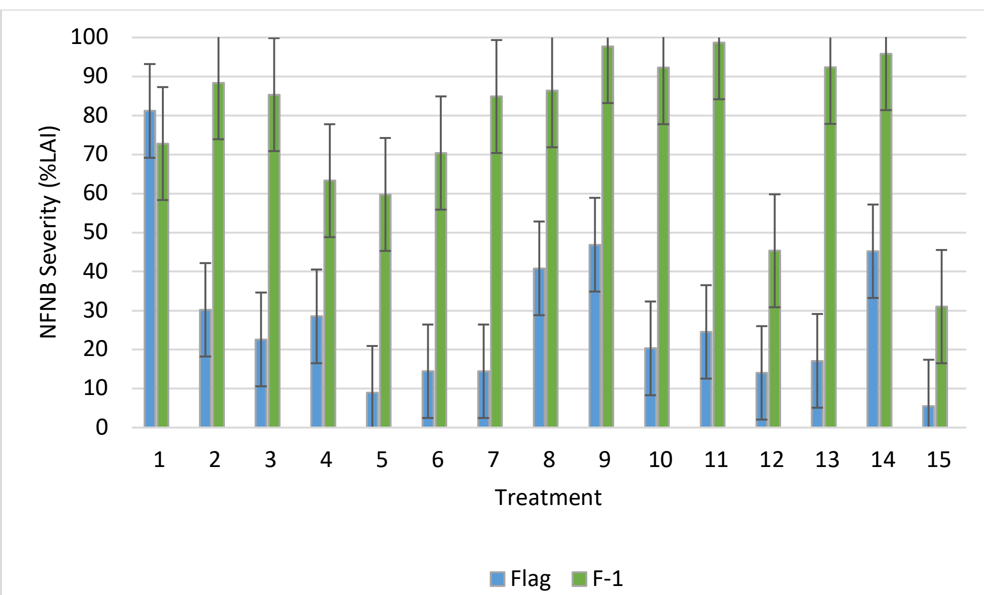

Figure 1. *The severity of Net Form Net Blotch (NFNB, %LAI) at GS79 (grain fill -doughy ripe) on the Flag and Flag-1 (Treatment list as per table 1).*

The HYC barley fungicide trial in RGT Planet, in which NFNB was the dominant disease, demonstrated that a single early (GS31) spray program was insufficient to control disease. When assessed at the doughy ripe growth stage (GS79), a single application of Tilt 250 mL/ha (Propiconazole) applied at early stem elongation (GS31) was seen to have the highest levels of NFNB on Flag-1 (the most important yield contributing leaf in barley) outside of the untreated plots (Figure 1). Both this treatment, and the single early application of Prosaro 300 mL/ha (Prothioconazole and Tebuconazole) were not significantly higher yielding than the untreated plots come harvest (Table 1). Treatments where SDHI chemistry was used on Flag-1 gave the best control of NFNB however using a four, three or two fungicide unit management regime did not offer any real change in yield outcome.

Table 1. *Influence of fungicide management on grain yield (t/ha).*

	Treatment				Yield		% of mean	
	GS00	**GS31**	**GS39-49**	**GS59**	t/ha		%	
1	---	---	---	---	3.06	e	71.1	e
2	Systiva	Prosaro 300 mL/ha	Radial 840 mL/ha		4.24	abc	98.7	abc
3	Systiva	Prosaro 300 mL/ha	Radial 840 mL/ha	Opus 500 mL/ha	4.66	ab	108.4	ab
4	---	Prosaro 300 mL/ha	Aviator Xpro 420 mL/ha		4.69	a	109.1	a
5	---	---	Aviator Xpro 420 mL/ha		4.63	ab	107.6	ab
6	---	Prosaro 300 mL/ha	FAR F1-19 750 mL/ha		4.82	a	112.1	a
7	---	FAR F1-19 750 mL/ha	Radial 840 mL/ha		4.66	ab	108.3	ab
8	---	Prosaro 300 mL/ha	----		3.54	cde	82.3	cde
9	--	Tilt 500 250 mL/ha	----		3.49	de	81.2	de
10	Systiva	---	Radial 840 mL/ha	---	4.43	ab	103.1	ab
11	---	Prosaro 300 mL/ha	Radial 840 mL/ha	---	4.29	ab	99.8	ab
12	---	Prosaro 300 mL/ha	Aviator Xpro 420 mL/ha	Opus 500 mL/ha	4.90	a	114.0	a
13	---	Aviator Xpro 420 mL/ha	Radial 840 mL/ha		4.38	ab	101.8	ab
14	---	Prosaro 300 mL/ha	Radial 420 mL/ha		3.96	bcd	92.1	bcd
15	Systiva	Prosaro 300 mL/ha	Aviator Xpro 420 mL/ha	Opus 500 mL/ha	4.75	a	110.4	a
				Mean	4.3		100.0	
				LSD (P=0.05)	0.72		16.7	
				P-Value	<0.001		<0.001	

Cultivar performance

After a number of years at the top there is now some evidence that newer barley cultivars are coming through that have a higher yield potential than RGT Planet and have greater disease resistance in trials conducted in the SA, Vic and WA HRZ. The screening work conducted in Millicent (Figure 2) as part of FAR Australia's Industry Innovation trial network showed the coded line IGB22102T, now named as Neo, significantly out-yielded Planet (average of 5.73 t/ha vs 5.01 t/ha). This variety has shown a greater resistance to NFNB when compared to RGT Planet although is seen to be more susceptible to leaf rust. Rosalind, the other control variety in this trial, again showed much better NFNB resistance and was also significantly higher yielding (5.69 t/ha) than RGT Planet. It has long been the aim in the HYC project to not only produce high yielding crops but more importantly produce 'hyper profitable' crops. Research completed in the HYC suggests that selection of newly emerged germplasm on farm can not only increase yields, but also reduce the reliance on fungicides and protect fungicide chemistry from the build up of fungicide resistance.

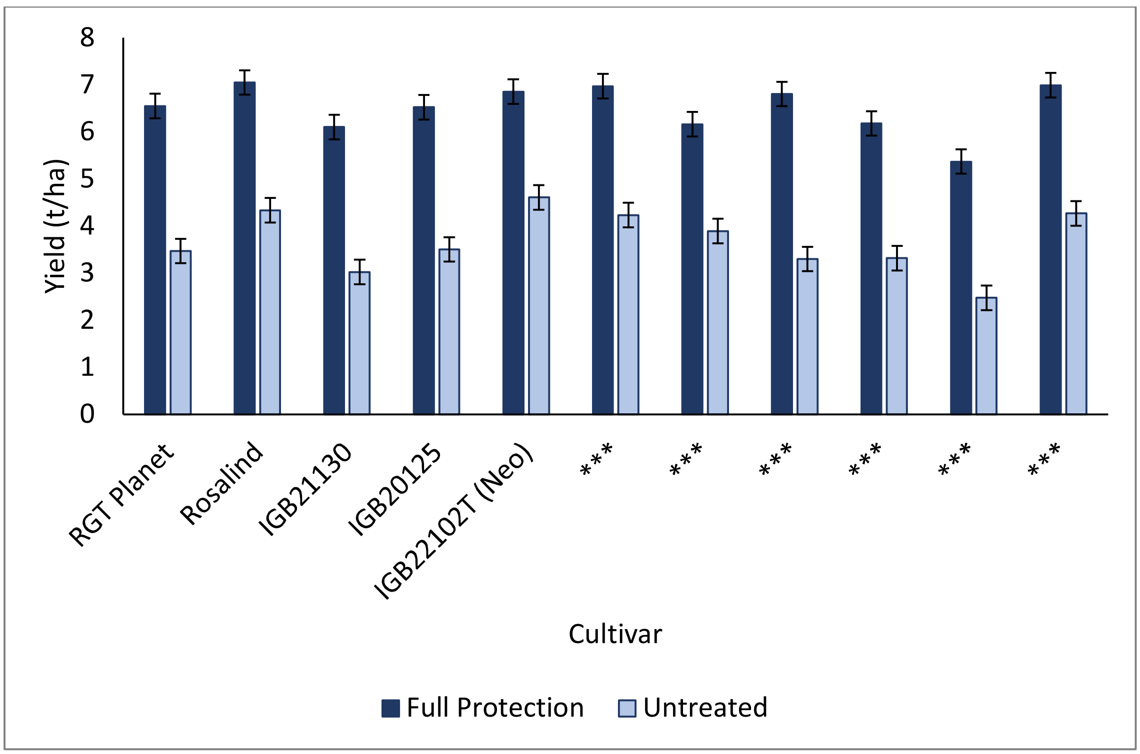

Figure 2. *Interaction between variety and grain yield (t/ha) – 2022 Millicent Barley Germplasm Evaluation Network trial.*
**** - Confidential experimental lines*

Integrated control measures for Septoria tritici blotch (STB) control – role of genetics and fungicides – Millicent, SA

Nick Poole[1], Max Bloomfield[1], Aaron Vague[1], Daniel Bosveld[1], Ben Morris[1], Tom Price[1], Darcy Warren[1]
[1] Field Applied Research (FAR) Australia

Key point summary

- Genetic resistance of the variety is one of the first lines of defence against this wet weather stubble borne disease.
- After three years of screening through the Hyper Yielding Crops (HYC) project and now the Germplasm Evaluation Network (GEN) several red grained feed wheats have shown good genetic resistance to STB.
- Breeding and screening wheats for resistance to this disease should remain a key focus for regions such as the HRZ, since genetic resistance appears to degrade in the field over time as virulence in the pathogen builds up or new pathotypes of other diseases expose weaknesses.
- The varieties that have given the best resistance to STB are Anapurna, RGT Cesario, BigRed, AGFWH004818 (to be released in 2024), Reflection (not commercial), AGTW0005 (to be released in 2024) and the new line AGFWH010222 (currently being evaluated).
- This erosion of genetic resistance has been observed with RGT Cesario and RGT Accroc as the new pathotype of stripe rust has reduced our ability to use less fungicides on these varieties making flutriafol at sowing a key input.
- In mainstream milling wheats which have little resistance to the disease one of the key defences against STB in the region is later sowing which significantly reduces disease pressure.
- Fungicide control of STB should be regarded as the last line of defence as fungicide resistance is a real threat to the sustainability of productivity.
- Research undertaken in 2018 and now in 2023 would indicate that fungicide efficacy against STB is changing in the field with epoxiconazole being less effective against STB than it was historically. Also note STB pathogen resistance to strobilurins (Group 11 QoIs) being identified in the lower SE and Tasmania, although currently we don’t know how widespread it is.
- Historically both prothioconazole and epoxiconazole have been widely used in Europe to combat this disease, but the last two seasons have revealed small differences in performance of these two DMI (Group 3) fungicides with prothioconazole being slightly stronger than epoxiconazole. Note however that for stripe and leaf rust control the reverse is the case and epoxiconazole is stronger than prothioconazole.
- The key message must be to avoid repeating the same active ingredient and for rust and STB scenarios don’t forget cyproconazole present in the mixture Amistar Xtra. This triazole fungicide gets less exposure to the STB and could be alternated

with epoxiconazole and prothioconazole in wheat disease management strategies.

- The future use of Mefentrifulconazole in Revystar (not yet commercialised) will also broaden the pressure put on our Group 3 DMI triazole fungicides.
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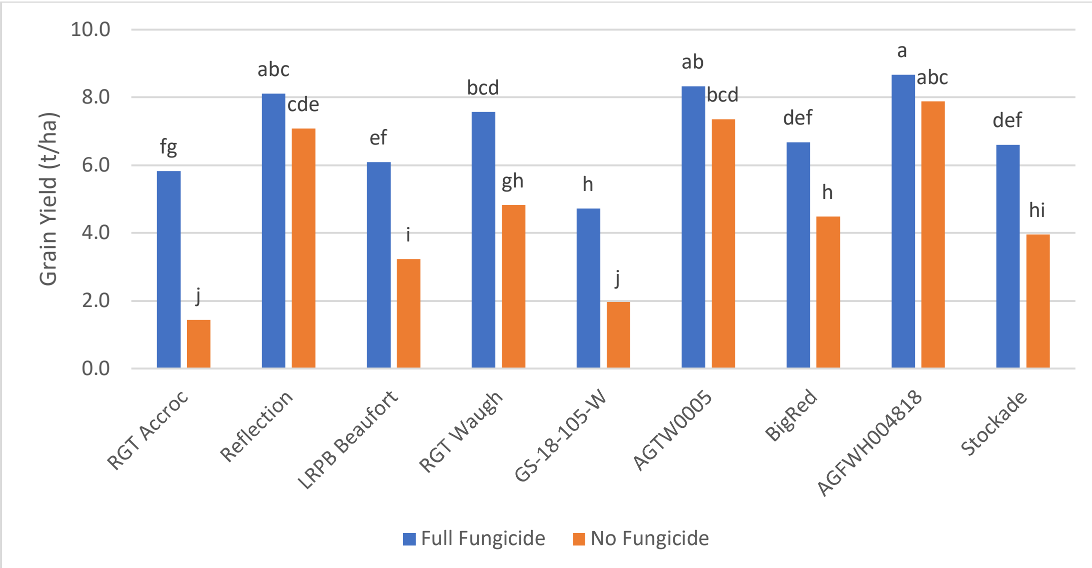

Figure 1. *Grain yield (t/ha) for each variety plus and minus fungicide management (Stripe rust, STB and leaf rust present) – HYC Millicent, SA 2022.*

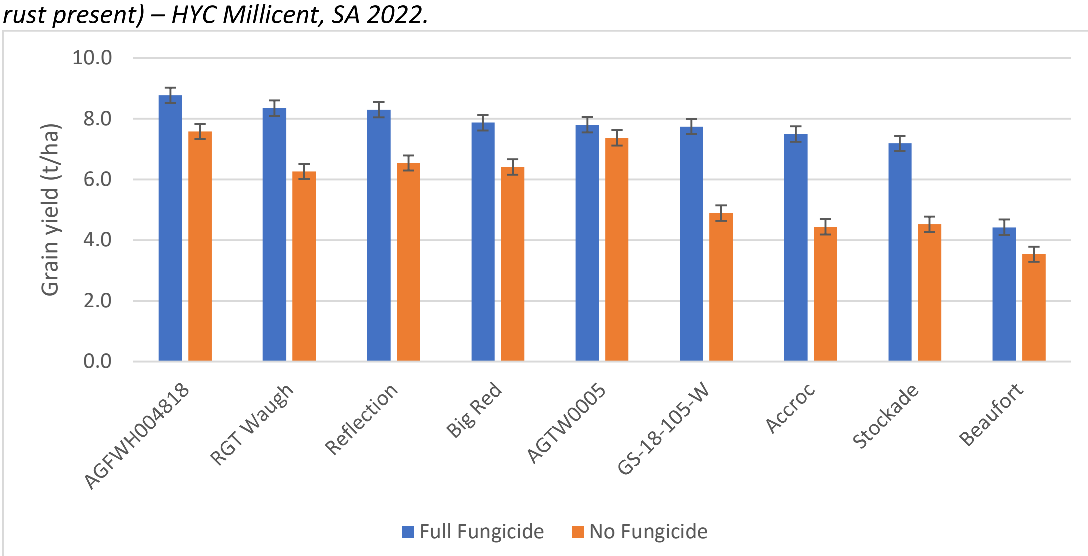

Figure 2. *Grain yield (t/ha) for each variety plus and minus fungicide management (Stripe rust and STB present) – HYC Gnarwarre, VIC 2022.*

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SOWING THE SEED FOR A BRIGHTER FUTURE

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