Department of Primary Industries
Department of Regional NSW

Southern NSW research results 2023

RESEARCH & DEVELOPMENT – INDEPENDENT RESEARCH FOR INDUSTRY

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an initiative of Southern Cropping Systems

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Front cover images: main: maximising the uptake of phosphorus by crops to optimise profit field experiment – Condobolin Agricultural Research and Advisory Station, Nick Moody; inset left: frost exclusion shelters over canola plots on a frosty night to evaluate the effects of frost damage – Wagga Wagga Agricultural Institute, Danielle Malcolm; inset centre: residual herbicide experiment – Leeton Field Station, part of Yanco Agricultural Institute, 2019, Eric Koetz; inset right: lupin and faba bean photoperiod experiment – Wagga Wagga Agricultural Institute, Mark Richards.

Back cover images: inset left: farming systems experiment site – Condobolin Agricultural Research and Advisory Station Field Day 2022, Dr Mehrshad Barary; inset centre: wheat and barley phenology experiments – Dirnaseer NSW, Rick Graham; inset right: pulse experiments – Wagga Wagga Agricultural Institute Field Day, Mark Richards.

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Foreword

NSW Department of Primary Industries (NSW DPI) welcomes you to the Southern NSW research results 2023. This book has been produced to increase awareness of research and development (R&D) activities undertaken by NSW DPI in the southern mixed farming region of NSW. It delivers the outcomes of these activities to our stakeholders including agribusiness, consultants and growers.

This document is a comprehensive, annual report of NSW DPI's R&D activities in southern NSW. The book includes research covering agronomy and physiology, weeds, farming systems, crop protection, water and irrigation in southern NSW.

NSW DPI, in collaboration with our major investment partner the Grains Research and Development Corporation (GRDC), is at the forefront of agricultural research in southern NSW and the largest research organisation in Australia. Our R&D teams conduct applied, scientifically sound, independent research to advance the profitability and sustainability of our farming systems.

The Department's major research centres in the southern region of NSW are Wagga Wagga, Yanco and Condobolin where our team of highly reputable research and development officers and technical staff are based. The regional geographic spread of the research centres allows for experiments to be replicated across high, medium and low rainfall zones with Yanco providing the opportunity to conduct irrigated experiments.

NSW DPI's research program includes the areas of:

- plant germplasm improvement
- agronomy and crop management
- plant product quality and market access
- productive and sustainable use of soil
- productive and sustainable use of water
- integrated pest management within production systems
- livestock genetic improvement
- integrated weed management
- animal productivity and value chain efficiency and meat quality
- intensive livestock industries
- feedbase productivity
- drought preparedness, response and recovery
- climate adaptation
- climate mitigation
- agriculture landuse planning
- energy solutions.

The following papers provide an insight into selected R&D activities taking place in the southern region. We hope you will find them interesting and valuable to your farming system or the farming system clients you work with.

Special thanks to all the authors and editorial officers for their willingness to contribute to this publication and I acknowledge the effort in reviewing the diverse range of papers.

We acknowledge the many collaborators (growers, agribusiness and consultants) that make this research possible. We encourage feedback to help us improve future editions.

Deb Slinger
Director Southern Cropping
On behalf of the Southern Research and Development Teams
NSW Department of Primary Industries

Contents

Seasonal conditions 2022

Kim Broadfoot[1], Dr Kurt Lindbeck[2], Andrew Carmichael[2], Dr Andrew Milgate[2], Brad Baxter[2] and Dr Mehrshad Barary[3]

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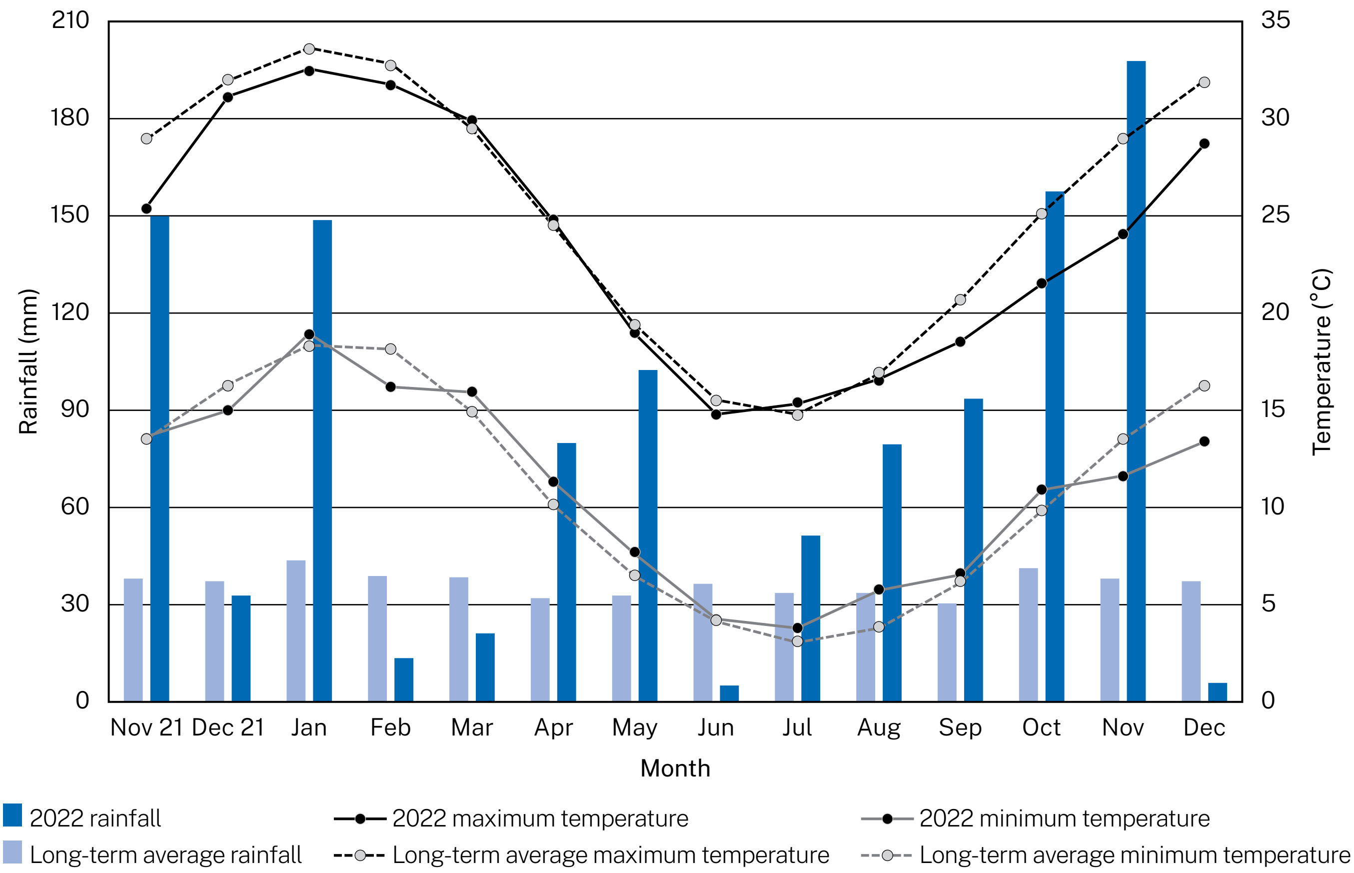
Climate summary

Condobolin Agricultural Research and Advisory Station

Minimum temperatures at Condobolin were generally above the long-term monthly average (LTA) for most of 2022 (Figure 1). February, November and December were exceptions with minimum temperatures being below the LTA. Maximum temperatures were generally near average to below the LTA during 2022. The maximum temperature for the summer fallow period was on average 1 °C lower than average and 1.1 °C lower than the average for the growing season.

There was average to above average rainfall in the early fallow period (November 2021 to January 2022), with more than 3 times the monthly average rainfall in November 2021 and January 2022. Below average rainfall was received in February and March. The remainder of the year had above average rainfall, with June and December being exceptions.



Source: SILO (Scientific Information for Land Owners) Patched Point Data, Queensland Government from station 50052, Condobolin Agricultural Research Station.

Figure 1 Average monthly minimum and maximum temperature, and total monthly rainfall in 2022, and long-term averages at Condobolin, including the November and December 2021 summer fallow period.

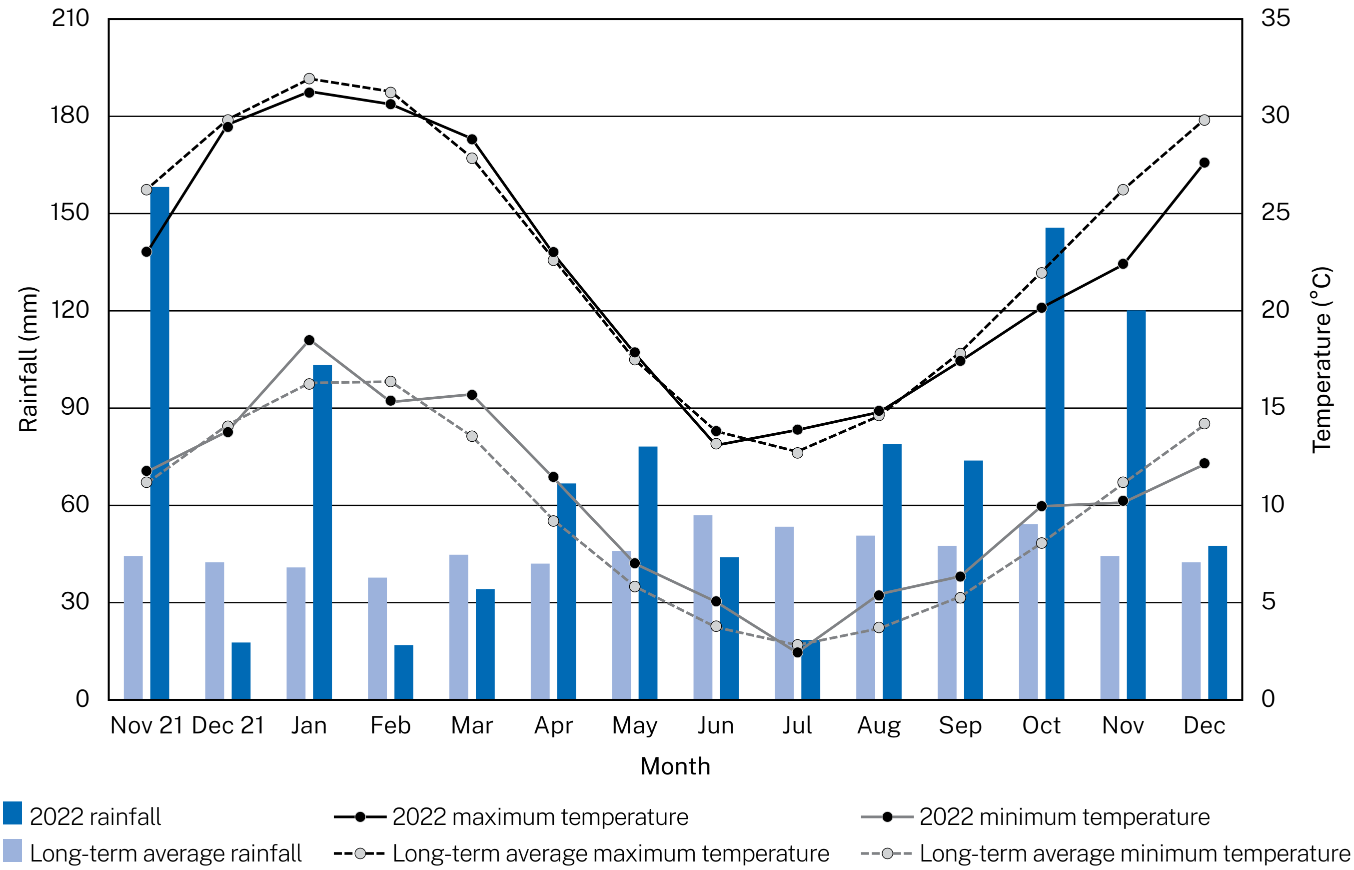
The combination of a full soil moisture profile and very high growing season rainfall meant crop yield was not water limited at Condobolin in the 2022 season. Too much in-crop rainfall was the biggest problem with waterlogging and its associated issues affecting research experiments. Waterlogged low-lying areas in experiments affected plant establishment, causing some plots to be resown at the site. Additional paddock flooding later in the season caused difficulty for field activities such as spraying and biomass cuts.

Pulse crops suffered in the cold and wet conditions, especially during the reproductive growth stage, resulting in chickpea and field pea producing little or no grain yield. With the wet and mild conditions all crops (especially chickpea) were sprayed for diseases and pests more than in past seasons.

The wet conditions at harvest time delayed machine harvest for some experiments. Nevertheless, cereals and canola produced high grain yield with acceptable quality, particularly when they were sown earlier.

Wagga Wagga Agricultural Institute

Minimum temperatures at Wagga Wagga were generally near to or above the LTA during 2022 (Figure 2). February, November and December were exceptions where minimum temperatures were between 1 °C and 2 °C cooler than the LTA. After a cool start in November 2021 the maximum temperatures during the 2021–22 fallow period were close to the average LTA. Maximum temperatures during the growing season were close to the LTA except for July which was 1 °C warmer than the LTA. The September to December period remained much cooler, prolonging the conditions favourable for increased chance of foliar disease.



Source: SILO (Scientific Information for Land Owners) Patched Point Data, Queensland Government from station 72150, Wagga Wagga Airport.

Figure 2 Average monthly minimum and maximum temperature, and total monthly rainfall in 2022, and long-term averages at Wagga Wagga, including the November and December 2021 summer fallow period.

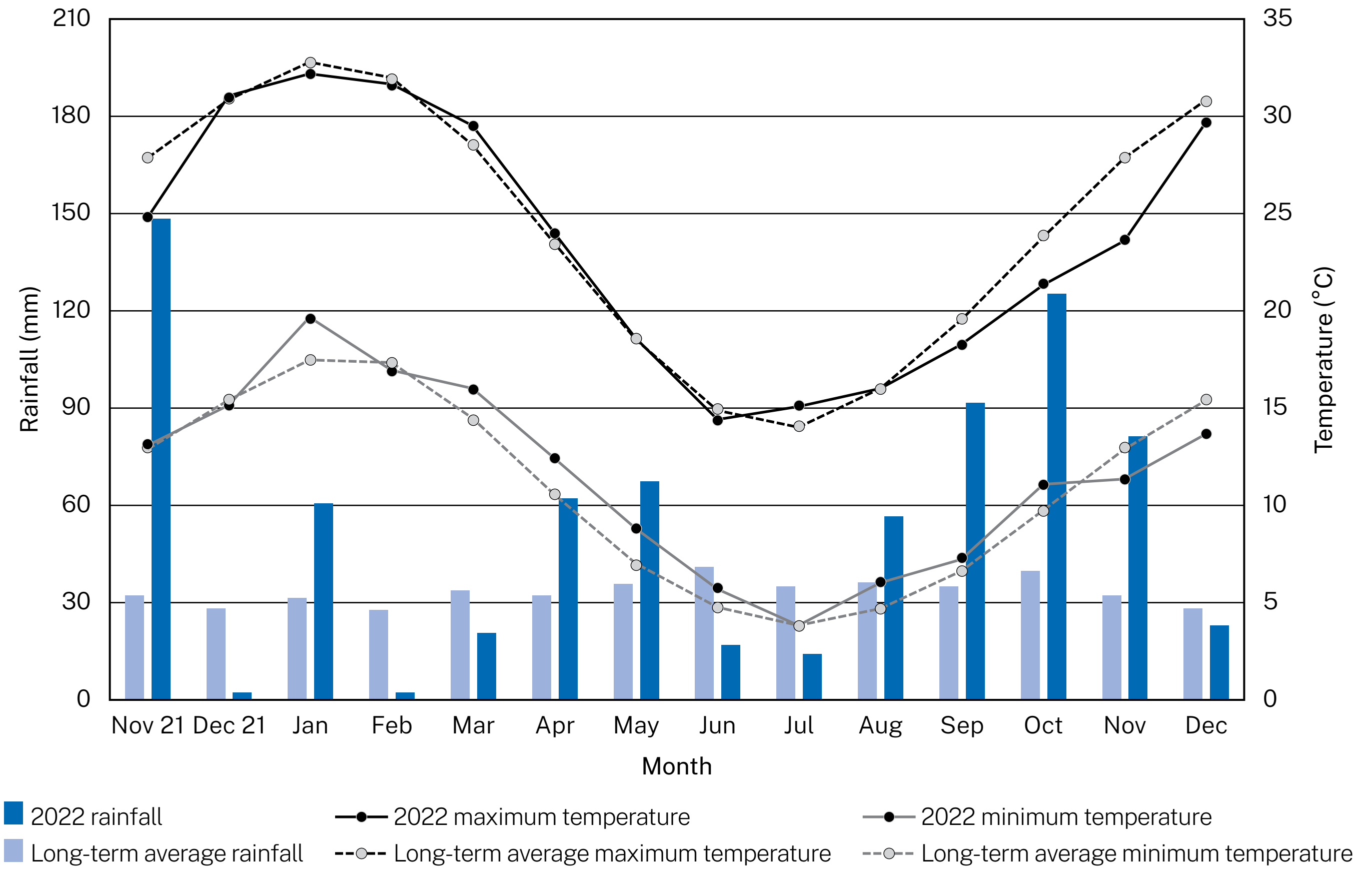
There was above average rainfall in the early fallow period (November 2021 and January 2022), with more than 3 times the monthly average rainfall in November 2021 and more than twice the LTA in January 2022. Below average rainfall was received in December 2021 and February 2022. The remainder of the year had above average rainfall, with June and July being exceptions.

High in-crop rainfall did cause some waterlogging, which affected experiment yields in lower lying paddock areas. Fortunately, the soil dried out sufficiently for plot harvesters to access paddocks, allowing harvest operations to start without ongoing problems.

Wheat protein levels were lower than normally achieved, which could be due to prolonged waterlogging resulting in soil nitrogen denitrification and protein dilution from high yields. Crops with high levels of disease incidence such as stripe rust and septoria tritici blotch (STB) lost leaf area from disease infection, which affected the ability of wheat crops to fill grain, with crops having higher screenings.

Yanco Agricultural Institute

Minimum temperatures at Yanco were generally near to or above the LTA during 2022 (Figure 3). November and December were exceptions where minimum temperatures were more than 1 °C cooler than the LTA. After a cool start in November 2021 the maximum temperatures during the 2021–22 fallow period were close to the LTA. Maximum temperatures during the growing season were close to the LTA from May to August and below the LTA during September and October.



Source: SILO (Scientific Information for Land Owners) Patched Point Data, Queensland Government from station 74037, Yanco Agricultural Institute.

Figure 3 Average monthly minimum and maximum temperature, and total monthly rainfall in 2022, and long-term averages at Yanco, including the November and December 2021 summer fallow period.

There was above average rainfall in the early fallow period (November 2021 and January 2022), with more than 3 times the monthly average rainfall in November 2021. Well below average rainfall was received in December 2021 and February 2022. The remainder of the year had above average rainfall, with June, July and December being exceptions.

The season was challenging for winter and summer crops at Yanco, with the wet weather at sowing, high in-crop rainfall, wet harvest period and flooding in some areas, making it a difficult year.

Winter cereal yields were generally ideal, but chickpea in particular had significant pod ghosting (seedless pods) from mild temperatures at flowering and therefore a reduced yield. Diseases were very active in all crops and additional fungicide applications were required for protection.

Summer crops had a challenging time establishing and were behind in their development from the mild spring temperatures. The hotter December helped plant growth but, yield potential was lost. All summer crop yields were down and later-sown crops suffered higher yield penalties.

Disease

Winter cereals

Disease management was challenging in 2022 with the wet conditions ideal for cereal diseases to develop and spread. Disease management was a significant concern for growers and advisors as paddock trafficability was limited through critical periods. Despite these challenges, crops well-managed for disease achieved high yields and economic returns.

Disease management was a factor for crops that did not meet their predicted yield potential, as well as limited nutrition and environmental factors such as waterlogging. The yield loss was mainly a result of pinched or aborted grains in the heads.

Heavy rainfall and trafficability issues delayed sowing in many areas, with seed germinating in cold, waterlogged soils. These conditions were not favourable for quick root development, which enables root systems to move below the bands of *Pythium* and *Rhizoctonia* in the soil. Early infections by these diseases, along with take-all and fusarium crown rot (FCR), compromised root systems, limiting root and vegetative growth. This was more evident in cereal-on-cereal rotations and disc seeding systems.

The series of disease-conducive cropping seasons and wet summers enabled disease inoculum to build-up to very high levels by the time of sowing in 2022. High inoculum loads, combined with prolonged cooler temperatures, rainfall and humidity placed cereal crops under enormous early disease pressure, particularly from foliar diseases.

Septoria tritici blotch was particularly devastating to wheat crops in the high to medium rainfall zone of southern NSW that were not protected by fungicide. Due to inoculum build up from previous seasons and optimal seasonal conditions, STB became a serious issue in regions where it does not usually pose a threat to yield. In these areas, varieties that were rated as more resistant to stripe rust but more susceptible to STB (e.g. Beckom⟨D⟩), were adversely affected due to reduced fungicide use in these crops, which was targeted at stripe rust. In some cases, STB still reduced yield in crops that were protected by 1–2 fungicide applications, highlighting that fungicide choice and timing is important for STB control.

In addition, paddock trafficability issues with ground application or availability of aerial application, delayed or prevented fungicide applications in some regions. This generally resulted in increased disease levels in unprotected susceptible varieties with significant loss of green leaf.

The combination of:

- waterlogging (shut down plant functions)
- compromised root systems (*Pythium* and *Rhizoctonia*)
- partially or fully blocked vascular systems (FCR and take-all)
- significant loss of green leaf area (foliar diseases)
- head diseases (fusarium head blight)
- lower than average solar radiation for southern NSW (reduced carbohydrate and protein transportation)

all potentially influenced abortion and pinching of grains to varying degrees leading to reduced yield, high screenings and quality downgrades in 2022.

Winter pulse and oilseed

Climatic conditions in 2022 brought mixed fortunes across central and southern NSW. These conditions resulted in a range of biotic and abiotic stresses being placed upon pulse and oilseed crops during the growing season. Ideal autumn rains allowed crops to be sown on time and into high soil moisture levels across the region. Early reports and detections of virus within crops were made in May and June, due to high aphid activity in some districts.

Winter rainfall was below average in June and July, but crop growth remained steady with few frosts recorded. Blackleg appeared in canola crops at the end of May to early June, which is typical for the time of year. Crop surveys that started in late August detected blackleg in virtually every canola crop assessed in southern NSW, and sclerotinia in 30% of crops. Above average rain from late August to November drove foliar disease development across all crops, especially:

- chocolate spot of faba bean
- sclerotinia disease across all broadleaf crops
- blackspot disease of field pea
- botrytis grey mould of lupin, lentil and chickpea.

Applying foliar fungicides to manage disease was a challenge due to untrafficable paddocks, limited suitable spray days and access to aircraft. Continued wet conditions resulted in some crops needing multiple fungicide applications. In some regions, saturated soils and waterlogging affected crop growth and potential grain yield.

Late rain during pod set and early harvest favoured alternaria and blackleg infection on canola, which resulted in some grain quality issues at delivery. High levels of sclerotinia infection in crops in 2022 has the potential to affect crops for the next few seasons as sclerotia can survive in soils for several years. The high disease levels observed in 2022 were a result of 3 favourable seasons in a row, with high pathogen inoculum levels and a favourable growing environment combining to produce epidemic conditions within crops.

Acknowledgements Thank you to Peter Matthews, NSW DPI Orange for technical review.

Seasonal Conditions Monitoring Program

State Seasonal Update: Conditions & Outlook

The **State Seasonal Update** is produced monthly and is the official point of reference of seasonal conditions across NSW for producers, government, stakeholders and the public.

Combined Drought Indicator: Latest NSW Drought Maps

Is an interactive tool that provides a snapshot of current seasonal conditions for NSW, factoring in rainfall, soil moisture and pasture/crop growth indices.

Seasonal Conditions Information Portal

Uses a technology that allows fast, stable transfer of data and information direct from the EDIS system to your computer. The portal contains several downloadable features from the **NSW Combined Drought Indicator.**

Farm Tracker Mobile Application

Farm Tracker is a tool you can use to record seasonal conditions. You can:

1. Complete a simple crop, pasture or animal survey
2. Keep and manage a photo diary of your farm
3. Monitor the same paddock over many years

Have your say

Complete this survey and tell us what is important to you as DPI continues to improve our Seasonal Conditions monitoring program. Eg. improved local accuracy of data and climate networks, better ways of communicating, or strengthening linkages to drought management and relief measures.

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Farm Tracker Mobile Application

Seasonal Conditions Monitoring Program

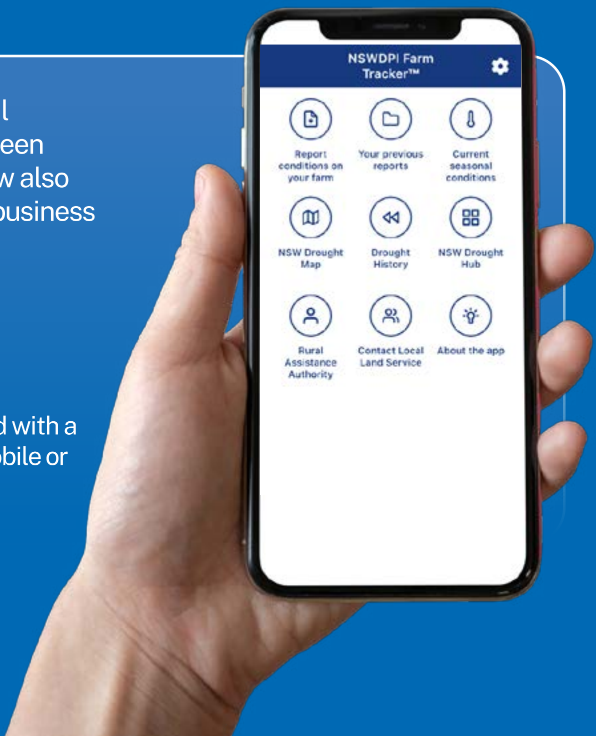
Farm Tracker is a simple tool you can use to help monitor seasonal conditions on your property. An upgraded version of the app has been released that now allows you to not only record conditions, but now also links users with other resources that may be useful to help make business decisions.

Farm Tracker allows you to:

- Complete a simple crop, pasture or animal survey
- Keep and manage a photo diary of your farm so you can monitor the same paddock over many years
- Reports can be completed in a few minutes and they are synchronised with a personal database as well as the statewide database when within mobile or wi-fi range.

The app connects you to other useful Government services like:

- The NSW Combined Drought Indicator map
- The monthly NSW State Seasonal Update
- NSW DroughtHub
- Local Land Services
- Rural Aisststance Authority



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Improving farming systems profitability in southern and central NSW – Condobolin 2022

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[3] CSIRO, Canberra

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Key findings

- Despite the wet and cold weather in 2022, all crops produced high grain yields in various cropping systems, except for the pulses.
- Chickpea produced very high vegetative growth, but failed to produce yield due to prolonged cold and wet growing season conditions. Field pea also suffered from the growing conditions, producing high biomass and a low grain yield.
- Barley produced the highest grain yield with a decile 2 nitrogen (N) strategy under the baseline cropping system (canola-wheat-barley) relative to all other crops and systems.
- The highest grain yield for timely sown wheat (Scepter⟮D⟯) was 7.4 t/ha produced under the intense baseline cropping system (canola–wheat) with a decile 7 N strategy.

Keywords 2022, Condobolin, farming system, profitability, crop sequence, nitrogen, sowing date, nitrogen management, diversity, red chromosol

Introduction

This experiment was conducted at the Condobolin Agricultural Research and Advisory Station (CARAS), Condobolin NSW in 2022 for the fifth year as part of the 'Improving farming systems efficiency in southern NSW' project.

The main goal of this project is to develop strategies to convert rainfall into more profit across various crop sequences, while managing soil fertility, weeds, diseases, and input costs. The key strategies under investigation include increasing farming system diversity, sowing early and improved nitrogen management.

Site details

Location	CARAS, Condobolin
Soil type	Red chromosol
Growing conditions	• Summer rainfall (December 2021 – March 2022): 216.2 mm • In-crop rainfall (April–October): 778.9 mm • Average minimum temperature ($T_{min.}$): 2.5 °C • Average maximum temperature ($T_{max.}$): 23.1 °C.

- Abiotic stresses (April–November): 6 frosts (−2.9 to 0.1 °C) between June and August and several waterlogging events between September and November 2022 for the whole site

Agronomic practice

Table 1 details the treatments and agronomic practices at Condobolin in 2022. Early crops are typically sown between 7 April and 21 April, and timely crops are sown after 24 April. The flexible cropping system treatment was recommended by the local consultant.

Table 1 Agronomic practices at Condobolin in 2022.

Crop	Cultivar	Sowing date	Harvest date	Target plant density (plants/m²)	Row spacing (cm)
Early wheat	Illabo⁽ᵇ⁾	13 Apr	23 Nov	120	30
Timely wheat	Scepter⁽ᵇ⁾	9 May	23 Nov	150	30
Early canola	SF Ignite TT	13 Apr	4 Nov	40	30
Timely canola	InVigor® T4510	10 May	8 Nov	40	30
Chickpea	CBA Captain⁽ᵇ⁾	10 May	9 Dec	40	30
Field pea	PBA Taylor⁽ᵇ⁾	15 Jun	28 Nov	55	30
Flexible	InVigor® T4510	10 May	8 Nov	40	30
Barley	LaTrobe⁽ᵇ⁾	9 May	23 Nov	115	30
Vetch	Timok⁽ᵇ⁾	13 Apr	20 Sep (brown manured)	40	30

Treatments

Table 2 details the experiment treatments for each cropping system at Condobolin in 2022. Treatments are a combination of crop/variety sequence, sowing time and N strategy. The flexible cropping system treatment was recommended by the local consultant.

The 2 nitrogen strategies (decile 2 N and decile 7 N) are determined each season by taking into account the starting soil water and N, modelling the crop using APSIM up until top dress timing (June/July), predicting 2 different rainfall outlooks (decile 2 and 7) for the remainder of the season and applying N fertiliser to target these outlooks/yield targets.

Table 2 Treatment detail at Condobolin in 2022.

Cropping system	Treatment description		
	Crop sequence	Sowing time	Nitrogen strategy
Baseline	canola–wheat–barley	timely	decile 2
Intense baseline (IntBase)	canola–wheat	timely	decile 2 and decile 7
Diverse high value 1 (DivHV1)	canola–wheat–chickpea	timely and early	decile 2
Diverse low value (DivLV)	canola–wheat–field pea (lupin)*	timely	decile 2
Diverse mixed (DivMix)	canola–wheat–vetch	timely	decile 2
Diverse high value 2	chickpea–wheat	timely	decile 2
Flexible (flex)	flexible	flexible	flexible
Fallow	canola–wheat–fallow	timely and early	decile 7

* Lupin was replaced by field pea due to poor establishment caused by waterlogging.

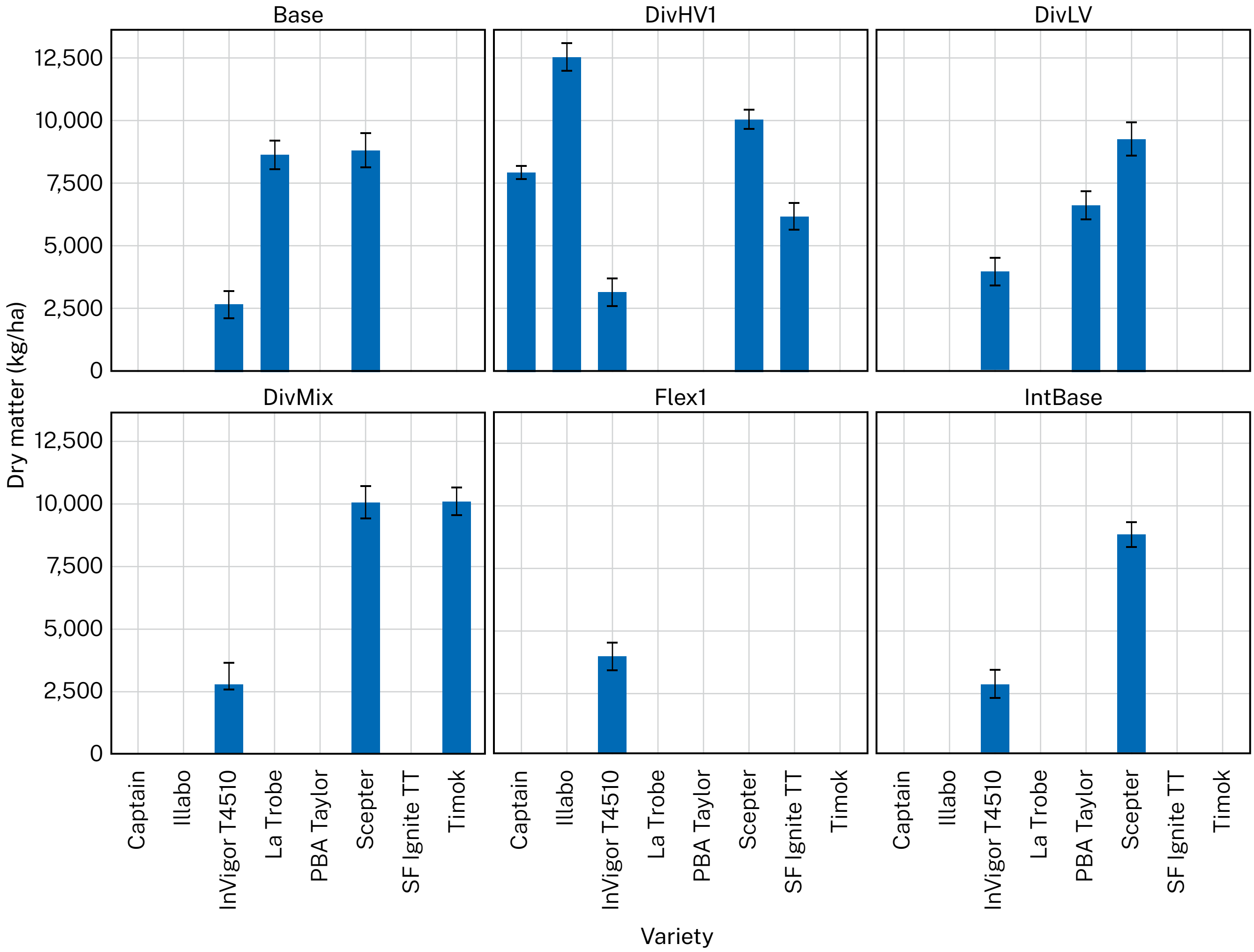
Results

Biomass (dry matter)

Dry matter (DM) was measured at different growth stages depending on the crop type. Dry matter varied significantly across different crops and treatments (Figure 1).

In the decile 2 N strategy, early wheat (Illabo⚹) produced the highest amount of DM (12.5 t/ha) compared with timely wheat and barley. Timely wheat (Scepter⚹) produced more DM in the crop sequences with pulses compared with other cropping systems without pulses, such as intense baseline and baseline, both with a decile 2 N strategy. Timely canola (InVigor® T4510) also produced higher DM in cropping systems that included pulses (Figure 1). Early canola (SF Ignite TT) produced higher DM than timely canola, an effect related to variety and earlier sowing time (Figure 1).

Early wheat produced the highest DM across crops and sowing time under the fallow system with the decile 7 N strategy. Timely canola produced a similar amount of DM in both the fallow and intense baseline systems, whereas timely wheat had higher DM under the fallow system compared with the intense baseline system (Figure 2).



Cropping systems: Base = baseline, DivHV1 = diverse high value 1, DivLV = diverse low value, DivMix = diverse mixed, Flex1 = flexible, IntBase = intense baseline.

Figure 1 Dry matter at 20–30% bloom for canola (GS62–63), at anthesis for cereals (GS61) and peak biomass (mid podding) for pulses for the decile 2 N strategy treatment in different cropping systems at Condobolin in 2022.

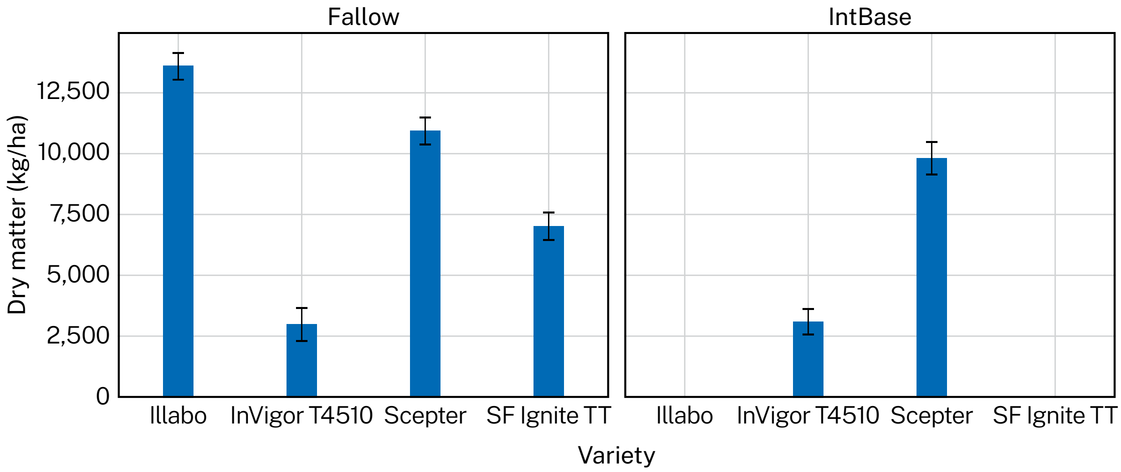


Figure 2 Dry matter at 20–30% bloom for canola (GS62–63) and at anthesis for cereals (GS61) with a decile 7 N strategy under fallow and intense baseline systems (IntBase) at Condobolin in 2022.

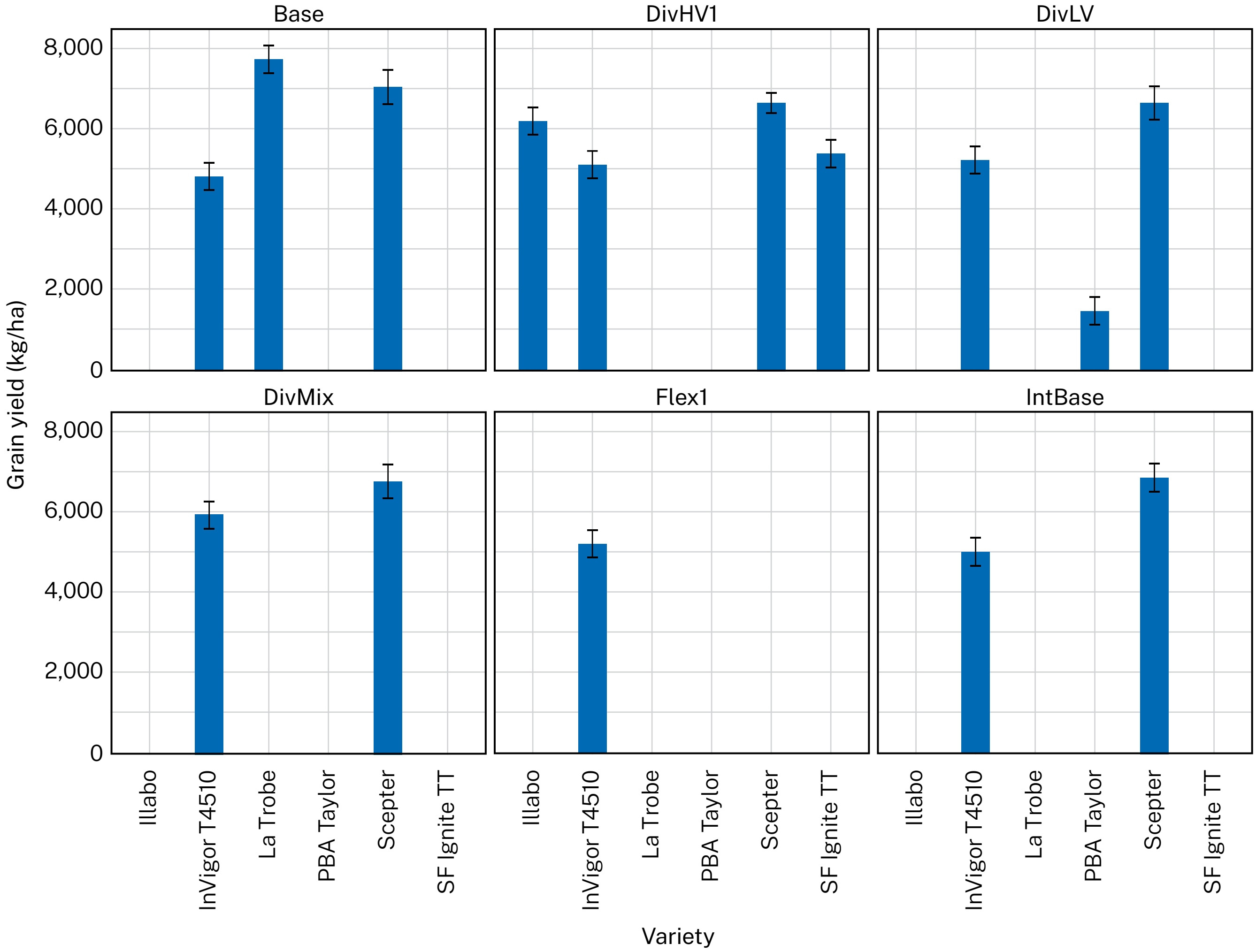
Grain yield and harvest index (HI)

Grain yield varied significantly across different systems and treatments. Barley (La Trobe⁽ᵇ⁾) had the highest grain yield (7.7 t/ha) in the baseline system (timely sowing, decile 2 N strategy) compared with other crops and cropping systems. The highest decile 2 N timely wheat grain yields were under the baseline system (7 t/ha), however, this yield was not significantly (P = 0.05) different to other systems with a decile 2 N strategy (Figure 3).

Despite having a high dry matter for both chickpea and field pea crops, chickpea had very low grain yield, while field pea only produced about 1.5 t/ha of grain.

Timely wheat with a decile 7 N strategy produced 7.4 t/ha grain yield under the intense baseline system compared with 7.1 t/ha under the fallow system. There was no significant difference between timely canola under the intense baseline and fallow systems (Figure 4).

Under the intense baseline system, increasing N from decile 2 to decile 7 resulted in a greater increase in grain yield for timely wheat than timely canola (Figure 5). Harvest index decreased for both timely wheat and timely canola when N was increased from decile 2 to decile 7 (Figure 6).



Cropping systems: Base = baseline, DivHV1 = diverse high value 1, DivLV = diverse low value, DivMix = diverse mixed, Flex1 = flexible, IntBase = intense baseline.

Figure 3 The grain yield of different cropping systems and varieties with a decile 2 N strategy at Condobolin in 2022.

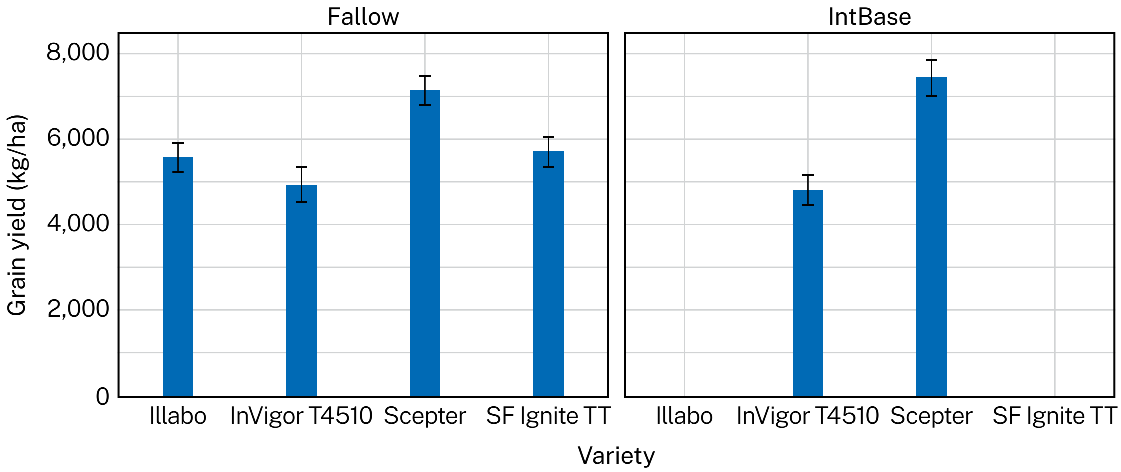


Figure 4 Grain yield for fallow and intense baseline (IntBase) cropping systems and varieties with a decile 7 N strategy at Condobolin in 2022.

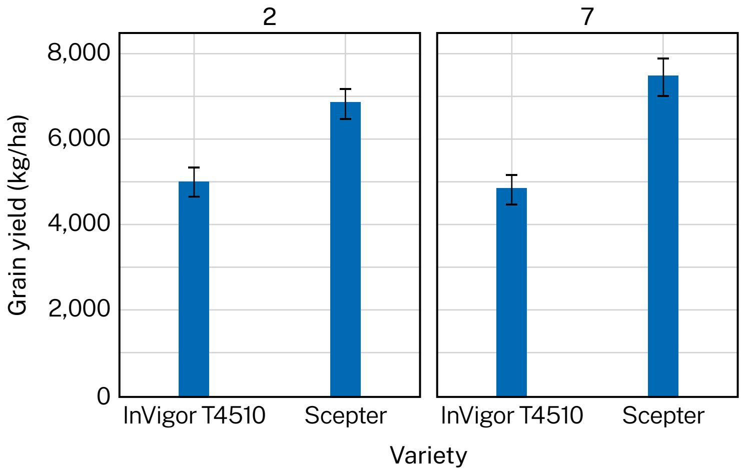


Figure 5 Grain yield of timely wheat and timely canola under the intense baseline system with decile 2 N strategy and decile 7 N strategy at Condobolin in 2022.

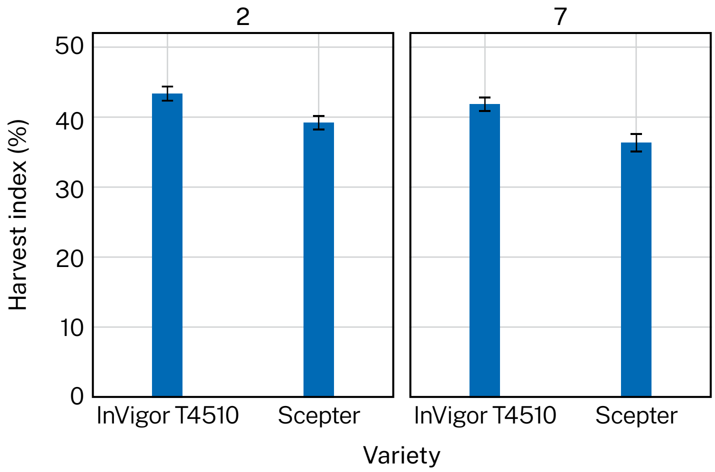


Figure 6 Harvest index for timely canola and timely wheat under the intense baseline cropping system with decile 2 N strategy and decile 7 N strategy at Condobolin in 2022.

Grain quality

Grain quality differed across cropping rotations, varieties and treatments (Table 3). Grain protein increased with increased N application rate, decile 7 compared with decile 2, in both early and timely wheat across different cropping systems ranging from 11.8% to 13.5%.

Canola seed oil content varied from 41.8% to 44% across varieties, treatments and cropping systems. The flexible system (wheat–lupin–canola) with a decile 2 N strategy had the highest seed oil percentage.

Thousand grain weight (TGW) for wheat was higher in the cropping systems with legumes included and a decile 2 N strategy compared with other systems and a decile 7 N strategy (Table 3).

Summary

All crops produced high dry matter compared with previous growing seasons. Despite the wet and cold growing season, canola and cereals showed robust grain yield, with no adverse effects on grain quality from these weather conditions. Canola responded differently to cropping systems treatments, such as N strategy, compared with cereals. Barley grain yield was higher than early and timely wheat under the intense base system. Grain quality (grain protein and oil content) varied with different cropping systems and mainly with N management. In cereals, protein content was more responsive to N strategies, compared with cropping sequences. Including pulses in the system did not significantly change the oil and protein content of canola seed.

Table 3 Grain quality for different crops, treatments and cropping systems*.

Crop	Variety	Sowing time	N decile strategy	Cropping system	Grain protein (%)	Seed oil (%)	TGW (g)
Wheat	Illabo	Early	2	DivHv1	11.8 (0.17)	–	36.5 (0.65)
			7	Fallow	13.5 (0.17)	–	32.6 (0.65)
	Scepter	Timely	2	Base	12.1 (0.21)	–	49.8 (0.80)
			2	DivHV1	11.9 (0.12)	–	49.9 (0.46)
			2	DivLV	12.1 (0.21)	–	49.7 (0.80)
			2	DivMix	12.1 (0.21)	–	49.8 (0.80)
			7	Fallow	12.1 (0.17)	–	48.7 (0.65)
			2	IntBase	12.2 (0.17)	–	50.5 (0.65)
			7	IntBase	12.6 (0.21)	–	48.2 (0.80)
Barley	LaTrobe	Timely	2	Base	11.0 (0.17)	–	37.5 (0.65)
Canola	SF Ignite TT	Early	2	DivHV1	21.0 (0.25)	41.8 (0.35)	–
			7	Fallow	21.5 (0.25)	42.1 (0.35)	–
	InVigor T4510	Timely	2	Base	20.3 (0.25)	41.9 (0.35)	–
			2	DivHV1	20.9 (0.25)	42.8 (0.35)	–
			2	DivLV	20.5 (0.25)	42.4 (0.35)	–
			2	DivMix	20.1 (0.25)	43.4 (0.35)	–
			7	Fallow	20.8 (0.25)	42.3 (0.42)	–
			2	Flex	19.3 (0.25)	44.0 (0.35)	–
			2	IntBase	20.5 (0.25)	43.0 (0.35)	–
			7	IntBase	21.1 (0.25)	42.4 (0.35)	–

* The values in parentheses are standard error. TWG = thousand grain weight.

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Influence of sowing date on wheat phenology and grain yield – Cudal 2020

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Key findings

- The 2020 mild spring temperatures and above average seasonal rainfall provided optimal conditions for crop growth and development, resulting in very high grain yields: >9 t/ha.
- Current genotypes were not broadly adapted across all sowing dates from mid April to early June. The highest grain yields were achieved when phenology was matched to sowing date (SD), to ensure flowering was achieved within the optimal period. In 2020, there was a significant yield penalty in quick developing spring types sown early, which were affected by frost.
- In 2020, the highest yields were achieved by slower developing winter and spring types.

Keywords Wheat, phenology, grain yield, variety, sowing date

Introduction

In 2020, field experiments were conducted across 4 locations in NSW: Harefield, Cudal, Narrabri and Wongarbon, targeting high grain yield potentials to determine differences in phenology and grain yield responses to sowing date for a diverse set of 36 wheat genotypes. This paper presents results from the Cudal site (central eastern NSW).

Site details

Location	Bowenfells, Cudal NSW
Soil type	Red–brown chromosol
Previous crop	Lucerne pasture
Sowing	• The site was pre-worked to remove residual lucerne plants from fallow spray treatment and pre-sowing phosphorus and nitrogen fertiliser application. • Sown with Horwood Bagshaw seeding units, spaced at 220 mm using a GPS auto-steer system. • Target plant density: 160 plants/m^2
Pre-irrigation	27 mm applied via sprinkler (12 March)

Soil pH_{Ca}	5.3 (0–10 cm); 5.2 (10–30 cm); 6.3 (30–60 cm); 6.4 (60–90 cm); 6.4 (90–120 cm); 6.7 (120–150 cm)
Soil nitrogen (N)	Mineral N at sowing (1.5 m depth) – 254 kg N/ha
Fertiliser	• 100 kg/ha mono-ammonium phosphate (MAP) (pre-sowing) • 100 kg/ha urea (pre-sowing) • 100 kg/ha MAP (sowing) • 100 kg/ha urea (sowing) • 100 kg/ha urea (24 July) • Stoller liquid fertiliser 6 L/ha
Weed control	Knockdown • Glyphosate (450 g/L) 2.0 L/ha • Spray.Seed® 250 (135 g/L paraquat + 115 g/L diquat) 2.0 L/ha Pre-emergent • Avadex® Xtra (500 g/L triallate) 1.6 L/ha + TriflurX® (480 g/L trifluralin) 1.6 L/ha + Boxer Gold® (800 g/L prosulfocarb + 120 g/L s-metolachlor) 2.5 L/ha (pre-sowing – SD1: 20 April; SD2: 8 May; SD3: 1 June) In-crop • Axial®100 EC (100 g/L pinoxaden + 25g/L cloquintocet-mexyl) 300 mL/ha + Lontrel® Advanced (600 g/L clopyralid) 100 mL/ha + Precept® (125 g/L MSPA + 25 g/L pyrasulfotole) 1 L/ha + Adigor® 500 mL per 100 L water (1 June) • Estercide® Xtra 680 (680 g/L 2,4-D) 1.2 L/ha (23 October)
Disease management	Seed treatment • Hombre® Ultra 200 mL/100 kg Fertiliser treatment • Flutriafol (250 g/L) 400 mL/ha In-crop foliar fungicides • Cogito™ 300 mL/ha (1 June) • Prosaro® 420 SC 300 mL/ha + BS1000 250 mL per 100 L water (7 August) • Aviator® Xpro® 500 mL/ha (4 September) • Prosaro® 420 SC 300 mL/ha + BS1000 250 mL per 100 L water (6 October)
Rainfall	• In-crop (April–November): 601 mm • Long-term average: 406 mm
Severe temperature events	• Eleven frosts (days <0 °C) during the critical reproductive period (6 July – 27 September), including one severe event on 4 August (–2.4 °C).

Cereals

- Nine heat stress events (days >30 °C) during the grain filling period, including 3 severe events (>35°C) on 20 November, 27 November, 30 November.

Harvest date	11 December 2020

Treatments

Genotype

Thirty-six wheat genotypes (Table 1), varying in phenology.

Sowing date

- SD1: 20 April 2020
- SD2: 8 May 2020
- SD3: 1 June 2020

Table 1 Expected relative phenology response groupings for wheat genotypes included in the 2020 experiment.

Phenology	Groupings	Genotypes
Winter	Slow	Manning$^{\phi}$, RGT Accroc$^{\phi}$
	Mid–slow	DS Bennett$^{\phi}$
	Mid	EGA Wedgetail$^{\phi}$, LongReach Kittyhawk$^{\phi}$
	Fast	Longsword$^{\phi}$
Spring	Very slow	EGA Eaglehawk$^{\phi}$, LongReach Nighthawk$^{\phi}$, Sunlamb$^{\phi}$, Sunmax$^{\phi}$
	Slow	Cutlass$^{\phi}$, RGT Zanzibar
	Mid–slow	Catapult$^{\phi}$, Coolah$^{\phi}$, DS Pascal$^{\phi}$, EGA Gregory$^{\phi}$, LongReach Lancer$^{\phi}$, LongReach Trojan$^{\phi}$, Mitch$^{\phi}$, Rockstar$^{\phi}$
	Mid	Beckom$^{\phi}$, Janz, Sunvale
	Mid–fast	LongReach Reliant$^{\phi}$, Suntop$^{\phi}$
	Fast	Corack$^{\phi}$, LongReach Hellfire$^{\phi}$, LongReach Mustang$^{\phi}$, LongReach Spitfire$^{\phi}$, Mace$^{\phi}$, Scepter$^{\phi}$, Sunprime$^{\phi}$
	Very fast	Condo$^{\phi}$, H45$^{\phi}$, LongReach Dart$^{\phi}$, Vixen$^{\phi}$

Results

Phasic development and grain yield

The optimal flowering period (OFP) for Cudal, derived using the Agricultural Production Systems sIMulator (APSIM) model simulation combined with long-term climatic data is typically mid–late October. The OFP is determined as a period whereby the combined risk from frost, heat and moisture stress is minimised, and grain yield potential is maximised. In 2020, the flowering window for this experiment spanned from 20 September to 25 October (Figure 1), approximately 7 days slower than reported in the dry year of 2019, which was from 13 September to 18 October (Roberts et al. 2020).

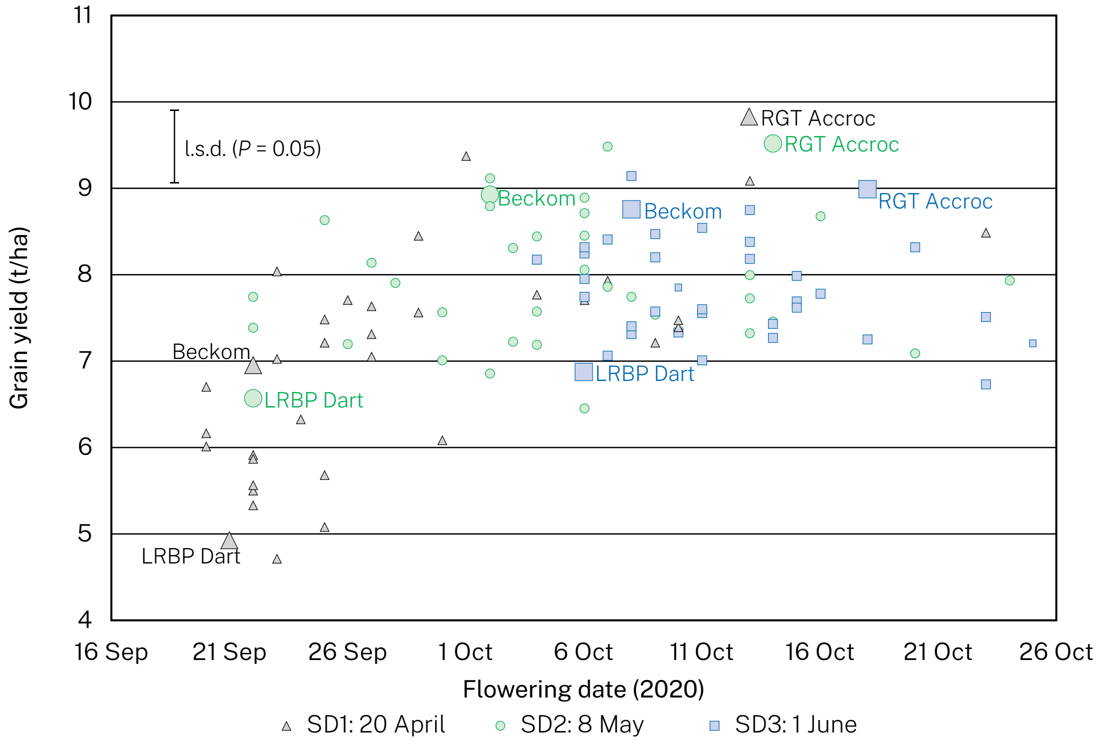
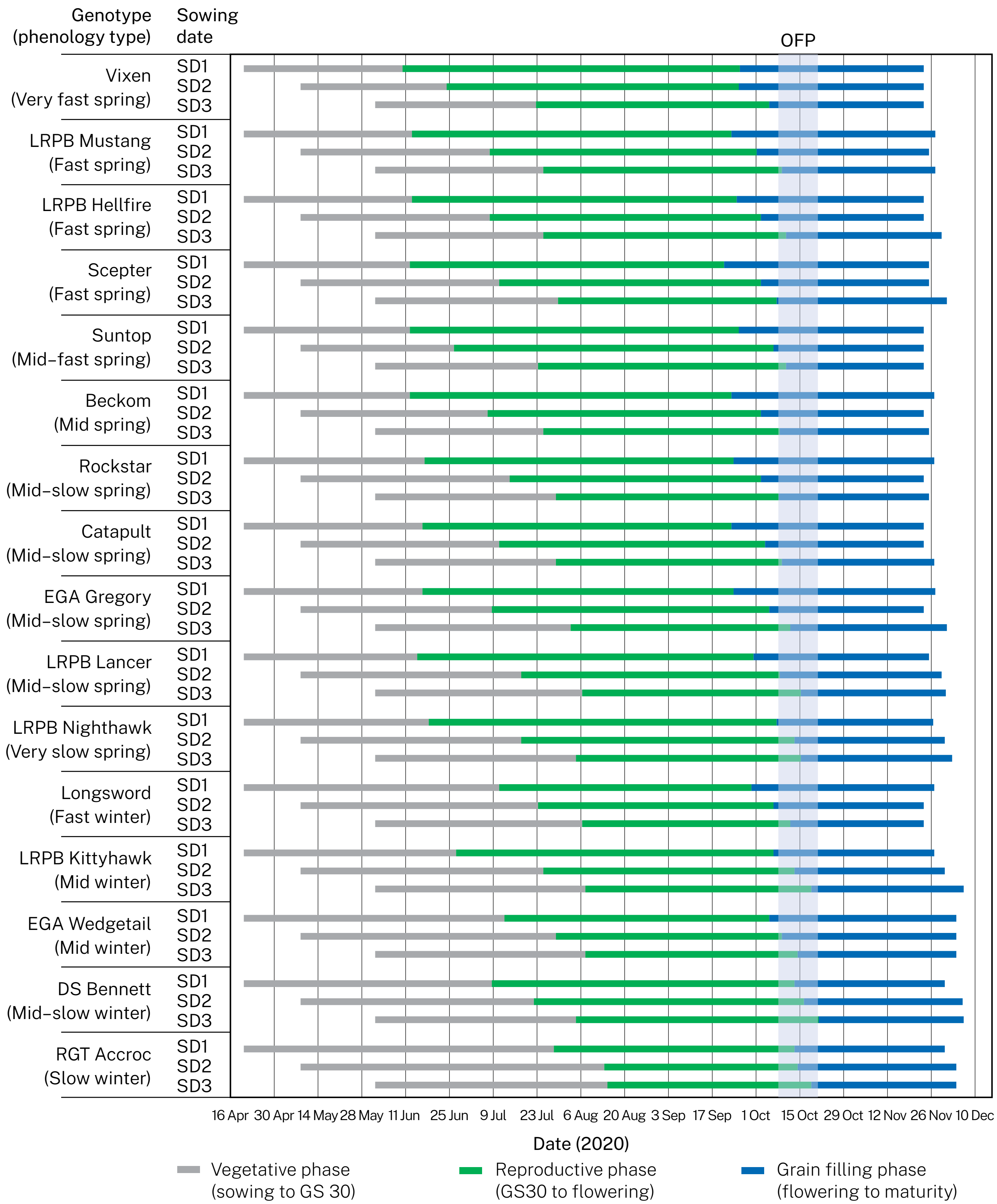


Figure 1 Relationship between flowering date and grain yield for 36 genotypes sown on 3 dates at Cudal, 2020.

Frost damage was observed for the mid to the very fast spring types, causing stem and head damage delaying recorded flowering dates for these groups in SD1 and SD2 (Figure 2). For example, very fast type cv. Vixen⊕ reached flowering (GS65) for both SD1 and SD2 on the same day (25 September) despite differences in onset of stem elongation with SD1 flowering 108 days post GS30, compared with 93 days for SD2.

In contrast, a later frost (27 September) coincided with flowering and early grain development in mid to slower developing cultivars and while the recorded flowering date was not affected, there was a significant reduction in grain yield. EGA Gregory⊕ had a 34% reduction in grain yield between SD1 and SD2.

The highest grain yields in this experiment were achieved with genotype × sowing date combinations which flowered from early to mid October. This date range is within the predicted OFP for Cudal. Mild temperatures combined with above average rainfall during late spring resulted in an extended grain filling period and favoured the slower developing genotypes. RGT Accroc⊕ (slow winter type) was the highest yielding genotype for SD1 (9.83 t/ha) and SD2 (9.51 t/ha), and Rockstar⊕ (mid spring type) achieved similarly high yields in SD3 (9.15 t/ha) (Table 2).



The shaded area indicates the optimal flowering period (OFP).

Figure 2 Sowing date influence on phasic development of selected genotypes sown on 3 dates at Cudal, 2020.

Table 2 Grain yield of genotypes across 3 sowing dates at Cudal, 2020.

Genotype	SD1: 20 April		SD2: 8 May		SD3: 1 June	
	Grain yield (t/ha)	Rank	Grain yield (t/ha)	Rank	Grain yield (t/ha)	Rank
Beckom	6.95	21	8.92	4	8.75	4
Catapult	6.94	22	8.31	12	8.20	12
Condo	5.33	33	7.39	27	7.74	19
Coolah	7.63	11	7.86	19	7.43	26
Corack	5.50	32	7.74	21	8.25	11
Cutlass	7.71	9	8.24	13	7.98	15
DS Bennett	9.08	3	8.67	8	8.31	10
DS Pascal	7.31	16	8.45	10	8.18	13
EGA Eaglehawk	7.39	15	7.46	26	7.51	25
EGA Gregory	4.72	36	7.18	31	7.55	24
EGA Wedgetail	7.77	8	7.53	25	7.27	30
H45	6.16	25	7.90	18	8.32	9
Janz	7.05	19	7.57	23	7.60	22
Longsword	8.45	5	8.89	5	8.54	5
LongReach Dart	4.92	35	6.56	35	6.87	35
LongReach Hellfire	6.33	24	6.86	34	7.33	28
LongReach Kittyhawk	7.71	10	7.32	28	7.25	31
LongReach Lancer	7.56	12	7.74	20	7.69	20
LongReach Mustang	5.91	28	7.00	33	7.57	23
LongReach Nighthawk	7.93	7	8.00	16	7.61	21
LongReach Reliant	5.56	31	7.22	29	7.31	29
LongReach Spitfire	5.08	34	7.57	24	7.06	33
LongReach Trojan	7.48	13	8.44	11	8.47	6
Mace	6.01	27	8.14	14	7.95	16
Manning	8.48	4	7.93	17	7.20	32
Mitch	7.02	20	8.71	7	8.38	8
RGT Accroc	9.83	1	9.51	1	8.99	2
RGT Zanzibar	9.37	2	9.49	2	8.75	3
Rockstar	8.04	6	8.79	6	9.15	1
Scepter	6.70	23	9.11	3	8.40	7
Sunlamb	7.48	14	7.09	32	6.73	36
Sunmax	7.21	17	7.72	22	7.78	18
Sunprime	5.87	29	7.20	30	7.40	27
Suntop	7.21	18	8.05	15	7.85	17
Sunvale	6.09	26	6.45	36	7.00	34
Vixen	5.68	30	8.63	9	8.17	14
Mean	6.99		7.93		7.85	
l.s.d. (P = 0.05) genotype	0.49					
l.s.d. (P = 0.05) SD	0.14					
l.s.d. (P = 0.05) genotype × SD	0.84					

Despite the favourable seasonal conditions in 2020 season, the effects from in season frosts, reinforced the importance of the selecting the correct genotype, based on matching phenology with an appropriate sowing date. As in previous studies (Harris et al. 2018, 2019; Roberts et al. 2020), earlier flowering resulted in grain yield penalties due to frost in genotypes that were sown early and developed too quickly. Genotypes that flower and fill grain later in the season normally undergo higher levels of heat stress, suffering a yield penalty. The mild 2020 conditions buffered any expected heat stress effects in this experiment (Figure 3).

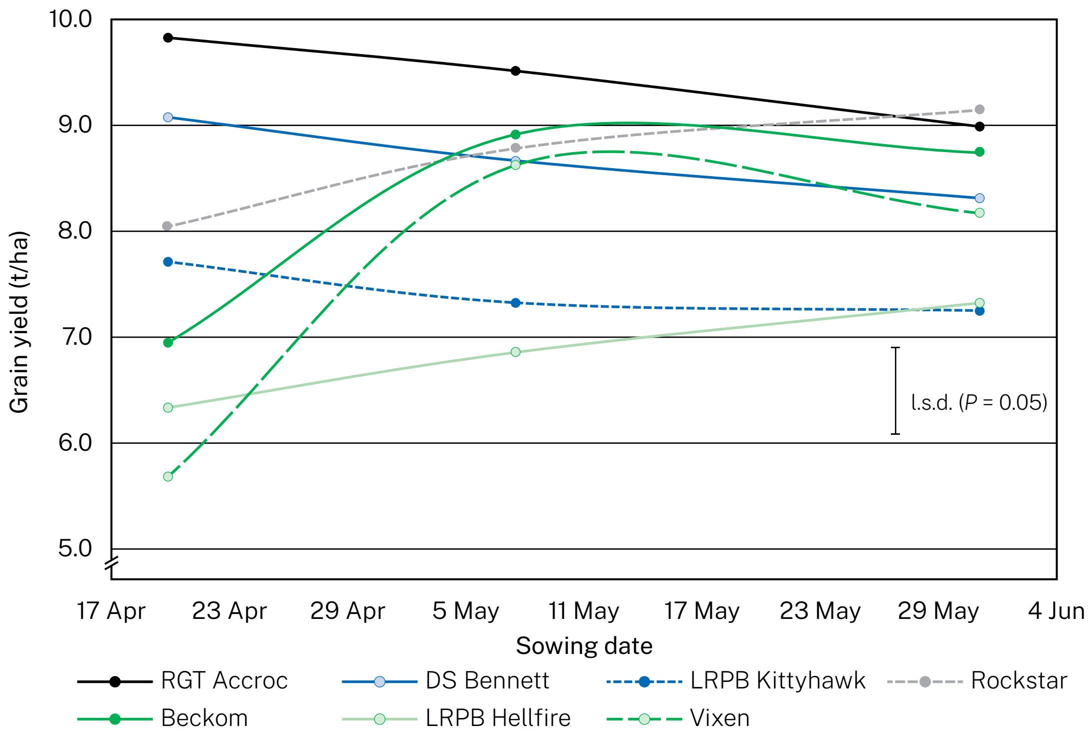


Figure 3 Grain yield of selected genotypes across 3 sowing dates at Cudal, 2020.

The winter types, such as RGT Accroc⊕ and DS Bennett⊕, were very high yielding, but delaying the sowing date from SD1 to SD3 reduced grain yield. Mid season genotypes such as Beckom⊕ were frost affected for SD1, with peak yield in SD2, before declining for SD3 as grain filling was pushed later in the season. Fast maturing spring-type genotypes, such as LongReach Hellfire⊕ and LongReach Mustang⊕, were frost affected for SD1 and SD2. Fast maturing spring-type genotypes achieved the highest yields in SD3, having avoided the frosts.

Grain quality

Genotype, sowing date, and the interaction between genotype and sowing date were all significant, affecting grain quality responses in 2020 (Table 3). To maximise grain yield, nitrogen was applied to target a minimum grain protein of 11.5% for all genotype × sowing date combinations. However, even with this nitrogen management, there were differences among genotypes, with known protein-accumulating genotypes such as LongReach Spitfire⊕ and LongReach Hellfire⊕ still having higher grain protein concentrations than other genotypes at a similar yield level (Figure 4).

Optimal conditions during grain filling resulted in all treatments achieving screenings of ≤5%. Screenings across genotypes were not consistent across sowing dates, with screenings for faster genotypes, e.g. Vixen⊕, increasing as sowing was delayed. For slower spring wheats, e.g. Sunmax⁽ᴾ⁾ and EGA Eaglehawk⁽ᴾ⁾, screenings decreased as sowing was delayed.

Across the experiment, test weight on average increased as sowing was delayed. All genotype × sowing date combinations achieved above industry minimum delivery standards of 76 kg/hL (GTA 2021), which can be attributed to positive seasonal conditions.

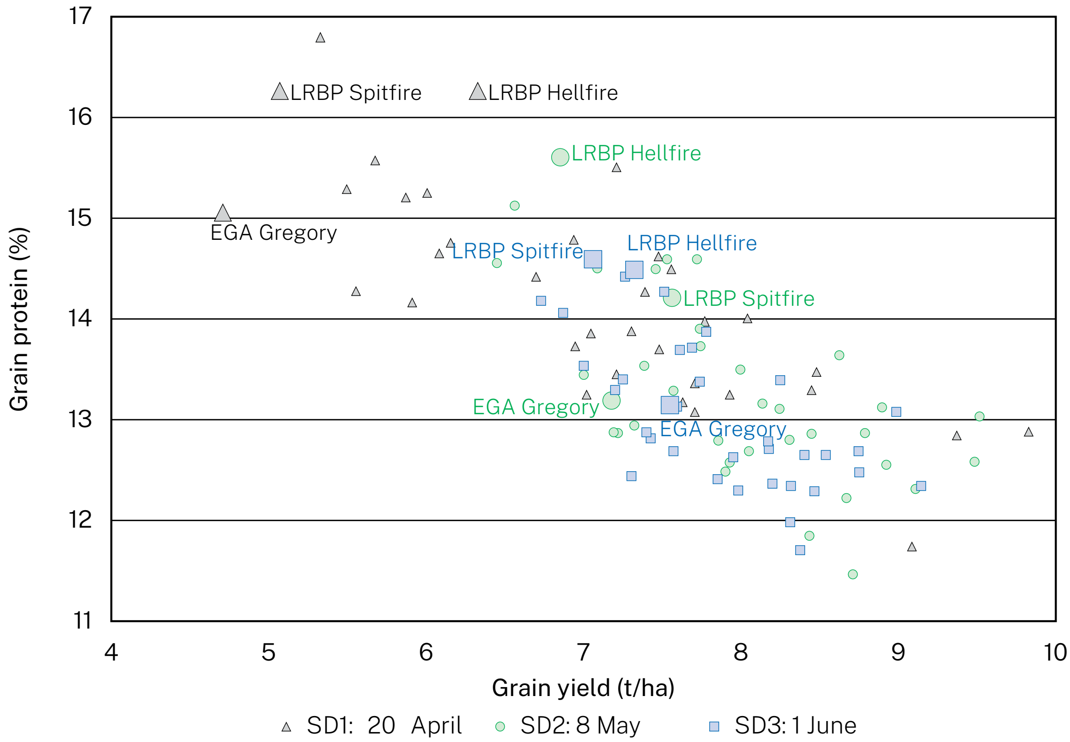


Figure 4 Relationship between grain yield and grain protein for 36 genotypes sown on 3 dates at Cudal, 2020.

Table 3 Grain protein (Protein), screenings (SCRN), and test weight (TW) of 36 genotypes across 3 sowing dates at Cudal, 2020.

Genotype	SD1: 20 April			SD2: 8 May			SD3: 1 June		
	Protein (%)	SCRN (%)	TW (kg/hL)	Protein (%)	SCRN (%)	TW (kg/hL)	Protein (%)	SCRN (%)	TW (kg/hL)
Beckom	13.7	0.8	79.4	12.6	1.7	79.6	12.7	1.3	81.0
Catapult	14.8	0.8	80.0	12.8	2.9	80.7	12.4	2.2	82.9
Condo	16.8	0.2	81.2	13.5	0.3	81.9	13.4	0.2	82.9
Coolah	13.2	0.3	80.7	12.8	0.5	81.7	12.8	0.2	82.0
Corack	15.3	0.1	80.5	13.9	0.1	81.2	13.4	0.5	82.4
Cutlass	13.1	0.4	81.5	13.1	0.4	81.5	12.3	0.1	83.1
DS Bennett	11.7	1.9	81.0	12.2	1.5	81.2	12.0	1.3	81.1
DS Pascal	13.9	1.0	79.0	12.9	0.7	81.3	12.7	0.4	82.2
EGA Eaglehawk	14.3	3.9	80.7	14.5	1.4	82.0	14.3	1.1	81.4
EGA Gregory	15.1	0.5	80.2	13.2	0.3	81.0	13.1	0.2	82.5
EGA Wedgetail	14.0	1.3	77.4	14.6	0.8	78.1	14.4	1.1	78.3
H45	14.8	0.5	81.6	12.5	1.9	80.7	12.3	1.8	82.6
Janz	13.9	1.2	80.6	13.3	2.6	81.3	13.1	0.6	82.5
Longsword	13.3	1.0	79.9	13.1	1.2	80.5	12.7	0.6	82.4
LongReach Dart	17.3	0.3	80.6	15.1	1.9	80.9	14.1	2.1	82.3
LongReach Hellfire	16.3	0.6	81.1	15.6	0.8	81.5	14.5	0.2	83.8
LongReach Kittyhawk	13.4	1.9	83.0	12.9	0.6	82.9	13.4	1.1	82.6
LongReach Lancer	14.5	0.2	79.3	13.7	0.1	81.3	13.7	0.2	81.8
LongReach Mustang	14.2	0.2	81.1	13.4	0.4	81.9	12.7	1.1	82.8
LongReach Nighthawk	13.3	0.9	81.9	13.5	0.6	82.1	13.7	0.3	81.2
LongReach Reliant	14.3	0.2	80.4	12.9	0.6	80.2	12.4	0.2	82.3
LongReach Spitfire	16.3	0.2	82.5	14.2	0.6	82.3	14.6	0.2	83.9
LongReach Trojan	13.7	0.5	81.1	11.8	1.5	82.7	12.3	0.4	83.7
Mace	15.3	0.6	79.9	13.2	2.2	80.5	12.6	2.2	82.5
Manning	13.5	2.4	77.1	12.6	2.6	78.1	13.3	2.3	77.4
Mitch	13.3	0.4	79.0	11.5	0.2	79.9	11.7	0.1	81.2
RGT Accroc	12.9	0.6	79.1	13.0	0.4	79.4	13.1	0.2	78.9
RGT Zanzibar	12.8	0.3	80.2	12.6	0.3	81.8	12.5	0.2	82.3
Rockstar	14.0	1.2	79.3	12.9	1.8	80.0	12.3	1.1	82.4
Scepter	14.4	0.1	80.8	12.3	1.2	81.6	12.6	1.8	83.1
Sunlamb	14.6	1.8	80.3	14.5	0.9	81.3	14.2	1.4	82.2
Sunmax	15.5	5.0	78.9	14.6	3.0	80.9	13.9	1.5	81.2
Sunprime	15.2	0.5	80.1	12.9	1.6	80.1	12.9	1.4	81.0
Suntop	13.5	1.0	80.4	12.7	2.2	81.2	12.4	0.5	82.3
Sunvale	14.7	0.2	81.1	14.6	2.0	80.5	13.5	0.1	82.1
Vixen	15.6	0.4	78.9	13.6	2.3	79.5	12.8	3.0	81.3
Mean	14.3	0.9	80.3	13.3	1.2	80.9	13.1	0.9	81.9
l.s.d. (*P*=0.05) genotype	0.6	0.5	0.6						
l.s.d. (*P*=0.05) SD	0.2	0.1	0.2						
l.s.d. (*P*=0.05) genotype × SD	1.1	0.8	1.0						

Summary

The 2020 season combined high rainfall (Decile 10) with mild temperatures during the critical late-reproductive to grain-filling stages, which resulted in very high yield potential (>9 t/ha) at the Cudal site. The 2020 season was a stark contrast to the drought year of 2019. Despite the ideal spring conditions, there was a significant effect from frost damage in treatments that flowered before the OFP, reducing yield potential. No single phenology group was adapted to all 3 sowing dates, supporting previous work suggesting that growers can maximise grain yield by selecting genotypes that target the OFP based on the seasonal sowing opportunities.

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Cereals

Evaluation of early-sown winter wheats: phenology and yield responses – Wagga Wagga 2022

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Key findings

- There was significant variation in phasic duration and grain yield responses to sowing date (SD) for the winter types in 2022.
- We observed 91 days difference in commencement of stem elongation (GS30) for SD1 (18 March) and 39 days difference for SD2 (25 April) amongst the winter wheat varieties. This resulted in a 28 day and 38 day difference in time to flowering (GS65) respectively, indicating differences in vernalisation responses and flowering stability among current commercial winter types.
- Despite some winter types (e.g. LongReach Kittyhawk⸸, DS Bennett⸸ and Manning⸸) reaching stem elongation earlier in SD1, they flowered within their expected flowering windows in 2022.
- Seasonal conditions had a significant effect on grain yield recorded in 2022, with 20–25% higher yields recorded for SD2 in both wheat and barley varieties, afforded by optimal conditions coinciding with later flowering in 2022 as well as an extended grain-filling period.
- Test weights (TWT) were significantly lower for all milling quality wheats for SD1 compared with SD2. Many varieties had TWT <76 kg/hL for SD1, which would have resulted in grain quality downgrades.
- In 2022, winter barley cv. Urambie⸸ flowered earlier than all wheat varieties and had a significant grain yield penalty. In contrast, slower-developing barley cv. Newton flowered later and recorded comparable grain yields to wheat at similar flowering dates.

Keywords Cereals, flowering time, grain quality, wheat, winter wheat, barley, grain yield, early sowing, Wagga Wagga, red chromosol, 2022

Introduction

Recent trends toward earlier sowing have renewed grower interest in winter wheats and breeder focus on selecting and releasing new winter genotypes suited to southern NSW farming systems. In recent years, experiments involving earlier sowings (i.e. March, early April) have resulted in unpredictable phenology responses in locally adapted varieties. A field experiment was conducted at Wagga Wagga to determine the influence of early sowings (mid March and late April) on the phenology, yield, and grain quality response of 13 wheat and 2 barley varieties.

Site details

Location	Wagga Wagga Agricultural Institute, Wagga Wagga

Soil type	Red chromosol
Paddock history	Canola (2021), lupins (2020)
Sowing	Direct drilled with DBS tynes spaced at 250 mm using a GPS auto-steer system
Target plant density	120 plants/m^2
Soil pH_{Ca}	5.6 (0–5 cm); 4.7 (5–10 cm); 4.6 (10–15 cm); 4.9 (15–20 cm)
Mineral nitrogen (N)	143 kg N/ha (1.5 m depth)
Fertiliser	• 100 kg/ha mono-ammonium phosphate (MAP) treated with 2 L/t flutriafol (sowing) • 46 kg N/ha applied as urea on 26 May and 2 August (92 kg N/ha for season)
Weed control	Knockdown • 1.2 L/ha Crucial® (600 g/L glyphosate) + 1 kg/ha ammonium sulfate (23 February) • 1.2 L/ha Muster 450 (450 g/L glyphosate) (pre-sowing, 18 March and 25 April) Pre-emergent • 2.5 L/ha Boxer Gold® + 1.6 L/ha Avadex® Xtra + 1 L/ha TriflurX® incorporated by sowing In-crop • 640 mL/ha MCPA 570 LVE + 25 g/ha Paradigm® Arylex® + Uptake spray oil (SD1 17 May, SD2 20 June)
Disease and pest management	Seed treatment • Seed treated with Hombre Ultra® and Evergol Energy® Fertiliser treatment • Flutriafol (2 L/t) In-crop foliar • Bumper®625 200 mL/ha (SD1 17 May and 20 June) • Soprano® 500 250 mL/ha + SpreadWet 1000 @ 0.25% (both sowing dates 29 July) • AmistarXtra® 800 mL/ha (both sowing dates 26 August) • Prosaro® 420SC 300 mL/ha (both sowing dates 30 September) • Bumper® 625 200 mL/ha (SD2 4 November) *Note*: The fungicide strategy used is not recommended practice; high disease pressure in adjacent trial paddock.
Harvest date	17 December 2022
Rainfall	• In-crop: 595 mm (18 March – 30 November) • Long-term average: 447 mm (March–November)

Treatments

Thirteen wheat and 2 barley varieties (Table 1), varying in phenology responses were sown on 2 sowing dates in 2022:

- SD1: 18 March
- SD2: 25 April.

Table 1 Phenology response of the 2022 experimental varieties according to Australian Cereal Phenology Classification (Celestina et al. 2023).

Phenology types	Varieties
Very slow winter (VSW)	Manning⦶, Einstein⦶, RGT Waugh⦶
Slow winter (SW)	DS Bennett⦶, RGT Accroc⦶, Anapurna⦶, RGT Cesario⦶
Mid winter (MW)	Illabo⦶, EGA Wedgetail⦶, LongReach Kittyhawk⦶, Newton (barley)
Quick winter (QW)	Longsword⦶
Very quick winter (VQW)	Urambie⦶ (barley)
Slow–very slow spring (SVSS)	LongReach Nighthawk⦶
Slow spring (SS)	Sunmax⦶

Results

Phasic development

In 2022, there was a 65-day range in anthesis date (6 September – 1 November) across both sowing dates (figures 1 and 2). Despite some winter types, namely LongReach Kittyhawk⦶, DS Bennett⦶ and Manning⦶, reaching stem elongation earlier than anticipated in SD1, they flowered within their expected flowering windows in 2022. Longsword⦶, a quick winter, and LongReach Nighthawk⦶, a slow–very slow spring type, were the quickest wheat varieties to anthesis for both sowing dates. The barley variety Urambie⦶ reached anthesis first for both sowing dates. The slow spring phenology type Sunmax⦶ was slower to reach anthesis than expected, likely due to its photoperiod responsiveness and the low level of light intensity during the 2022 growing season.

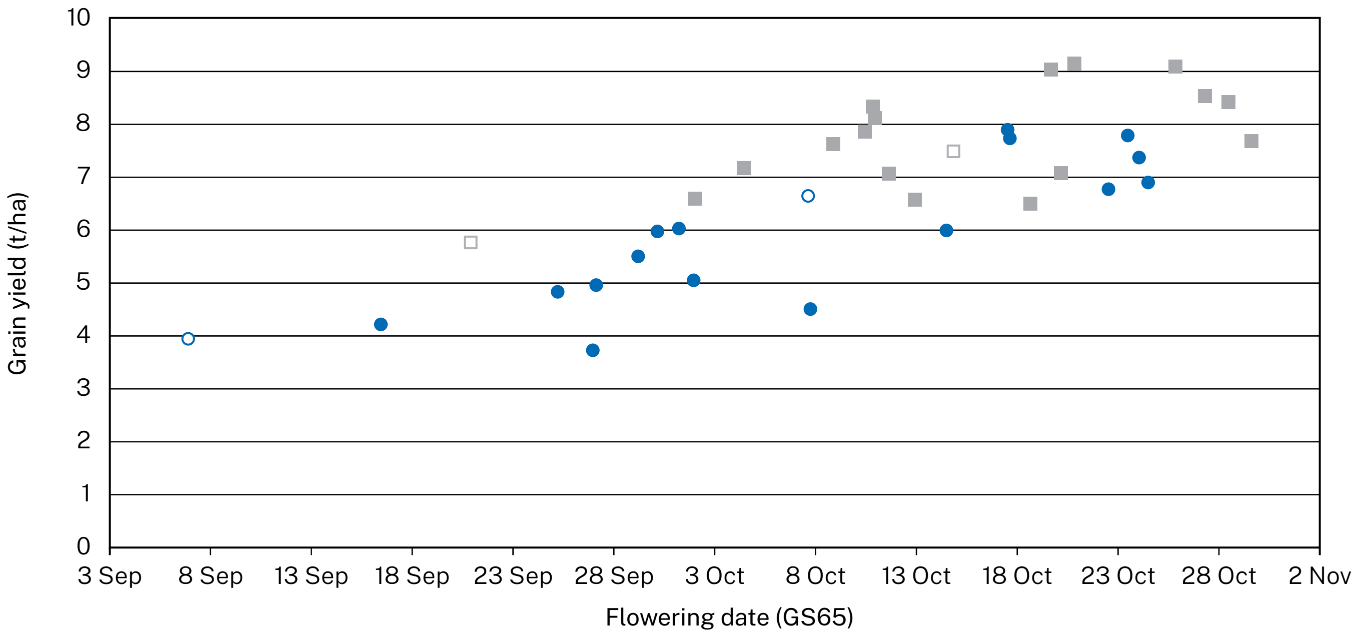

Figure 1 Relationship between flowering date (GS65) and grain yield for SD1 (18 March) and SD2 (25 April) at Wagga Wagga, 2022.

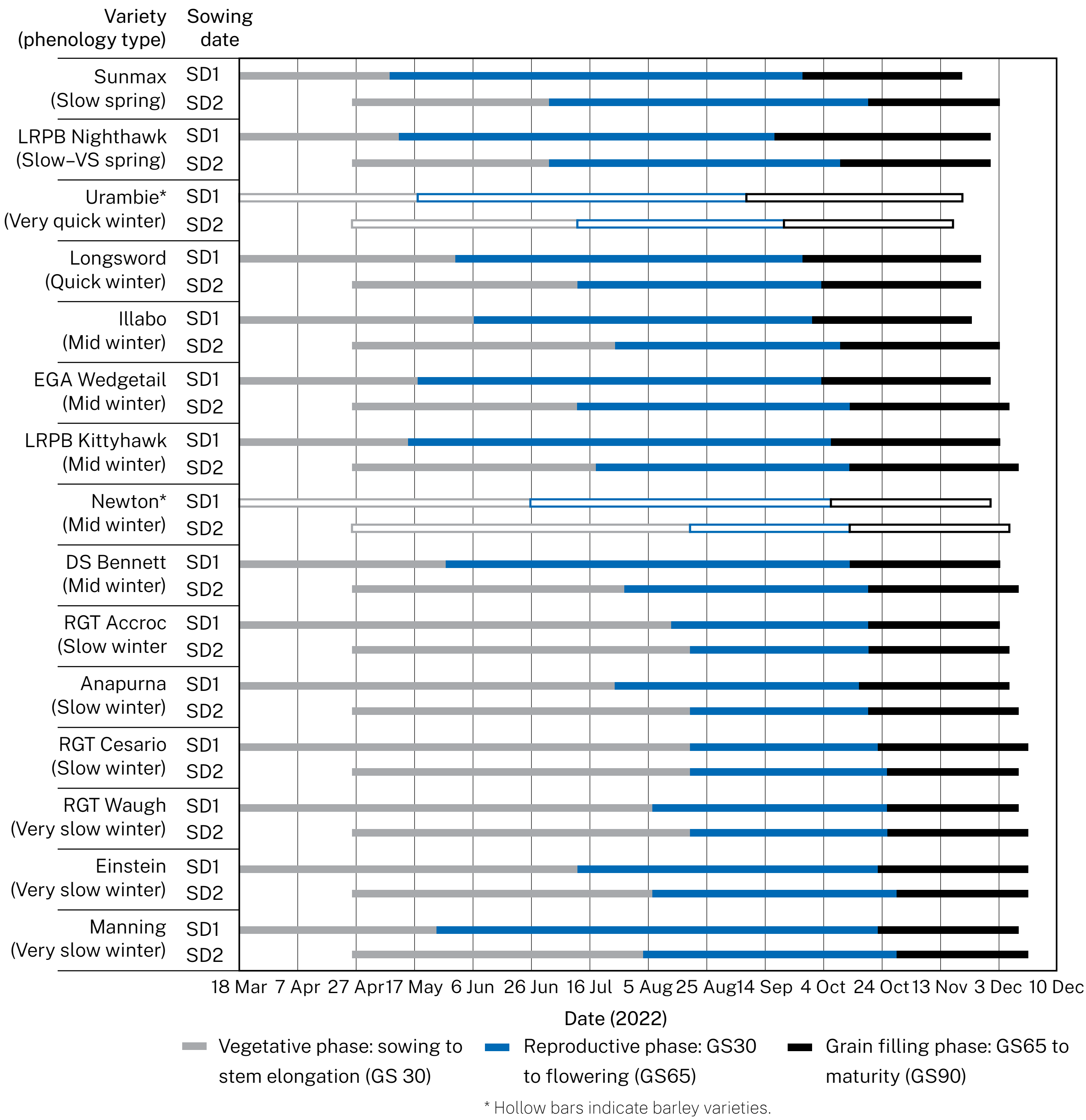

Figure 2 Difference in phasic duration of varieties for SD1 (18 March) and SD2 (25 April) at Wagga Wagga, 2022.

Grain yield

Mild weather conditions throughout the growing season, coupled with few frosts, resulted in medium to high yield potential being attained. Mean grain yield across sowing dates varied from 5.83 t/ha (SD1) to 7.75 t/ha (SD2) across both wheat and barley (Table 2). Anthesis coincided with low temperatures in several of the varieties for SD1, which significantly reduced final grain yield including EGA Wedgetail⦶, Longsword⦶, LongReach Kittyhawk⦶, LongReach Nighthawk⦶, and Urambie⦶. The highest yields were achieved by the wheat varieties RGT Accroc⦶ (7.91 t/ha) for SD1 and Anapurna⦶ (9.14 t/ha) for SD2. Barley cv. Urambie⦶ ranked second lowest for yield for SD1 as it flowered earlier than all other wheat and barley entries. In contrast, barley cv. Newton achieved comparable yields to wheat at similar flowering times.

Table 2 Grain yield of varieties across 2 sowing dates at Wagga Wagga, 2022.

Variety	SD1: 18 March		SD2: 25 April	
	Grain yield (t/ha)	Yield ranking	Grain yield (t/ha)	Yield ranking
Anapurna	7.72	(3)	9.14	(1)
DS Bennett	5.96	(9)	7.08	(12)
EGA Wedgetail	5.00	(11)	7.13	(11)
Einstein	7.34	(4)	8.40	(5)
Illabo	6.12	(8)	8.34	(6)
Longsword	3.72	(15)	7.15	(10)
LongReach Kittyhawk	4.38	(12)	6.71	(13)
LongReach Nighthawk	4.18	(13)	8.12	(7)
Manning	6.75	(6)	7.68	(8)
Newton*	6.65	(7)	7.47	(9)
RGT Accroc	7.91	(1)	8.95	(3)
RGT Cesario	7.80	(2)	9.02	(2)
RGT Waugh	6.86	(5)	8.56	(4)
Sunmax	5.04	(10)	6.43	(14)
Urambie*	3.97	(14)	5.78	(15)
Mean (Wheat)	5.83		7.75	
Mean (Barley)	5.31		6.63	
l.s.d. (Variety)	0.57			
l.s.d. (SD)	0.19			
l.s.d. (Variety × SD)	0.81			

* winter barley variety

Grain quality

Test weight (TWT) for all milling wheats for SD1 was significantly lower than SD2. Many varieties had test weights <76 kg/hL, which would have resulted in delivery grain quality downgrades. Screenings across both sowing dates were generally within the industry benchmark (<5%). Grain protein (GP) and yield were related inversely with decreasing GP as yield increased.

Summary

Seasonal conditions significantly influenced phenology, grain yield and grain quality responses to sowing date in 2022. Mild temperatures, combined with unlimited soil moisture and low light intensity during the critical period (late stage of stem elongation to just after anthesis), together with an extended grain filling period, resulted in grain yields being 20–25% higher for SD2 for both wheat and barley. The slow winter types (e.g. Anapurna$^{\phi}$, RGT Cesario$^{\phi}$ and RGT Accroc$^{\phi}$) and the very slow winter types (e.g. RGT Waugh$^{\phi}$) as a group, tended to reach anthesis later and were able to take advantage of the extended grain fill period and favourable temperatures, yielding well from both sowing dates. Importantly, results from this experiment showed that there was significant genotypic (variety) and environmental (sowing date) variation for the start of stem elongation (GS30) and anthesis date. This indicates that there are differences in vernalisation response and flowering stability among commercial winter types. This experiment needs to be repeated in lower rainfall seasons, as 2022 experienced decile 9 rainfall with unusually cool temperatures, which don't reflect the average growing season.

Table 3 Grain protein (GP), test weight (TWT), screenings (SCRN) and retention (RET, barley) of varieties for SD1 (18 March) and SD2 (25 April) at Wagga Wagga, 2022.

Variety	SD1: 18 March					SD2: 25 April				
	GP (%)	TWT (kg/hL)	SCRN (%)	RET	Lodging (0–9)	GP (%)	TWT (kg/hL)	SCRN (%)	RET	Lodging (0–9)
Anapurna	11.3	77.0	2.1	–	0.0	10.8	79.0	1.9	–	0.0
DS Bennett	9.9	77.0	5.2	–	4.3	10.4	78.3	4.9	–	0.0
EGA Wedgetail	12.6	72.8	1.7	–	3.0	11.6	75.6	1.9	–	0.7
Einstein	11.0	73.9	2.0	–	0.0	10.8	75.3	1.8	–	0.0
Illabo	12.4	73.4	0.7	–	1.3	11.9	77.5	1.1	–	0.0
Longsword	15.0	68.3	0.8	–	1.0	12.9	79.1	0.3	–	1.0
LongReach Kittyhawk	12.3	71.7	5.0	–	4.7	11.7	76.2	6.3	–	0.0
LongReach Nighthawk	14.6	70.8	1.8	–	1.3	11.7	78.2	1.9	–	1.0
Manning	10.3	72.8	3.3	–	0.0	10.5	72.7	3.9	–	0.0
Newton*	10.2	63.6	4.5	76.9	6.7	10.8	64.9	3.4	90.1	4.3
RGT Accroc	9.8	75.5	1.0	–	0.0	9.9	76.8	1.6	–	0.0
RGT Cesario	9.9	74.9	1.6	–	0.0	9.9	77.2	2.3	–	0.0
RGT Waugh	11.1	75.3	1.2	–	0.0	11.2	76.0	0.5	–	0.0
Sunmax	13.5	73.5	4.6	–	3.0	12.1	74.0	7.6	–	3.0
Urambie*	11.5	60.8	13.2	41.5	9.0	11.5	64.0	4.5	71.8	8.7
Mean (Wheat)	11.8	73.6	2.4	–	1.4	11.2	76.6	2.8	–	0.4
Mean (Barley)	10.9	62.2	8.8	59.2	7.8	11.2	64.5	4.0	81.0	6.5
l.s.d. (Genotype)	0.6	1.7	1.1		1.5					
l.s.d. (SD)	0.2	0.6	0.4		0.5					
l.s.d. (Genotype × SD)	0.9	2.5	1.5		2.1					

* winter barley variety

Reference

Celestina C, Hunt J, Kuchel H, Harris F, Porker K, Biddulph B, Bloomfield M, McCallum M, Graham R, Matthews P, Aisthorpe D, Al-Yaseri G, Hyes J, Trevaskis B, Wang E, Zhao A, Zheng B, Huth N and Brown H (2023) 'A cultivar phenology classification scheme for wheat and barley', *European Journal of Agronomy*, 143:126732, doi:10.1016/j.eja.2022.126732.

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In-season agronomic manipulation of early sown spring wheat to delay flowering and reduce frost impact – Wagga Wagga 2022

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Key findings

- In-crop mechanical defoliation 'apical pruning' of early sown spring wheat during early stem elongation (Zadoks growth stage: GS31–32) was able to delay/reset anthesis by 8–25 days.
- Apical pruning enabled the quick, mid spring cultivar Scepter⦶, sown approximately 14 days earlier than its recommended sowing window, to flower in the optimal flowering period (OFP) for this environment as opposed to the untreated control, which flowered 8 days before the OFP.
- Lack of abiotic stress factors, namely frost and heat, combined with adequate in-season rainfall in 2022 contributed to a yield advantage for early sowing dates. Scepter⦶ for example, sown on 25 April (approximately 14 days earlier than the start of its optimum sowing window) yielded 7.24 t/ha.
- Although it was possible to reset and delay anthesis so that it occurs within the OFP, delays in anthesis in response to apical pruning at GS31–32 were associated with either a decrease in grain yield and/or no significant increase in grain yield.
- The yield penalties were greater when defoliation timing was delayed (e.g. GS32), and intensity increased (cut at 3–4 cm).
- Reduction in grain yield in response to apical pruning was associated with reduced biomass accumulation at mid flowering (GS65).
- Both yield and grain protein (GP) correlated with dry matter (DM) at GS65, highlighting nitrogen (N) application post apical pruning, to compensate for biomass, to achieve yield potential and targeted GP classification.

Keywords Wagga Wagga, 2022, anthesis, apical pruning, early, mechanical defoliation, anthesis, grain yield, grain protein, optimal flowering period, red chromosol, spring wheat

Introduction

Although the concept of defoliation is not new, its application as a targeted approach to remove and/or impede the emerging apical meristem, could be a useful strategy to delay crop development. Apical pruning by mechanical defoliation during early stem elongation (GS31–32), aims to impede the emerging stem apices, to impose a 'phenology reset' on fast-developing spring wheat crops (Porker et al. 2022). Generally, with dual-purpose winter wheats defoliation/grazing is not recommended after the onset of stem elongation (i.e. GS30) to avoid damage to the emerging apical meristem.

This experiment investigated the effect of mechanical defoliation, timing, and cut intensity as a method of resetting flowering time to stabilise the yield potential of early sown and/or quick maturing spring wheats. If successful, this would enable the realignment of the crop lifecycle and widen the spring wheat sowing window, possibly reducing the need for multiple cultivars. It could also provide a strategy to reset flowering time and slow cultivar development when sown too early.

The objective of this approach was to delay crop development so that flowering occurs within or close to the OFP for a given environment. This aims to:

- balance the risks of frost damage during flowering, and moisture and heat stress during grain fill
- minimise production risk
- optimise grain yield potential.

The OFP for Wagga Wagga is considered to be from 26 September to 12 October (Matthews et al. 2023).

Cereals

Site details

Location	Wagga Wagga Agricultural Institute, Wagga Wagga
Soil type	Red chromosol
Paddock history	Canola (2021), lupins (2020)
Sowing	• Direct drilled with DBS tynes spaced at 250 mm using a GPS auto-steer system • Target plant density: 120 plants/m^2
Soil pH$_{Ca}$	5.6 (0–5 cm); 4.7 (5–10 cm); 4.6 (10–15 cm); 4.9 (15–20 cm)
Soil mineral N	143 kg N/ha at sowing (1.5 m depth)
Fertiliser	• 100 kg/ha mono-ammonium phosphate (MAP) treated with 200 mL/ha flutriafol (sowing) • 46 kg N/ha applied as urea on 26 May and 2 August (92 kg N/ha for season)
Weed control	Knockdown • 1.2 L/ha Crucial® (600 g/L glyphosate) + 1 kg/ha ammonium sulfate (23 February) Pre-sowing • 1.2 L/ha Muster 450 (450 g/L glyphosate) (25 April) Pre-emergent • 2.5 L/ha Boxer Gold® + 1.6 L/ha Avadex® Xtra + 1 L/ha TriflurX® incorporated by sowing In-crop • 640 mL/ha MCPA 570 LVE + 25 g/ha Paradigm® Arylex® + 5% Uptake spray oil
Disease and pest management	*Seed treatment* • Hombre® Ultra @ 2 L/t + EverGol® Energy @ 2.6 L/t.

	In-crop foliar • 250 mL/ha Soprano® 500 + 0.25% SpreadWet 1000 (29 July) • 800 mL/ha AmistarXtra® (26 August) • 300 mL/ha Prosaro® 420SC (30 September) • 200 mL/ha Bumper® 625 (4 November). *Note*: high disease pressure in adjacent research paddock, not recommended commercial practice.
Harvest date	17 December 2022
Rainfall	• In crop: 458 mm (April–October) • Long-term average: 352 mm
Growing conditions	The site was not water limited and temperatures (T) were mild during the critical period (i.e. 28 days before flowering), which extended through to grain filling. Importantly, there were no severe frosts (T min. <−2.0 °C) in the 3-month period between 15 August and 15 November. There were only 2 moderate frosts (T min. <0 °C) both −1 °C on 24 August and 4 September, respectively (Figure 1). While there were only 9 mild frosts (T min. <2 °C) recorded during this period, temperatures (T max.) did not exceed 30 °C, further underlining the mild spring temperatures in 2022.

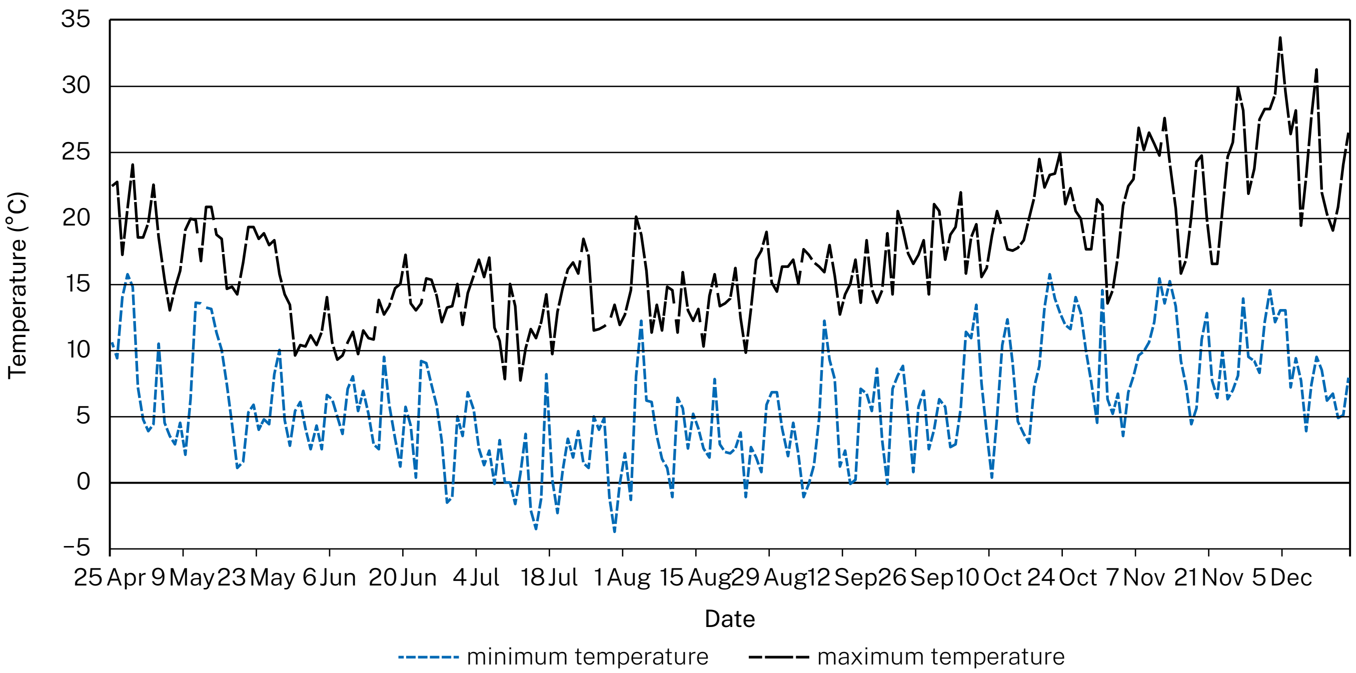

Figure 1 Minimum temperature (T min.) and maximum temperature (T max.) recorded at Wagga Wagga in 2022.

Treatments

Variety

Four wheat cultivars (Table 1), varying in phenology type were sown on 25 April in 2022.

Cereals

Table 1 Phenology type of cultivars according to Australian Cereal Phenology Classification (Celestina et al. 2023).

Phenology types	Cultivars
Mid winter (MW)	Illabo⍭
Mid spring (MS)	Rockstar⍭
Quick–mid spring (Q–MS)	Scepter⍭
Quick spring (QS)	Vixen⍭

Mechanical defoliation

Mechanical defoliation treatments (Table 2) were applied to Rockstar⍭ and Scepter⍭ at different growth stages and intensities using a slasher, with the cut material removed from plots. The defoliation intensity levels were:

- 'heavy' cut ~3–4 cm from the plant base (Figure 2a)
- 'light' cut ~6–7 cm from plant base (Figure 2b).

Defoliant treatments were not applied to either Illabo⍭ or Vixen⍭, which were included as controls.

Table 2 Mechanical defoliation timings and intensities.

Treatment/timing	Intensity
Cut combo	Cut low (3–4 cm) at ~GS22 and again at GS31
Tillering low	Cut low (3–4 cm) at ~GS22
Tillering high	Cut high (6–7 cm) at ~GS22
GS31 low	Cut low (3–4 cm) at GS31
GS31 high	Cut high (6–7 cm) at GS31
GS32 low	Cut low (3–4 cm) at GS32
GS32 high	Cut high (6–7 cm) at GS32
Control	No cuts

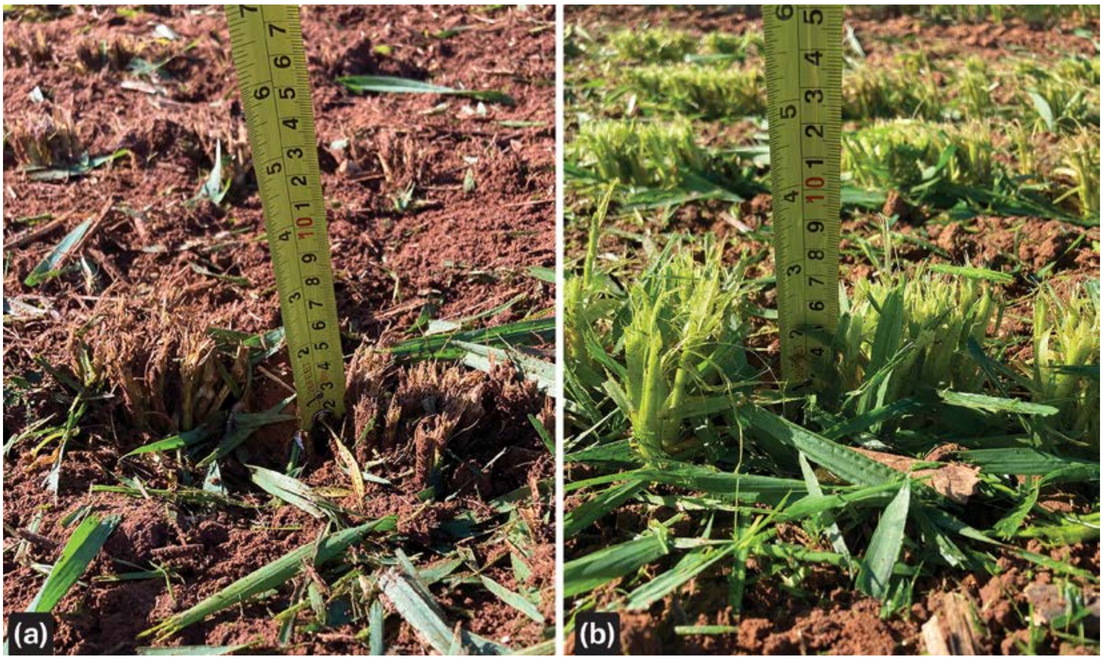

Figure 2 Mechanical defoliation intensity levels (a) heavy cut ~ 3–4 cm from the plant base and (b) light cut ~ 6–7 cm from the plant base.

Crop measurements included flowering time, biomass at anthesis (GS65), harvest index, grain yield and yield components.

Results

This experiment demonstrated that apical pruning delayed/reset the flowering time of spring wheat varieties sown earlier than their ideal sowing window through strategic defoliation timing and intensity (Table 3).

Delaying defoliation timing (e.g. GS32), in combination with increased intensity resulted in the greatest delays in flowering for both Scepter⊕ and Rockstar⊕. When defoliation was delayed to GS32 and intensity was increased (i.e. cut low), flowering was delayed by 25 days for Scepter⊕ and by 20 days for Rockstar⊕. This was in contrast to earlier defoliation at a lower intensity (i.e. cut high). For example, flowering was only delayed by 5 days for Scepter⊕ and by 6 days for Rockstar⊕ for the respective tillering high treatments.

Table 3 Effect of defoliation treatment on flowering time and grain yield (t/ha).

Cultivar	Treatment/timing	Flowering date	Defoliation effect (days delayed) *	Grain yield (t/ha)
Vixen	Phenology control	15 September	–	7.48
Illabo	Phenology control	12 October	–	8.11
Rockstar	Untreated control	22 September	–	7.37
Scepter	Untreated control	18 September	–	7.24
Scepter	Tillering low	23 September	−5	7.55
	Tillering high	23 September	−5	7.49
	GS31 low	10 October	−22	6.09
	GS31 high	26 September	−8	6.60
	Cut combo	5 October	−17	6.41
	GS32 low	13 October	−25	5.28
	GS32 high	8 October	−20	5.39
Rockstar	Tillering high	28 September	−6	7.26
	GS31 low	2 October	−10	6.82
	GS31 high	27 September	−5	7.44
	Cut combo	3 October	−11	6.95
	GS32 low	12 October	−20	5.13
	GS32 high	2 October	−10	6.10
P value				*P*<0.001
l.s.d. (P<0.05)				0.447

*Defoliation effect on anthesis (days delayed) relative to untreated control.

Grain yield

Illabo⊕, a mid winter maturity variety as the phenology control treatment, sown towards the end of its preferred sowing window and flowering at the end of the OFP on 12 October, was the highest yielding variety at 8.11 t/ha, (Table 3). This result supports the best management practice of sowing the correct phenology type in its preferred sowing window.

Growing conditions in 2022, which included limited severe frosts in late August and early September, resulted in Vixen⊕, a quick variety as the spring control and sown approximately 3 weeks earlier than its ideal sowing window (Matthews et al. 2023), flowering on 15 September and yielding 7.48 t/ha. Likewise, the quick mid spring cultivar Scepter⊕, sown approximately 2 weeks earlier than its recommended sowing window, flowered outside the OFP on 18 September and yielded 7.24 t/ha. The mid spring variety

Rockstar⁽ᵇ⁾ as the untreated control, sown in the early part of its sowing window, flowered on 22 September and yielded 7.37 t/ha.

Although results for Scepter⁽ᵇ⁾ showed that it was possible to reset and delay anthesis so that it occurred within the OFP, there was a strong relationship between delay in anthesis and a decline in grain yield (Figure 3). Importantly, low biomass accumulation at anthesis (GS65 DM) was found to be highly correlated (R^2 = 0.79) to yield potential, with low yields associated with low DM at GS65 (Figure 4). Apart from the early tillering treatments, which delayed flowering by ~5 days, all other defoliation treatments resulted in significant decreases in grain yield for Scepter⁽ᵇ⁾, ranging from 0.64 t/ha for the GS31 high treatment to 1.96 t/ha for the GS32 low treatment (Table 3).

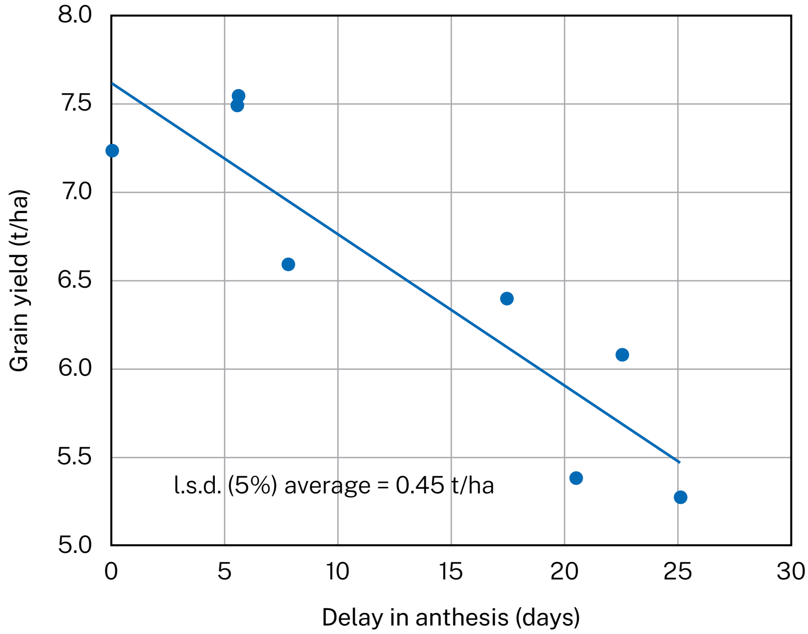

Figure 3 Relationship between delay in anthesis due to defoliation and grain yield for Scepter⁽ᵇ⁾.

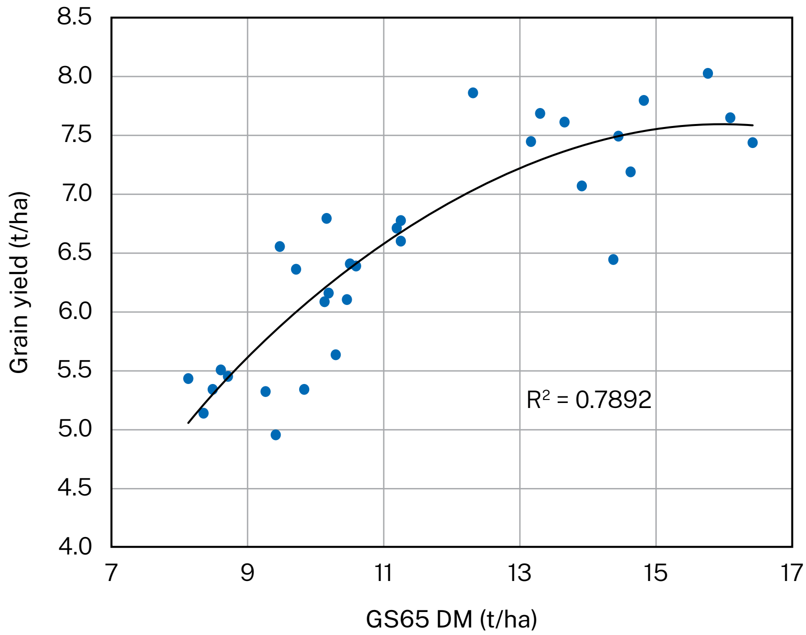

Figure 4 Relationship between GS65 DM (t/ha) and grain yield (t/ha) for Scepter⁽ᵇ⁾.

Rockstar$^{\text{⌀}}$ grain yield responses to the reset defoliation treatments showed that there was no significant effect on grain yield apart from the intensive low GS31 and both the GS32 treatment timings, which resulted in decreases in grain yield. There was, however, a trend for grain yield to decline with delays in time to flowering due to later treatment timings (i.e. GS32) and intensities (low versus high defoliation heights) resulting in larger delays in flowering. Dry matter accumulation at GS65 was also showed a strong correlation to yield.

Grain quality

Results for Scepter$^{\text{⌀}}$ in this experiment showed that there was a trend for grain protein (%) to increase with grain yield (Figure 5). Generally, there is a negative relationship between grain yield and grain protein (GP) due to a yield dilution effect. One possible reason for this response was the effect from defoliation intensity/timing on DM production at anthesis (GS65 DM) and its corresponding source-sink implications (Table 4). Importantly, both yield and GP were found to be highly correlated to GS65 DM production, highlighting the need to consider applying N post apical pruning to compensate for biomass to achieve yield potential and targeted GP classification.

Table 4 Effect of defoliation treatments on grain yield, GS65 biomass, grain protein and seed weight.

Cultivar	Treatment/timing	Grain yield (t/ha)	GS65 DM (t/ha)	Grain protein (%)	Seed weight (g/1000)*
Scepter	Untreated control	7.24	14.99	12.87	42.70
	Tillering low	7.55	13.71	12.55	42.97
	Tillering high	7.49	14.60	12.65	40.75
	GS31 low	6.09	10.31	11.51	42.18
	GS31 high	6.60	10.68	12.30	43.64
	Cutting combo	6.41	10.24	11.73	42.78
	GS32 low	5.28	9.09	11.43	44.59
	GS32 high	5.39	8.66	11.83	40.06
Rockstar	Untreated control	7.37	15.99	12.90	40.88
	Tillering high	7.26	15.44	12.31	42.25
	GS31 low	6.82	10.50	11.67	46.73
	GS31 high	7.44	12.91	11.93	46.39
	Cutting combo	6.95	11.37	11.21	46.23
	GS32 low	5.13	8.47	10.87	41.56
	GS32 high	6.10	8.84	11.96	45.26
P value		*P*<0.001	*P*<0.001	*P*<0.001	0.003
l.s.d. (*P*<0.05)		0.447	1.474	0.489	3.12

*Thousand seed weight (TSW).

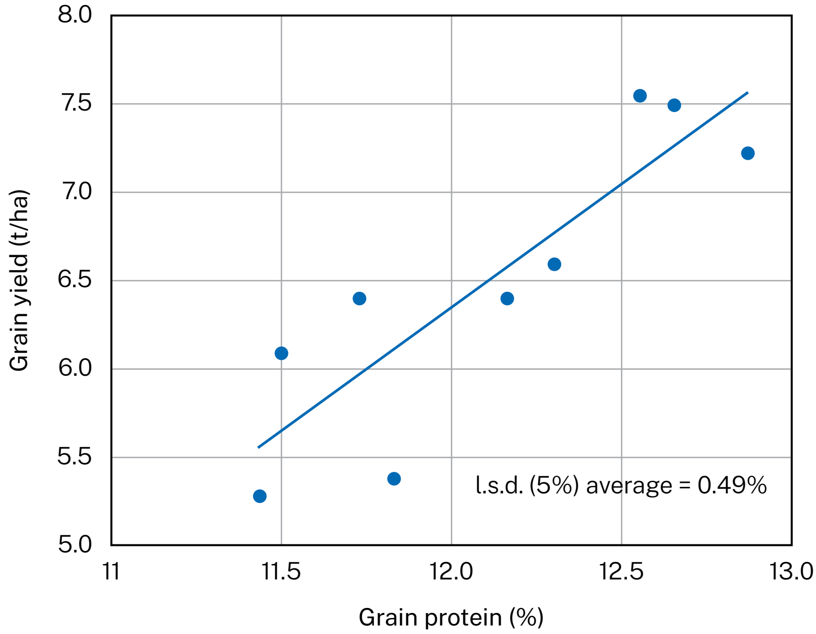

Figure 5 Relationship between grain protein (%) and grain yield for Scepter⦶.

In terms of grain receival implications, all Scepter⦶ treatments, achieved a GP >11.5%, except for the GS32 low treatment (GP of 11.43%). Although there were differences in thousand seed weight (TSW) in response to defoliation treatments, this did not translate to quality downgrades, with all Scepter⦶ treatments recording low screenings <5% (% grain <2 mm). Similarly, all treatments recorded test weights >76 kg/hL (data not shown).

Rockstar⦶ responses to defoliation treatments likewise found that the GS32 low treatment had both the lowest grain yield (5.13 t/ha) and GP (10.9%) (Table 4). The cutting combo treatment also failed to achieve a GP >11.5% (GP of 11.2%) and would have been downgraded from H2 to APW. The results similarly showed that there was a trend for GP to be lower for the more intense treatments at the same defoliation timing, despite grain yields being significantly lower (e.g. GS32 low versus high). This highlighted the need for additional in-crop N application. Although there were differences in TSW, these differences did not translate into quality downgrades, with all treatments achieving screenings of <5% and test weights of >76 kg/hL. The physical grain quality results indicate the favourable growing conditions during the critical period (~28 days before flowering) and through to grain fill.

Summary

This experiment demonstrated that it is possible to reset the flowering time of early sown spring wheat varieties through in-crop mechanical defoliation during early stem elongation (GS31–32). Depending on the timing and intensity of the defoliation treatments, flowering was delayed by 8–25 days for Scepter⦶, a quick mid spring cultivar, sown approximately 14 days earlier than the start of its optimum sowing window. The defoliation treatments enabled the cultivar to flower in the OFP for this environment as opposed to the untreated control, which flowered approximately 8 days earlier.

Although results showed that it was possible to reset and delay flowering time to occur within the OFP, delays in flowering in response to apical pruning at GS31–32 were associated with either a decrease in grain yield ($P<0.001$) or no significant increase in grain yield. What needs to be noted however, is that growing conditions in 2022 were not greatly influenced by frost, masking the potential effects from frost on grain yield when sown early.

Declines in grain yield in response to delays in defoliation timing and increased intensity correlated with GS65 biomass accumulation. These results imply that although it is possible to delay flowering through in-crop defoliation, there is often a yield penalty associated with reduced biomass accumulation. This results in the yield penalty being greater when defoliation is delayed, and intensity increased. This, in turn, needs to be weighed up against the potential for yield penalties associated with sowing incorrect phenology types early and hence the probability and/or likelihood of frost during anthesis.

Favourable growing conditions during grain fill helped ensure that physical grain receival standards were achieved (e.g. screenings <5%). There were, however, some implications related to reduced GP, most likely associated with decreased biomass at GS65 and the need for additional N to compensate for biomass removal.

In conclusion, there is scope for using apical pruning to reset early sown spring wheats so they flower within the OFP for a given environment. The obvious question to consider is: what is the potential yield penalty for apical pruning versus the risk and potential for yield losses from early flowering and frost damage? Preliminary results from this study indicate that delays in defoliation (e.g. GS32) and increased intensity (cut at ~ 3–4 cm), although significantly delaying flowering are more likely to result in a decline in yield potential, relative to untreated controls, due to reduced biomass accumulation. There is also the need to consider N management post apical pruning (GS33–37) to compensate for biomass removal in order to achieve target yield potential to ensure that GP is maintained.

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Improving and understanding the interactions between water use efficiency and nitrogen use efficiency in canola

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Key findings

- The split application (4–6-leaf + bud visible) of nitrogen (N) provided several significant benefits over the single application (4–6-leaf) strategy as it:
  - did not significantly (*P*<0.05) limit yield potential across all 3 water treatments (maintained profile, 100 mm top up at flowering and starting soil water only)
  - provided a risk mitigation strategy by reducing upfront N costs with the option to top up N supply later in the season depending on the seasonal outlook
  - resulted in both greater N uptake and increased N use efficiency than the equivalent N rate as a single application across all 3 water treatments.
- A higher N rate resulted in increased crop water use, however no evidence was found to support the phenomenon of 'haying off', i.e. the negative grain yield response to N fertiliser under late season water stress.

Canola

Keywords Canola, water use efficiency, nitrogen use efficiency, Wagga Wagga, red kandosol, 2021, 2022, variety, irrigation, split application, nitrogen timing, biomass

Introduction

With the vigorous deep rooting ability of modern long-season hybrid canola cultivars, there is a perception that increased soil water extraction earlier in the season leaves these cultivars highly susceptible to dry spring seasons when sub soil moisture is low. This proposition often leads to the suggestion that a conservative N management approach might help to limit early biomass accumulation and soil water extraction, resulting in higher soil water availability later in the season. This experiment examined the available soil water and N interactions to identify the optimum N management strategy to optimise canola profitability.

The experimental approach included using a rain-out shelter combined with drip irrigation to implement multiple in-crop soil water regimes. The experiment was conducted at Wagga Wagga.

All treatments started with a full soil water profile due to above average summer rainfall between December 2021 and March 2022. Three water regimes were tested:

- one which remained full (through dripper irrigation)
- one which was topped up at flowering with 100 mm supplementary water applied
- one which was not topped up at all.

The soil water treatments were overlaid with a range of N rates and timings to assess the interaction between these 2 management factors. One mid season hybrid cultivar was sown in mid April to flower within the optimal flowering window for Wagga Wagga.

With increasing fertiliser prices it is important for growers to manage in-season N requirements based on water availability and seasonal conditions. Refining N management strategies will also increase confidence to grow canola in low rainfall regions and provide the indirect benefits of a disease and weed break for the cereal-dominant rotations in these environments.

Site details

Location	Wagga Wagga Agricultural Institute, Wagga Wagga
Soil type	Red kandosol
Rainfall	• Actual fallow rainfall (1 November 2021 – 31 March 2022): 316 mm • Long term average (LTA) fallow rainfall: 260 mm • Actual in-crop rainfall (21 April – 7 July; before the rainout shelter was in place): 157.8 mm • Long term average in-crop rainfall (April–June): 121.6 mm
Soil nitrogen	23 kg N/ha (0–120 cm)

Treatments

One mid season cultivar (HyTTec Trifecta) was sown on 21 April with 162 kg/ha Croplift15 starter fertiliser. This sowing time allowed this variety to flower within the correct flowering period for Wagga Wagga.

Three water regimes were imposed using a rainout shelter to exclude in-season rainfall and drip irrigation to supplement soil water. All treatments started with a near full soil water profile. Water treatments were:

- maintained profile
- 100 mm of additional water at the start of flowering (Z60)
- no irrigation or rainfall (7 July to harvest).

Nitrogen was applied to each water treatment at three rates: 0, 120 and 240 kg N/ha. The 120 kg/ha rate was applied either all at the 4–6-leaf stage or split with 60 kg/ha at the 4–6-leaf stage and 60 kg/ha just before the start of flowering.

Measurements

Soil cores were taken before sowing the experiment and from each plot at harvest for nutrient and plant available water (PAW) analysis. The soil water profile was measured throughout the season by neutron probes to a depth of 100 cm.

Plant cuts (0.5 m^2 quadrants) were taken at the:

- start of flowering (measured when 50% of the plants had one open flower)
- start of the critical growth period (100 degree days after the start of flowering)
- end of the critical growth period (500 degree days after the start of flowering).

The critical growth period is the time in the plants growth where it is more susceptible to frost or heat stress due to the large number of sensitive organs – recently opened flowers, flower buds and small pods (Kirkegaard et al. 2018).

These samples were analysed for N content as well as biomass accumulation.

The experiment was harvested at maturity by sampling one metre square hand cuts; grain yield, biomass and yield components were recorded. The following yield parameters were extrapolated from these hand harvests:

- maturity biomass (t/ha)

- grain yield (t/ha)
- seeds/pod
- pods/m^2
- pod biomass (t/ha)
- pod harvest index
- branches/plant
- branches/m^2
- pods/branch.

Results

Seasonal conditions

Rainfall from 1 November 2021 – 31 March 2022 at the experiment site was 316 mm; much higher than the long-term average of 260 mm, resulting in a full soil water profile at sowing.

The rainout shelter was moved over the experiment plots on 7 July. The site had 157.8 mm between sowing on 21 April and when the rainout shelter was moved over these plots.

Figure 1 shows the PAW (mm) from the neutron probe measurements taken throughout the season. The sharp spike in the profile that was topped up at flowering shows when the additional 100 mm of water was applied through dripper irrigation. The graph also shows the steady decline in PAW for the profile that relied on starting soil water only.

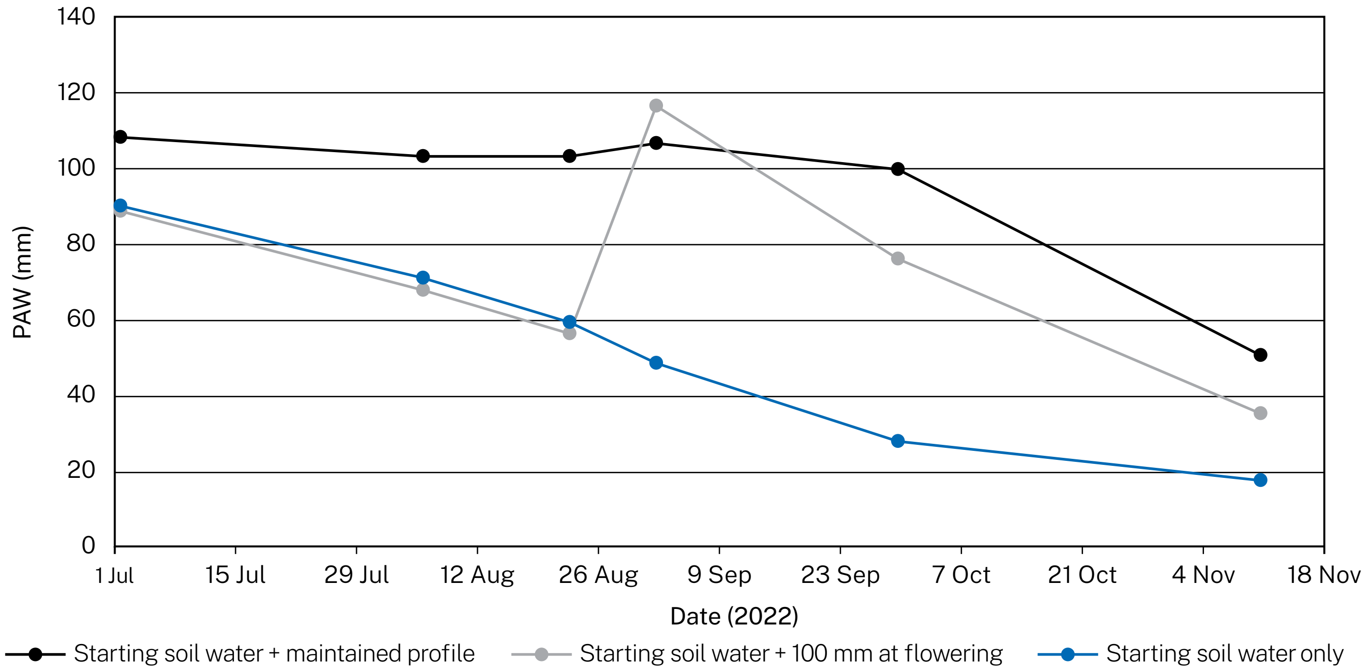


Figure 1 Neutron moisture-meter-derived PAW (mm) averaged for each water treatment.

Establishment

Target plant establishment was achieved with an average of 47 plants per square metre.

Phenology

There were no differences in flowering time between the different water treatments or N rates. This is due to all treatments receiving the same natural rainfall up until the shelter was put in place on 7 July.

Supplementary water delayed the end of flowering, therefore prolonging the flowering period; the maintained profile had the longest flowering period (Table 1). Supplementary water also delayed maturity (Table 1).

Table 1 Start of flowering dates (when 50% of plants have one open flower), end of flowering dates and maturity dates for Wagga Wagga, 2022.

Treatment	Date		
	50% flowering	End of flowering	Maturity
Starting soil water only	15 Aug	27 Sep	28 Oct
Starting soil water + 100 mm at flowering	16 Aug	30 Sep	2 Nov
Starting soil water + maintained profile	17 Aug	2 Oct	9 Nov

Plant growth and yield

Biomass accumulation varied significantly ($P<0.05$) with N rate on all 4 occasions it was measured (Table 2). This N supply effect on biomass can be attributed to the low soil N content of 23 kg/ha at sowing.

Above average rainfall until the rainout shelter was installed masked the influence of the water treatments on biomass accumulation at the start of flowering and at the start of the critical growth period. There were significant differences between biomass accumulated under the different water treatments at the end of the critical growth period and at maturity. There were no significant interactions between water treatment and N supply at any time.

Biomass accumulation was highest for the single application of 240 kg N/ha for all water treatments at all sampling times (Table 2). In the 'starting soil water + maintained profile' treatment at the 240 kg N/ha rate, there was 12.0 t/ha of biomass at the end of the critical growth period. In the 'starting soil water only' treatment at the same N rate, the biomass accumulation at the end of the critical period was 9.2 t/ha. The biomass accumulation at the end of the critical growth period from the high N rate when the profile was not topped up was higher than that of the nil N rate when the profile was topped up at flowering and when it was kept full (5.8 t/ha and 5.7 t/ha). This data shows that if there is adequate N available to the plants with adequate starting soil water only, plant biomass will still be greater than if no N is applied.

At maturity, biomass was lower than at the end of the critical growth period in most treatments. However, 3 N rates of the 'starting soil water + maintained profile' treatment (0, 120 and 120 kg N/ha split) had more biomass at maturity than at the end of the critical growth period (Table 2).

Table 2 The effect of N rate on biomass accumulation at 4 sampling occasions at Wagga Wagga, 2022.

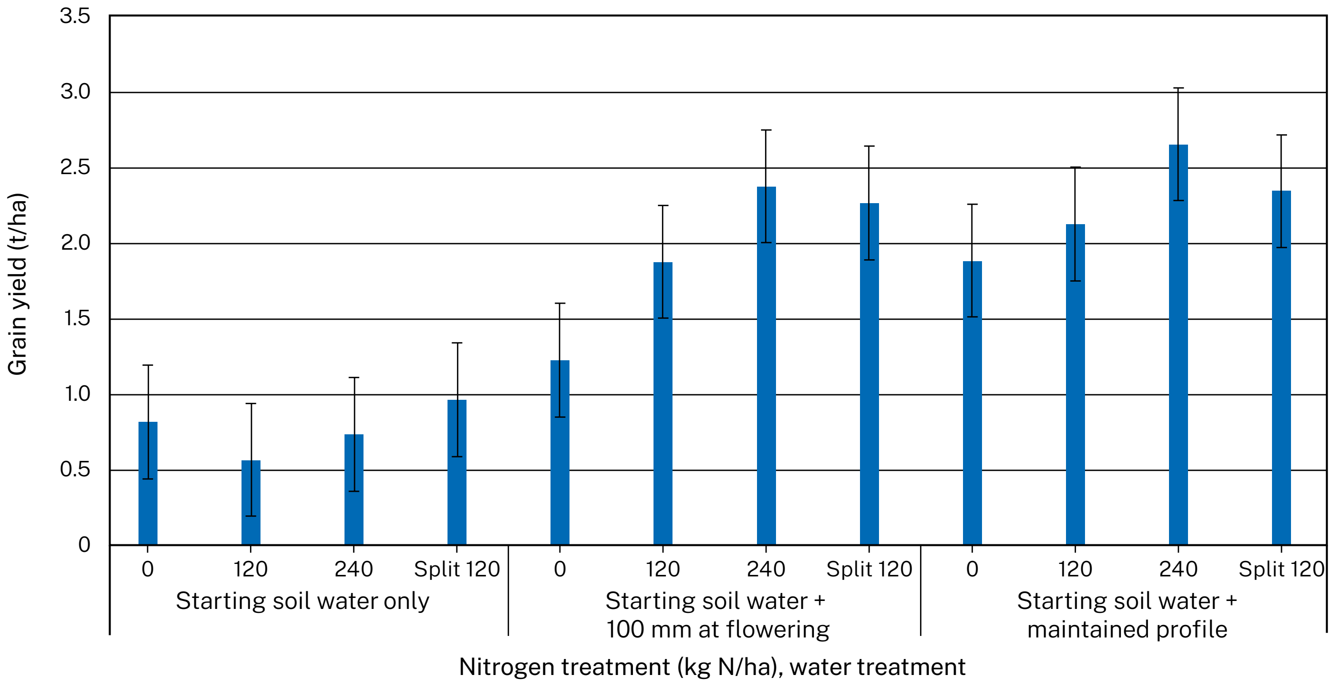
Treatment		Dry matter biomass (t/ha)			
Water treatment	**N rate**	**Start of flowering period**	**Start of critical growth period**	**End of critical growth period**	**At maturity**
Starting soil water only	0 kg N/ha	2.5	3.2	6.0	5.0
	120 kg N/ha	3.9	5.0	7.2	6.5
	240 kg N/ha	4.8	6.1	9.2	7.4
	120 kg N/ha split	4.1	5.1	7.1	7.0
Starting soil water + 100 mm at flowering	0 kg N/ha	3.1	3.7	5.8	5.3
	120 kg N/ha	4.0	5.1	9.5	8.7
	240 kg N/ha	4.8	6.6	11.5	9.7
	120 kg N/ha split	3.9	5.3	10.0	9.6
Starting soil water + maintained profile	0 kg N/ha	3.2	4.0	5.7	6.7
	120 kg N/ha	3.6	5.8	7.1	9.4
	240 kg N/ha	4.5	6.4	12.0	10.4
	120 kg N/ha split	3.4	5.0	6.9	9.3
P-value (water)		0.799	0.599	0.031	<0.001
P-value (N supply)		0.005	<0.001	<0.001	<0.001
P-value (interaction)		0.913	0.974	0.264	0.54
l.s.d. P = 0.05 (water)		n.s.	n.s.	1.356	0.918
l.s.d. P = 0.05 (N supply)		0.875	1.081	1.566	1.06
l.s.d. P = 0.05 (interaction)		n.s.	n.s.	n.s.	n.s.

n.s. = not significant.

Splitting the 120 kg N/ha increased yield above the single application of 120 kg N/ha at the 4–6-leaf stage for all water scenarios.

There were significant differences in grain yields between water treatments and N treatments (Figure 2). The highest yield (2.65 t/ha) came from the 'starting soil water + maintained profile' treatment at the high N rate (240 kg N/ha). The high N rate in the 'starting soil water + 100 mm at flowering' and the split rate of N in the 'starting soil water + maintained profile' treatments yielded around 300 kg/ha less than the highest yield achieved.

Bird damage reduced yields in the 'starting soil water only' water treatment. However, there was still only a reduction of 240 kg/ha in the highest yielding N rate within this treatment (120 kg N/ha split) compared with the nil N rate in the 'starting soil water + 100 mm at flowering' treatment. The high N rate of 240 kg N/ha in the 'starting soil water only' treatment yielded 0.73 t/ha (Figure 2).



Vertical bars indicate l.s.d. ($P<0.05$).

Figure 2 Grain yield (t/ha) for each N treatment within each water treatment scenario.

Water use efficiency

Neutron probes were read when biomass was sampled. A calibration was created and used to monitor the change in soil water of each plot monitored over the growing season. The change in soil water from 0–110 cm was used to estimate crop water use (CWU) during 3 growth periods: the 'pre-critical period', during the 'critical period' and the post 'critical period'. Assuming no deep drainage below the root zone, CWU was calculated as:

$$CWU\ (mm) = (I + R) - \Delta S$$

Where I is applied water (mm), R is rainfall (mm) and ΔS is the change is soil water (mm) during a given period.

Water use during the critical growth period and the total water use was significant between N rates, although no interaction between water scenario and N rate was observed. Water use was higher during the pre-critical growth period in the 'starting soil water only' and 'starting soil water + 100 mm at flowering' treatments than during the critical growth period. In the 'starting soil water + maintained profile' treatment the water use was similar for the pre-critical growth period and critical growth period. (Table 3).

Total water use, and in most cases, water use in the pre-critical growth period and during the critical growth period was lower in the nil N treatments for all water scenarios. The 120 kg N/ha split application had similar water use to the higher single application of 240 kg N/ha in the 'starting soil water + 100 mm at flowering' and 'starting soil water + maintained profile' water scenarios.

Water use efficiency (WUE) (grain yield / crop water use) was significantly different between water scenarios, however, it was not significant between N treatments. WUE was higher in the 'starting soil water + maintained profile' scenario in all N rates compared with the other water scenarios (Table 3).

Table 3 Crop water use and WUE across all N treatments and each water scenario for Wagga Wagga, 2022.

Treatment		Crop water use (mm)			
Water treatment	**N rate**	**Pre-critical growth period**	**During critical growth period**	**Total**	**WUE (kg/ha/mm)**
Starting soil water only	0 kg N/ha	32	17	49	16.9
	120 kg N/ha	46	17	63	9.0
	240 kg N/ha	45	24	70	10.5
	120 kg N/ha split	43	24	68	14.0
Starting soil water + 100 mm at flowering	0 kg N/ha	69	34	103	11.7
	120 kg N/ha	68	49	117	14.7
	240 kg N/ha	80	44	124	19.3
	120 kg N/ha split	70	52	121	18.7
Starting soil water + maintained profile	0 kg N/ha	59	50	109	17.2
	120 kg N/ha	61	57	118	17.9
	240 kg N/ha	62	62	124	21.3
	120 kg N/ha split	65	58	123	19.2
P-value (water)		<0.001	<0.001	<0.001	0.031
P-value (N supply)		0.074	<0.001	<0.001	0.533
P-value (interaction)		0.466	0.172	0.993	0.417
l.s.d. *P* = 0.05 (water)		6.12	4.22	6.83	4.6
l.s.d. *P* = 0.05 (N supply)		n.s.	4.87	7.89	n.s.
l.s.d. *P* = 0.05 (interaction)		n.s.	8.44	n.s.	n.s.

n.s. = not significant.

Canola

Nitrogen use efficiency

Crop biomass and shoot N content was measured at the start of the critical growth period, the end of the critical growth period and at maturity to estimate N uptake. Nitrogen uptake varied significantly ($P<0.05$) between N treatments between the start of the critical growth period, end of the critical growth period and maturity. Significant differences ($P<0.05$) between water treatments for N uptake were seen at the end of the critical growth period and maturity.

Nitrogen uptake at the end of the critical growth period varied largely depending on the N treatment however, it was fairly consistent between water treatments. Higher N rates resulted in higher N uptake across all water treatments. The split N treatment resulted in higher N uptake at the start of the critical growth period, end of the critical growth period and at maturity compared with the equivalent rate single application. This effect was consistent across all 3 water treatments (Figure 3).

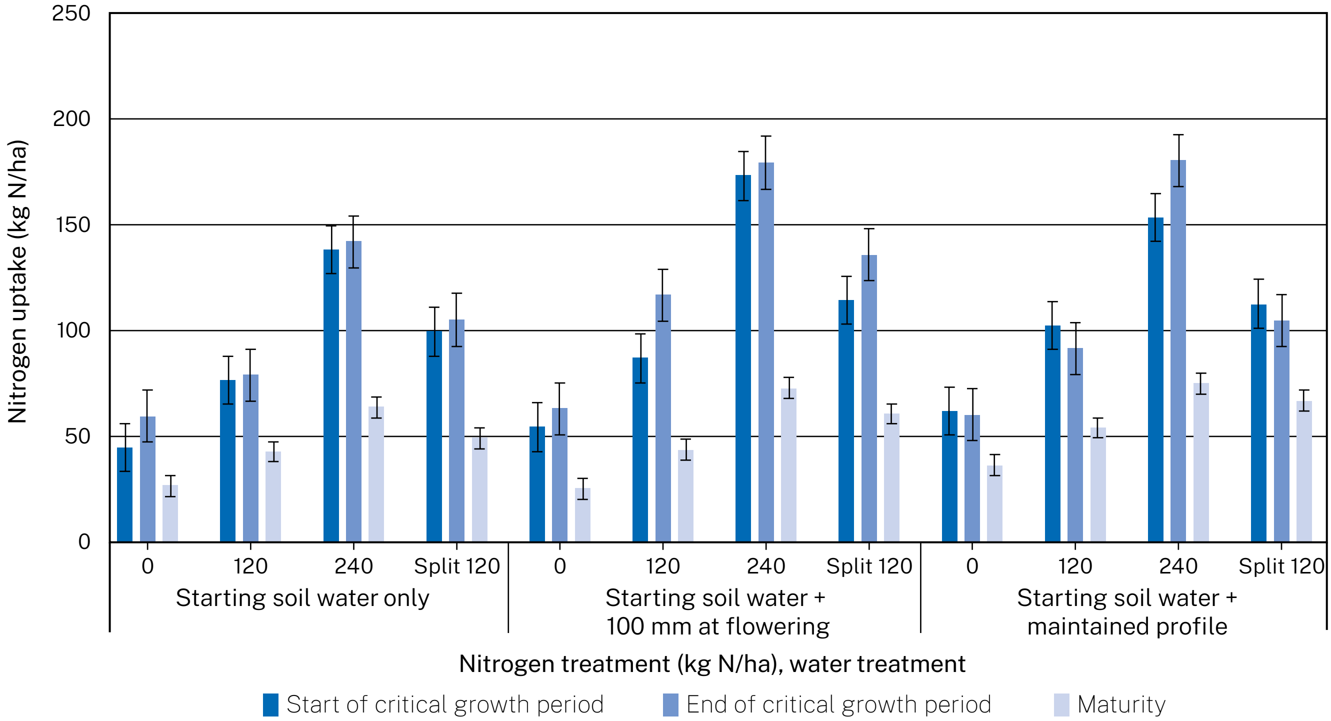
Nitrogen use efficiency (NUE) and growing season mineralisation was calculated using the following formulas (Riar et al. 2020):

$$\text{NUE (kg/kg)} = \frac{\text{Grain yield (kg/ha)}}{\text{Soil mineral N (kg/ha) + mineralisation N (kg/ha) + fertiliser N (kg/ha)}}$$

Mineralisation N (kg/ha) = 0.15 × (growing season rainfall + supplementary water (mm)) × soil organic matter (%)

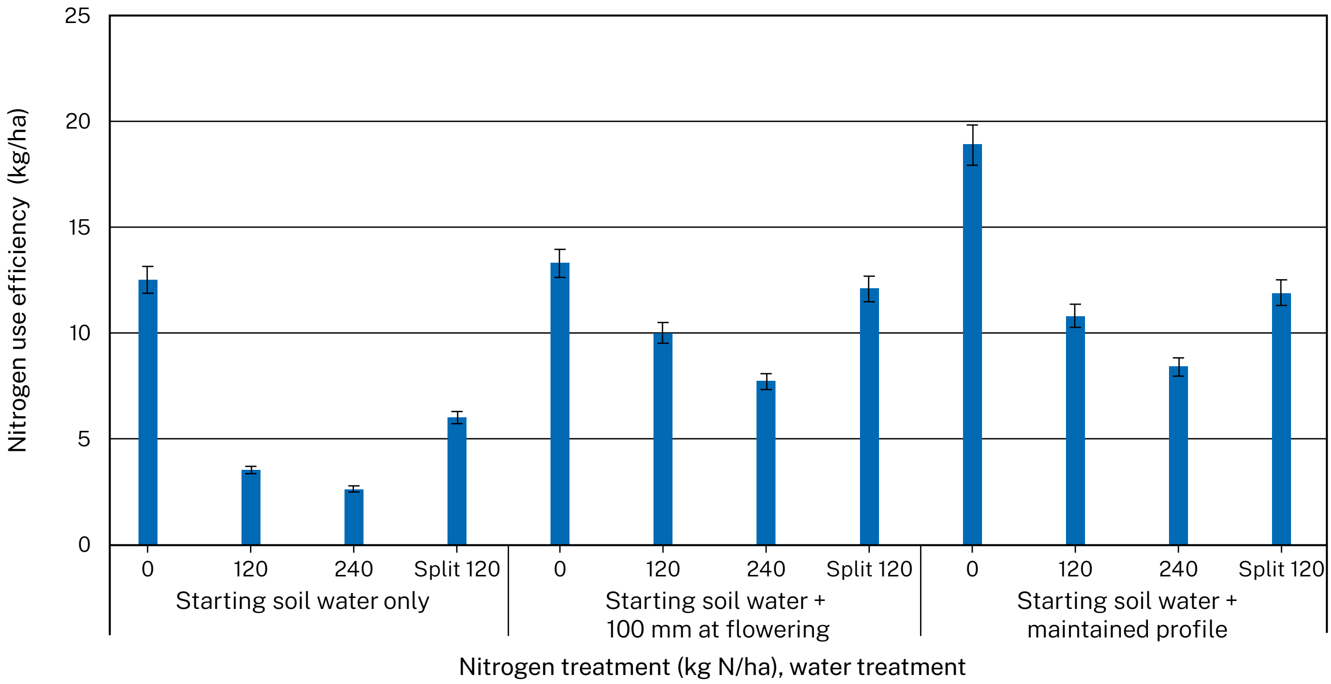
Nitrogen use efficiency at Wagga Wagga varied significantly ($P<0.05$) between water treatments and N supply treatments with no significant interactions found.

Nitrogen use efficiency was highest in the nil N rate treatments for each water treatment, the highest NUE resulting from the 'starting soil water + maintained profile' treatment. A 120 kg N/ha split application resulted in a higher NUE than a single application of 120 kg N/ha and 240 kg N/ha in all water scenarios (Figure 4).



Vertical bars indicate l.s.d. (*P*<0.05).

Figure 3 Crop nitrogen uptake for each N rate within each water treatment at different growth stages in the Wagga Wagga field experiment.



Vertical bars indicate l.s.d. (*P*<0.05).

Figure 4 Nitrogen use efficiency across each water and N supply treatment in the Wagga Wagga field experiment.

Summary

Yields were highest when N rate and water availability were maximised. When starting the growing season with a full soil water profile, grain yield was not affected by having high soil water availability throughout the season or allowing it to decline until flowering when it was replenished with a 100 mm irrigation.

A medium rate of N (120 kg N/ha) as a split application reduced early reproductive stage biomass (when water was available), however, a similar grain yield was achieved from a single application of 120 kg N/ha applied at the 4–6-leaf growth stage. By maturity, the biomass from a split application was either comparable or greater than the biomass from a single application of 120 kg N/ha. The 120 kg N/ha split application improved NUE by 20% when the profile was topped up at flowering when compared with applying 120 kg N/ha upfront.

A split application of N can be used as a management strategy to minimise upfront N fertiliser cost, reducing the financial risk, but still leaving the option to top up N supply later in the season without reducing yield potential.

Further work is needed to establish if splitting the N rate in different proportions and at different total N rates rather than an even split will achieve similar results.

Canola

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Faba bean, chickpea, lupin, lentil, field pea and vetch variety experiments –Wagga Wagga 2022

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Key findings

- Mild wet conditions favoured high grain yields in faba bean varieties. The average across all varieties tested was 5.80 t/ha. PBA Zahra^(D), PBA Nanu^(D), PBA Samira^(D) and Nura^(D) all yielded over 6 t/ha.
- In comparison, grain yields were for lentil (2.41 t/ha), field pea (3.87 t/ha), albus lupin (2.90 t/ha), narrow-leaf lupin (3.13 t/ha) and vetch (3.64 t/ha).
- Cool spring temperatures negatively impacted chickpea crops, causing delayed pod formation and reduced yield potential for both desi and kabuli varieties, averaging 2.24 t/ha 1.20 t/ha, respectively, well below expectations.

Keywords Wagga Wagga, 2022, pulses, legumes, variety, phenology, lupin, lentil, chickpea, field pea, vetch, faba bean, phenology, establishment, flowering, grain yield

Introduction

Pulse varietal experiments were conducted in 2022 at the Wagga Wagga Agricultural Institute. Establishment, crop phenology, days to flowering, flowering duration, and grain yield responses for commercially available albus lupin (3), narrow-leaf lupin (6), lentil (6), desi chickpea (6), kabuli chickpea (3), field pea (8), faba bean (15) and vetch (4) varieties were evaluated (Table 1). This paper reports the findings from these experiments.

Site details

Location	Wagga Wagga Agricultural Institute, Wagga Wagga
Soil type	Red kandosol
Soil pH_{Ca}	5.2 (0–10 cm), 5.3 (10–30 cm), 5.8 (30–50 cm), 5.7 (50–90 cm), 6.3 (90–120 cm)
Previous crop	Wheat
Rainfall	• Fallow (December 2021 – March 2022): 202 mm • Fallow long-term average (LTA): 158 mm • In-crop (April–October): 466 mm • In-crop LTA: 330 mm
Fertiliser	Mono-ammonium phosphate (MAP) 100 kg/ha, 50% and single super phosphate (SSP) 50% (blend) (nitrogen [N]:5, phosphorus [P]:15.4, potassium [K]:0, sulfur [S]:6.25).
Sowing and harvest date	See Table 2

Treatments

Variety

Table 1 Pulse and legume species and varieties evaluated at Wagga Wagga Agricultural Institute in 2022.

Species	Type	Variety
Lupin	Albus	Rosettaᶲ, Luxorᶲ, Murringoᶲ
	Narrow-leaf	Jindaleeᶲ, Mandelupᶲ, PBA Batemanᶲ, PBA Gunyidiᶲ, PBA Jurienᶲ, Wongaᶲ
Lentil	Red	PBA Aceᶲ, PBA Boltᶲ, PBA Hallmark XTᶲ, PBA Jumbo2ᶲ, PBA Kelpie XTᶲ
	Green	PBA Greenfieldᶲ
Chickpea	Desi	PBA Boundaryᶲ, PBA Slasherᶲ, PBA Strikerᶲ, CBA Captainᶲ, PBA HatTrickᶲ, PBA Drummondᶲ
	Kabuli	PBA Royalᶲ, PBA Magnusᶲ, Genesis™090
Field pea	Kaspa	PBA Butlerᶲ, PBA Taylorᶲ, PBA Whartonᶲ
	White	PBA Pearlᶲ, Sturtᶲ
	Dun	PBA Percyᶲ, PBA Ouraᶲ
	Blue	PBA Noosaᶲ
Faba bean		Cairoᶲ, Dozaᶲ, Farahᶲ, Nuraᶲ, FBA Aylaᶲ, Fiesta VF, PBA Amberleyᶲ, PBA Bendocᶲ, PBA Marneᶲ, PBA Nanuᶲ, PBA Nasmaᶲ, PBA Ranaᶲ, PBA Samiraᶲ, PBA Wardaᶲ, PBA Zahraᶲ
Vetch		Moravaᶲ, Studenicaᶲ, Timokᶲ, Volgaᶲ

Table 2 Sowing and harvest dates for the 6 species evaluated in variety experiments at Wagga Wagga Agricultural Institute in 2022.

Species	Sowing date	Harvest date
Lupin – albus and narrow-leaf	17 May 2022	9 January 2023
Lentil	17 May 2022	11 January 2023
Chickpea – desi and kabuli	17 May 2022	6 January 2023
Field pea	20 June 2022	6 January 2023
Faba bean	5 May 2022	12 January 2023
Vetch	18 May 2022	20 January 2023

Seasonal conditions

The 2022 season started with high stored soil water levels. Over 110 mm of rain fell in January, well above the LTA of 40.5 mm (Figure 1). Rainfall from August onwards was close to or in excess of the LTA, which resulted in very wet conditions and increased pressure from fungal pathogens and insects. Plentiful in-crop moisture combined with a mild growing season resulted in large biomass developing in all pulse species. These conditions favoured fungal pathogens which were hard to control due to the dense crop canopies. Lower than expected temperatures delayed the start of pod formation, especially in chickpeas, which reduced their potential yield. For other pulse species, such as faba bean, lupin and field pea, the milder spring conditions were conducive to the development of high grain yields.

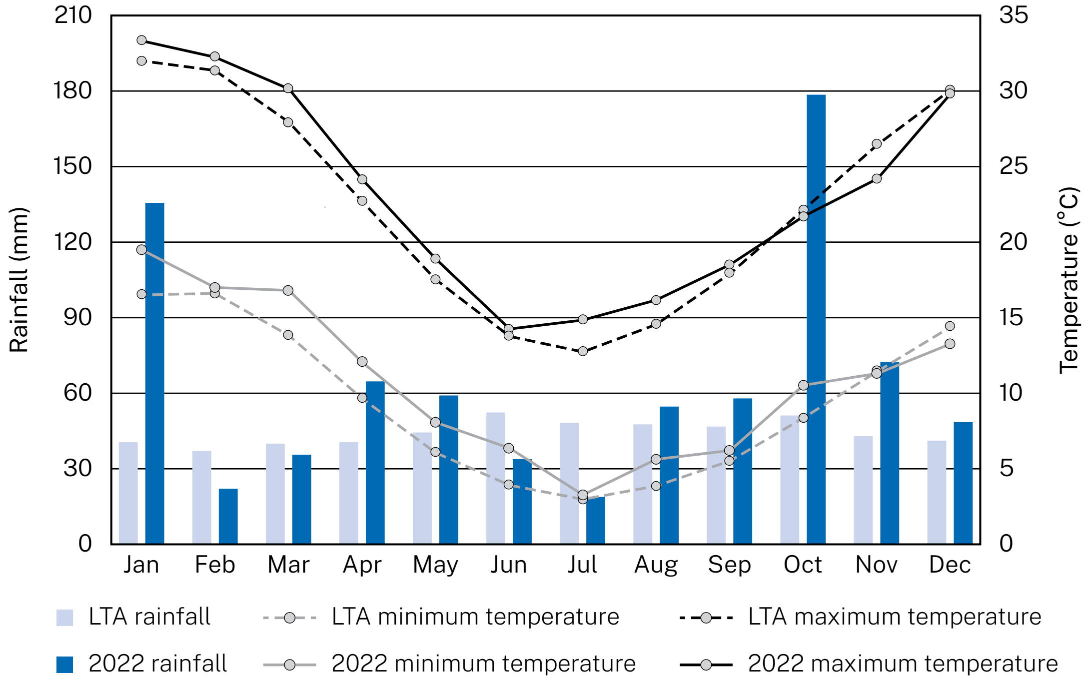

Figure 1 Monthly rainfall and temperature for Wagga Wagga Agricultural Institute in 2022, and associated long-term averages.

Results

Lupin

Albus

Grain yields of all 3 varieties were similar with a site mean of 2.90 t/ha (Table 3).

Plant establishment for all varieties was similar and close to the optimal rate for southern NSW (35 plants/m²).

There was a difference of 6 days between the earliest and latest flowering variety. Murringo⦶ started flowering on 2 September, 4 days before Luxor⦶ and 6 days before Rosetta⦶.

Flowering duration was significantly longer for Murringo⦶ (96.7 days) compared with either Luxor⦶ or Rosetta⦶ (88.3 and 88.7 days respectively).

The average flowering duration for albus lupin was 91.2 days, twice as long as narrow-leaf lupin at 46.3 days (tables 3 and 4).

Table 3 Albus lupin variety experiment results at Wagga Wagga Agricultural Institute in 2022.

Variety	Establishment (plants/m²)	Date of 50% flowering	Date of flower end	Flowering duration (days)	Grain yield (t/ha)	Seed weight (g/100 seeds)
Luxor	35.5	6 Sep	3 Dec	88.3	2.92	35.2
Murringo	35.9	2 Sep	7 Dec	96.7	2.98	34.8
Rosetta	36.2	5 Sep	5 Dec	88.7	2.83	34.8
Site mean	35.8	5 Sep	5 Dec	91.2	2.90	35.0
l.s.d. (*P*<0.05)	n.s.	3.2	2.9	3.7	n.s.	n.s.

l.s.d. = least significant difference; n.s. = not significant.

Narrow-leaf

Jindalee⊕ had the highest grain yield (4.06 t/ha), significantly higher than all other varieties (Table 4). PBA Jurien⊕, PBA Gunyidi⊕ and Mandelup⊕ had grain yields of 3.23 t/ha, 3.17 t/ha and 3.01 t/ha respectively and were similar to each other. Wonga⊕ had the lowest grain yield at 2.30 t/ha, a 40% reduction when compared with Jindalee⊕.

Establishment was similar for the 6 varieties with a site mean of 38.7 plants/m², comparable with the optimal rate for southern NSW (35 plants/m²).

There were significant differences between varieties for days to flower, days to end of flowering and flowering duration. PBA Bateman⊕ and PBA Jurien⊕ were the first varieties to flower (4 September). PBA Gunyidi⊕ and Mandelup⊕ flowered within the next 2 days, whereas Jindalee⊕ was the last to flower (17 September).

Table 4 Narrow-leaf lupin variety experiment results at Wagga Wagga Agricultural Institute in 2022.

Variety	Establishment (plants/m²)	Date of 50% flowering	Date of flower end	Flowering duration (days)	Grain yield (t/ha)	Seed weight (g/100 seeds)
Jindalee	34.6	17 Sep	12 Nov	56.1	4.06	14.1
PBA Jurien	38.0	4 Sep	22 Oct	48.3	3.23	14.5
PBA Gunyidi	39.0	5 Sep	23 Oct	48.1	3.17	14.3
Mandelup	40.1	6 Sep	22 Oct	45.9	3.01	14.5
PBA Bateman	41.8	4 Sep	8 Oct	34.0	2.74	15.1
Wonga	39.3	9 Sep	25 Oct	45.5	2.30	13.0
Site mean	38.7	8 Sep	24 Oct	46.3	3.13	14.4
l.s.d. (*P*<0.05)	n.s.	1.1	0.8	2.0	0.35	n.s.

l.s.d. = least significant difference; n.s. = not significant.

Lentil

There was no varietal difference for establishment and the site mean was 121.4 plants/m² (Table 5).

Grain yields varied across the varieties. PBA Ace⊕ had the highest yield (2.75 t/ha), similar to all varieties except PBA Greenfield⊕ (1.75 t/ha).

There were varietal differences in hundred seed weight (g/100 seeds):

- PBA Jumbo2⊕ and PBA Kelpie XT⊕ (large red seeded lentils): over 4 g/100 seeds
- PBA Greenfield (medium green seeded lentil): 3.7 g/100 seeds
- the other varieties (medium red seeded lentils): 3.5–3.7 g/100 seeds.

The first variety to flower was PBA Kelpie XT⊕ (12 September), PBA Ace⊕ was the last to flower, 10 days later.

Pulses

Table 5 Lentil variety experiment results at Wagga Wagga Agricultural Institute in 2022.

Variety	Establishment (plants/m²)	Date of 50% flowering	Grain yield (t/ha)	Seed weight (g/100 seeds)
PBA Ace	121.0	22 Sep	2.75	3.7
PBA Bolt	112.6	13 Sep	2.72	3.5
PBA Kelpie XT	130.8	12 Sep	2.54	4.1
PBA Jumbo2	127.7	20 Sep	2.42	4.2
PBA Hallmark XT	116.5	15 Sep	2.31	3.5
PBA Greenfield	120.2	21 Sep	1.75	3.7
Site mean	121.4	17 Sep	2.41	3.8
l.s.d. (*P*<0.05)	n.s.	2.1	0.48	0.2

l.s.d. = least significant difference; n.s. = not significant.

Chickpea

Desi

In this experiment, PBA Drummond⦶ and PBA Slasher⦶ had a slightly higher establishment rate than all the other varieties (Table 6).

The 4 highest yielding varieties, CBA Captain⦶ (2.52 t/ha), PBA Slasher⦶ (2.41 t/ha), PBA Boundary⦶ (2.38 t/ha) and PBA Striker⦶ (2.34 t/ha), were statistically similar. In contrast PBA HatTrick⦶ and PBA Drummond⦶ were 23% and 25% lower yielding, respectively, when compared with CBA Captain⦶. During the 2022 growing season, the average daily temperature did not consistently rise above 15 °C until 18 October, and the ongoing sub-optimal temperatures throughout the spring significantly reduced yield potential.

Grain yield was lower than anticipated and might be due to observed diseases and delayed pod set from the cool spring temperatures. Chickpea varieties started to flower between 16 September (PBA HatTrick⦶) and 26 September (PBA Boundary⦶), a range of 10 days.

Table 6 Desi chickpea variety experiment results at Wagga Wagga Agricultural Institute in 2022.

Variety	Establishment (plants/m²)	Date of 50% flowering	Grain yield (t/ha)	Seed weight (g/100 seeds)
CBA Captain	39.1	20 Sep	2.52	22.3
PBA Slasher	44.7	25 Sep	2.41	19.9
PBA Boundary	40.6	26 Sep	2.38	20.9
PBA Striker	41.5	24 Sep	2.34	23.3
PBA HatTrick	37.2	16 Sep	1.92	20.5
PBA Drummond	46.2	22 Sep	1.87	23.5
Site mean	41.5	22 Sep	2.24	21.7
l.s.d. (*P*<0.05)	4.5	1.8	0.42	1.3

l.s.d. = least significant difference.

Kabuli

Kabuli chickpea varieties had a site mean yield of 1.20 t/ha (Table 7). The low yields compared with other pulse species was in part due to fungal pathogen infections and cool spring temperatures. The low yield reflected the below LTA spring temperatures. Chickpea varieties are sensitive to temperatures below an average of 15 °C, during pod set. The average temperature at Wagga Wagga did not consistently exceed 15 °C until 18 October. This reduced the effective yield formation window, resulting in a relatively lower yield when compared with other pulse and legume species. Both Genesis™090 (1.43 t/ha) and PBA Royal⁽ᐞ⁾ (1.39 t/ha) had yields that were 180% higher than PBA Magnus⁽ᐞ⁾ (0.79 t/ha). Optimal plant establishment is between 30 plants/m² and 35 plants/m². The site average of 36.5 plants/m² was slightly higher than optimal when averaged over the 3 varieties.

PBA Magnus⁽ᐞ⁾ (28 September) was the earliest to flower, followed by PBA Royal⁽ᐞ⁾ (3 October). Genesis™090 (6 October) was the last variety to flower.

With relatively large, accumulated biomass, and high winds and rainfall in October, November and December, PBA Magnus⁽ᐞ⁾ lodged severely, scoring 8.3 on a scale of 1–9 where 9 indicates plants are flat on the ground. In contrast, Genesis™090 and PBA Royal⁽ᐞ⁾ were still standing with lodging scores of 4.0 and 3.3, respectively.

Table 7 Kabuli chickpea variety experiment results at Wagga Wagga Agricultural Institute in 2022.

Variety	Establishment (plants/m²)	Date of 50% flowering	Lodging score++	Grain yield (t/ha)	Seed weight (g/100 seeds)
Genesis090	38.4	6 Oct	4.0	1.43	31.4
PBA Royal	37.2	3 Oct	3.3	1.39	30.4
PBA Magnus	34.0	28 Sep	8.3	0.79	42.1
Site mean	36.5	2 Oct	5.2	1.20	34.6
l.s.d. (*P*<0.05)	n.s.	1.6	3.8	0.43	8.0

l.s.d. = least significant difference; n.s. = not significant; ++Lodging score: 1 = erect plants, 9 = severe lodging.

Field pea

The average field pea grain yield for the site was 2.87 t/ha. The highest yielding varieties (PBA Taylor⁽ᐞ⁾ and PBA Butler⁽ᐞ⁾, 4.42 t/ha) had a yield advantage of 128% when compared with the lowest yielding variety (Sturt⁽ᐞ⁾, 3.15 t/ha) (Table 8). Four of the 8 varieties tested had grain yields over 4 t/ha (PBA Taylor⁽ᐞ⁾, PBA Butler⁽ᐞ⁾, PBA Noosa⁽ᐞ⁾ and PBA Percy⁽ᐞ⁾).

There was a 13-day difference between the earliest flowering variety (PBA Percy⁽ᐞ⁾, 23 September) and the latest flowering variety (PBA Butler⁽ᐞ⁾, 6 October).

Vetch

Morava⁽ᐞ⁾ had the highest grain yield at 3.69 t/ha while Timok⁽ᐞ⁾ (3.26 t/ha) and Volga⁽ᐞ⁾ (2.96 t/ha) were statistically similar (Table 9).

Plant establishment rates depend on the crop's end use. Establishment rates for the varieties ranged from 43.5 plants/m² to 49.5 plants/m², which was within the optimal establishment rate for grain production.

Studenica⁽ᐞ⁾ was the earliest to flower (6 September), followed by Volga⁽ᐞ⁾ (12 September), Timok⁽ᐞ⁾ (13 September) and Morava⁽ᐞ⁾ (22 September).

Table 8 Field pea variety experiment results at Wagga Wagga Agricultural Institute in 2022.

Variety	Establishment (plants/m²)	Date of 50% flowering	Date of flower end	Flowering duration (days)	Grain yield (t/ha)	Seed weight (g/100 seeds)
PBA Taylor	43.3	3 Oct	12 Nov	40.1	4.42	21.3
PBA Butler	42.6	6 Oct	12 Nov	35.5	4.42	21.9
PBA Noosa	43.4	30 Sep	12 Nov	44.4	4.12	21.1
PBA Percy	38.2	23 Sep	16 Nov	55.4	4.00	24.8
PBA Pearl	49.8	29 Sep	14 Nov	46.1	3.75	20.5
PBA Wharton	49.3	5 Oct	11 Nov	36.9	3.60	21.1
PBA Oura	46.3	27 Sep	12 Nov	45.6	3.47	21.8
Sturt	36.2	27 Sep	n.a.	n.a.	3.15	17.9
Site mean	43.7	30 Sep	13 Nov	43.4	3.87	21.3
l.s.d. (*P*<0.05)	7.15	1.7	0.8	2.4	0.26	1.6

l.s.d. = least significant difference; n.a. = not recorded

Table 9 Vetch variety experiment results at Wagga Wagga Agricultural Institute in 2022.

Variety	Establishment (plants/m²)	Establishment score*	Early vigour++	Date of 50% flowering	Grain yield (t/ha)
Morava	45.1	7.7	8.2	22 Sep	3.69
Timok	46.0	8.4	8.2	13 Sep	3.26
Volga	49.5	8.6	8.7	11 Sep	2.96
Studenica	43.5	8.3	8.3	6 Sep	2.48
Site mean	46.7	8.3	8.4	14 Sep	3.64
l.s.d. (*P*<0.05)	5.8	n.s.	n.s.	1.4	0.8

l.s.d. = least significant difference; n.s. = not significant; *Establishment score: 1 = poor plant establishment, 9 = high plant establishment; ++Early vigour score: 1 = less vigorous growth, 9 = vigorous growth.
Data provided by the Vetch Breeding Program.

Faba bean

Plentiful moisture and mild temperatures were ideal for faba bean productivity and yield was in excess of 5 t/ha for all varieties. The highest yielding varieties PBA Zahraᶲ (7.11 t/ha), PBA Nanuᶲ (6.79 t/ha), PBA Samiraᶲ (6.52 t/ha) and Nuraᶲ (6.16 t/ha) were statistically similar and all over 6 t/ha (Table 10).

Plant establishment was assessed visually as acceptable (scores ranging from 7.6 to 9.0) with all varieties except PBA Bendocᶲ and PBA Ranaᶲ being similar.

There were varietal differences in early plant vigour (visual assessment of plant growth). PBA Nanuᶲ, PBA Samiraᶲ, Nuraᶲ, Dozaᶲ, PBA Bendocᶲ, FBA Aylaᶲ, PBA Amberleyᶲ, PBA Marneᶲ and Fiesta VF all had lower scores than PBA Wardaᶲ (8.3).

There was a range of flowering dates and durations which reflected the origin of the varieties. Varieties more suited to northern NSW started flowering on 8 August and flowered for 50 days, whilst varieties more suited to southern NSW started flowering on 20 August and flowered for 57 days (Table 10).

Table 10 Faba bean variety experiment results at Wagga Wagga Agricultural Institute in 2022.

Variety	Establishment score++	Vigour score†	Date of 50% flowering	Flowering duration (days)	Maturity score*	Grain yield (t/ha)
PBA Zahra	8.6	7.9	22 Aug	55.3	3.6	7.11
PBA Nanu	7.7	7.1	8 Aug	49.4	4.0	6.79
PBA Samira	9.0	6.9	25 Aug	54.3	3.7	6.52
Nura	8.4	6.7	24 Aug	54.2	3.0	6.16
PBA Warda	8.3	8.3	8 Aug	50.3	1.9	5.86
Doza	8.7	7.3	7 Aug	51.4	4.0	5.81
PBA Bendoc	7.6	5.8	20 Aug	58.5	2.6	5.79
Cairo	8.7	7.8	7 Aug	50.1	3.7	5.74
PBA Nasma	8.3	7.5	10 Aug	48.6	3.1	5.71
FBA Ayla	8.3	6.9	8 Aug	50.1	3.4	5.61
PBA Amberley	7.7	7.1	24 Aug	57.3	5.0	5.56
PBA Marne	8.7	6.8	15 Aug	59.4	3.0	5.38
Fiesta VF	8.0	6.8	12 Aug	65.6	3.2	5.17
Farah	8.4	7.4	15 Aug	62.5	3.4	5.16
PBA Rana	7.6	7.5	24 Aug	49.7	3.3	4.86
Site mean	8.1	7.1	17 Aug	55.1	3.2	5.80
l.s.d. (P<0.05)	1.3	0.9	2.9	6.1	1.6	1.0

l.s.d. = least significant difference; ++Establishment score: 1 = poor plant establishment, 9 = high plant establishment; †Vigour Score 1 = low, 9 = high; *Maturity score: 1 = early, 9 = late.
Data provided by Faba Bean Breeding Australia.

Pulses

Summary

The 2022 winter cropping season was long and wet, with above average rainfall throughout the year. Mild temperatures and ample rainfall throughout the growing season resulted in substantial biomass being generated with high canopy humidity. The resulting fungal pathogens needed multiple fungicide applications for control.

Grain yields varied between the different species. The average faba bean yield (5.80 t/ha) was 4.8 times the average yield of kabuli chickpea (1.20 t/ha). Faba beans prefer higher rainfall environments which prevailed in 2022. In contrast, the low average air temperatures, which did not consistently exceed 15 °C until 18 October, delayed the beginning of yield accumulation in chickpea varieties and limited yield potential. The average yield of desi (2.24 t/ha) and kabuli (1.20 t/ha) chickpea was low when compared with the other pulse species. The other pulse species had higher average site grain yields: field pea (3.87 t/ha), vetch (3.64 t/ha), lentil (2.41 t/ha), narrow-leaf lupin (3.13 t/ha) and albus lupin (2.90 t/ha).

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Faba bean, chickpea, lupin, lentil and vetch variety experiments – Rankins Springs 2022

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Key findings

- Faba bean had the highest average grain yield (4.50 t/ha) of all the legume and pulse species, with yields ranging from 3.38 t/ha to 5.28 t/ha. Vetch had the second highest average grain yield (3.90 t/ha).
- The average albus lupin yield (3.38 t/ha) was higher than the average narrow-leaf lupin yield (3.11 t/ha).
- Cool spring temperatures delayed pod formation, resulting in reduced yield potential for both desi and kabuli chickpea varieties, well below expectations.

Keywords

Rankins Springs, 2022, pulses, legumes, variety, phenology, chickpea, faba bean, lupin, lentil, vetch, waterlogging, establishment, phenology, grain yield, flowering, seed weight, botrytis grey mould

Introduction

Variety experiments were conducted at Rankins Springs in 2022 to evaluate the phenology and grain yield responses of 6 faba bean, 6 narrow-leaf lupin, 3 albus lupin, 4 vetch, 3 kabuli chickpea and 11 lentil varieties (Table 1). Data was collected to assess each variety's establishment (scores), flowering dates, maturity rating, grain yield and seed weight.

Additional chickpea evaluation experiments were conducted at Rankins Springs from 2017 to 2022 to assess a range of commercially available chickpea cultivars (Table 1). The predicted mean yield values from these experiments are also presented.

Site details

Location	Hillside, Rankins Springs (33°58'9.39"S, 146°8'16.77"E) NSW
Soil type	Red chromosol
Soil pH_{Ca}	4.8 (0–10 cm), 5.5 (10–30 cm), 6.0 (30–50 cm), 7.7 (50–90 cm), 8.3 (90–120 cm)
Previous crop	Wheat
Rainfall	• Fallow (December 2021 – March 2022): 297 mm • Fallow long-term average (LTA): 131 mm • In-crop (April–October): 449 mm • In-crop LTA (April–October): 233 mm
Fertiliser	Mono-ammonium phosphate (MAP) 100 kg/ha, 50% and single super phosphate (SSP) 50% (blend) (nitrogen [N]:5; phosphorus [P]:15.4; potassium [K]:0; sulfur [S]:6.25).

Sowing and harvest date	See Table 2

Treatments

Variety

Table 1 Pulse and legume species and varieties evaluated at Rankins Springs in 2022*.

Species	Type	Variety	
Faba bean		PBA Amberleyɸ, PBA Bendocɸ, PBA Marneɸ, PBA Nanuɸ, PBA Nasmaɸ, PBA Samiraɸ	
Lupin	Narrow-leaf	Jindaleeɸ, Mandelupɸ, PBA Batemanɸ, PBA Gunyidiɸ, PBA Jurienɸ, Wongaɸ	
	Albus	Luxorɸ, Murringoɸ, Rosettaɸ	
Vetch		Moravaɸ, Studenicaɸ, Timokɸ and Volgaɸ	
Lentil	Red	Nipperɸ, PBA Aceɸ, PBA Blitzɸ, PBA Boltɸ, PBA Flashɸ, PBA Hallmark XTɸ, PBA Highland XTɸ, PBA Hurricane XTɸ, PBA Jumbo2ɸ, PBA Kelpie XTɸ	
	Green	PBA Greenfieldɸ	
Chickpea	Kabuli	PBA Royalɸ, Genesis™090, PBA Magnusɸ	
	Desi	Year 2017	Neelamɸ, PBA Boundaryɸ, PBA Slasherɸ, PBA Strikerɸ
		Year 2019	CBA Captainɸ, Neelamɸ, PBA Boundaryɸ, PBA HatTrickɸ, PBA Maidenɸ, PBA Seamerɸ, PBA Slasherɸ, PBA Strikerɸ(desi) Genesis™090 (kabuli)
		Year 2020	CBA Captainɸ, Neelamɸ, PBA Maidenɸ, PBA Slasherɸ, PBA Strikerɸ
		Year 2021	CBA Captainɸ, Neelamɸ, PBA Maidenɸ, PBA Slasherɸ, PBA Strikerɸ
		Year 2022	CBA Captainɸ, Neelamɸ, PBA Slasherɸ, PBA Strikerɸ

* Includes chickpea varieties evaluated in additional experiments from 2017 to 2022.

Table 2 Sowing and harvest dates for the different pulse species and legumes species at Rankins Springs in 2022.

Pulse species	Sowing date	Harvest date
Faba bean	10 May 2022	15 December 2022
Vetch	9 May 2022	16 December 2022
Lentil	19 May 2022	14 December 2022
Lupin – albus	10 May 2022	15 January 2023
Lupin – narrow-leaf	10 May 2022	14 January 2023
Chickpea – kabuli	9 May 2022	16 January 2023
Chickpea – desi	19 May 2022	15 January 2023

Seasonal conditions

Stored soil water levels were high at the start of the 2022 season. Approximately 200 mm of rain fell in January, which was well above the LTA of 36.4 mm (Figure 1). Rainfall from August to November was also in excess of the LTA resulting in wet conditions especially in spring and early summer. In addition, from July until December the maximum and minimum temperatures were below the LTA, resulting in mild spring conditions.

The very wet conditions combined with a mild growing season meant all species developed substantial biomass. The dense crop canopies favoured fungal pathogens, which were difficult to control post canopy closure. Lower than required spring temperatures, delayed the start of pod formation, especially in chickpea thus reducing yield potential. For other pulse species, such as faba bean, lupin, vetch and lentil, the mild spring conditions were conducive to high grain yield.

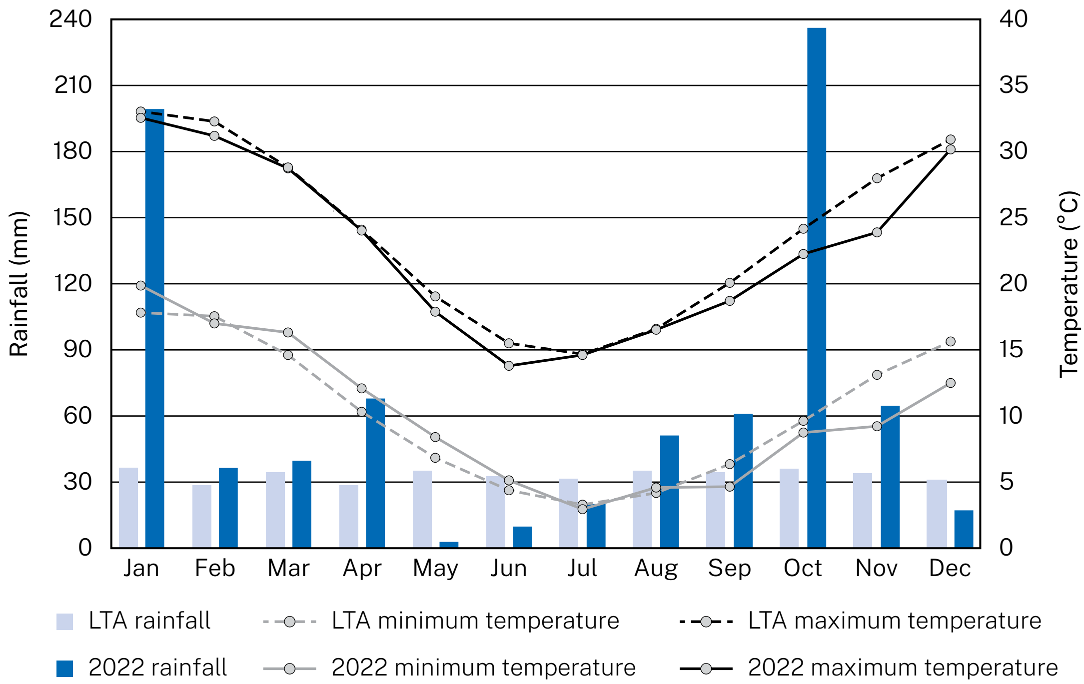

Figure 1 Monthly rainfall and temperature for Hillview, Rankins Springs in 2022, and associated long-term averages.

Results

Faba bean

Grain yields for the highest yielding faba bean varieties: PBA Amberley⁽ᶲ⁾ (5.28 t/ha), PBA Nanu⁽ᶲ⁾ (5.21 t/ha), PBA Marne⁽ᶲ⁾ (4.84 t/ha) and PBA Nasma⁽ᶲ⁾ (4.29 t/ha), were statistically similar (Table 3).

Plant establishment was similar across all varieties with a mean of 28.3 plants/m^2.

Time to flowering loosely fell into 2 groups:

1. the early flowering group (PBA Nanu⁽ᶲ⁾, PBA Marne⁽ᶲ⁾ and PBA Bendoc⁽ᶲ⁾), which flowered before 10 August
2. the late flowering group (PBA Amberley⁽ᶲ⁾ and PBA Samira⁽ᶲ⁾), which flowered around 20 August.

Table 3 Faba bean variety evaluation experiment results at Rankins Springs in 2022.

Variety	Establishment (plants/m^2)	Date of 50% flowering	Grain yield (t/ha)	Seed weight (g/100 seeds)
PBA Amberley	28.1	21 Aug	5.28	71.8
PBA Nanu	32.6	5 Aug	5.21	64.5
PBA Marne	29.6	7 Aug	4.84	72.8
PBA Nasma	28.4	n.a.	4.29	78.3
PBA Samira	24.9	20 Aug	4.00	73.7
PBA Bendoc	26.2	14 Aug	3.38	58.0
Site mean	28.3	13 Aug	4.50	69.8
l.s.d. (P<0.05)	n.s.	2.04	1.11	3.04

l.s.d. = least significant difference; n.a. = not recorded; n.s. = not significant.

Albus lupin

The average grain yield for albus lupin was 3.38 t/ha. Both Murringo⊕ (3.59 t/ha) and Luxor⊕ (3.56 t/ha) had higher yields than Rosetta⊕ (3.01 t/ha) (Table 4).

Plant establishment was similar across all varieties with a mean of 35.3 plants/m^2.

Murringo⊕ was the first to start flowering on 15 August and flowered for 48 days. Rosetta⊕ was the last to start flowering on 25 August and flowered for 40 days.

Table 4 Albus lupin variety evaluation experiment results at Rankins Springs in 2022.

Variety	Establishment (plants/m^2)	Date of 50% flowering	Date of end of flowering	Flowering duration (days)	Lodge score[†]	Maturity score[++]	Grain yield (t/ha)	Seed weight (g/100 seeds)
Murringo	35.7	15 Aug	3 Oct	48.0	4.4	7.8	3.59	35.2
Luxor	33.6	21 Aug	2 Oct	42.3	4.3	4.3	3.56	36.9
Rosetta	36.5	25 Aug	5 Oct	40.7	2.6	6.4	3.01	38.1
Site mean	35.3	20 Aug	3 Oct	43.7	3.8	6.2	3.38	36.7
l.s.d. (*P*<0.05)	n.s.	2.6	1.2	1.6	3.0	2.2	0.35	n.s.

l.s.d. = least significant difference; n.s. = not significant; [†]Lodge score: 1 = lodged, 9 = upright;
[++]Maturity score: 1 = early, 9 = late.

Narrow-leaf lupin

The average grain yield for narrow-leaf lupin was 3.11 t/ha (Table 5). There were no significant differences between varieties.

Plant establishment was similar across all varieties with a mean of 35.5 plants/m^2.

Mandelup⊕ was the first to start flowering (9 August) while Jindalee⊕ was the last (30 August).

PBA Jurien⊕, PBA Bateman⊕ and Mandelup⊕ flowered for around 50 days while Wonga⊕ had the shortest flowering duration of 42 days (Table 5).

Table 5 Narrow-leaf lupin variety evaluation experiment results at Rankins Springs in 2022.

Variety	Establishment (plants/m^2)	Date of 50% flowering	Date of end of flowering	Flowering duration (days)	Grain yield (t/ha)	Seed weight (g/100 seeds)
PBA Jurien	40.0	10 Aug	1 Oct	50.6	3.30	12.8
PBA Gunyidi	35.6	15 Aug	30 Sep	46.5	3.29	12.7
PBA Bateman	35.7	11 Aug	29 Sep	49.1	3.25	14.8
Mandelup	37.7	9 Aug	29 Sep	50.6	2.97	13.5
Wonga	32.3	20 Aug	2 Oct	42.4	2.95	12.3
Jindalee	31.9	30 Aug	n.a.	n.a.	2.89	11.6
Site mean	35.5	16 Aug	30 Sep	47.8	3.11	12.9
l.s.d. (*P*<0.05)	n.s.	4.2	1.0	1.4	n.s.	0.6

l.s.d. = least significant difference; n.a. = not recorded n.s. = not significant.

Pulses

Vetch

Grain yield varied between the vetch varieties. Timokɸ had the highest yield (4.42 t/ha) and Studenicaɸ had the lowest (1.82 t/ha) (Table 6).

Wet weather and high humidity caused botrytis grey mould (BGM) infections during late winter and spring. There was a large difference in BGM infection levels between the 4 varieties: Moravaɸ was most resistant to BGM with a score of 0.8 whereas Volgaɸ and Studenicaɸ were severely infected with scores of 8.5 and 8.0, respectively.

The establishment rate was similar across all varieties and was 56.2 plants/m^2.

Studenicaɸ was the first to start flowering (5 September) and Volgaɸ was last (12 September). Studenicaɸ continued to flower until 12 October and Moravaɸ until 28 October.

Table 6 Vetch variety evaluation experiment results at Rankins Springs in 2022.

Variety	Establishment (plants/m^2)	Date of 50% flowering	Date of end of flowering	Flowering duration (days)	BGM score**	Grain yield (t/ha)
Timok	57.3	7 Sep	14 Oct	36.1	2.4	4.42
Volga	56.8	11 Sep	11 Oct	39.0	8.5	2.54
Morava	54.4	6 Sep	28 Oct	44.7	0.8	2.32
Studenica	54.1	5 Sep	12 Oct	46.6	8.0	1.86
Site mean	56.2	7 Sep	16 Oct	40.4	3.9	3.05
l.s.d. (P<0.05)	n.s.	n.s.	1.6	1.2	1.3	0.8

l.s.d. = least significant difference; n.s. = not significant; **BGM score: 1 = low BGM, 9 = high BGM.
Data provided by the Vetch Breeding Program.

Lentil

Grain yield for lentil varieties ranged from 2.43 t/ha (PBA Hurricane XTɸ) to 1.03 t/ha (PBA Boltɸ), with the top 6 varieties: PBA Hurricane XTɸ, PBA Kelpie XTɸ, PBA Highland XTɸ, PBA Hallmark XTɸ, PBA Jumbo2ɸ and PBA Greenfieldɸ being similar and superior to the other 5 varieties (Table 7).

PBA Blitzɸ was the first to flower (24 August). PBA Boltɸ, PBA Kelpie XTɸ and PBA Highland XTɸ all flowered within 5 days of PBA Blitzɸ. Nipper was the latest variety to start flowering (12 September), 18 days after PBA Blitzɸ.

Flowering duration ranged from 71.4 days for PBA Blitzɸ to 51.9 days for Nipperɸ, a difference of nearly 3 weeks.

Chickpea

Analysis of grain yield over many locations and years can move the predicted value towards the average yield of all trials used in the analysis. The data presented is part of Chickpea Breeding Australia (CBA) programs analysis which covers a wide proportion of Australia, over the past 5 years. In 2022, with very low yields in the paddock, the analysis increased predicted yields to be closer to the average. This means that the yields presented in this paper (Table 8) are higher than those observed in fields.

The average grain yield over all the varieties tested was 2.96 t/ha (Table 8). PBA Slasherɸ had the highest grain yield of 3.17 t/ha, 14% higher than the average yield; the lowest yielding variety was CBA Captainɸ at 3.03 t/ha, 2% higher than the average yield. CBA Captainɸ, PBA Slasherɸ and PBA Strikerɸ yields have been stable and high yielding over time, with each achieving over the site mean for most years.

PBA Royal⁽ᵇ⁾ and Genesis™090 had yields above 2.30 t/ha, which was significantly higher than PBA Magnus⁽ᵇ⁾ at 1.55 t/ha (Table 9). Chickpea varieties are sensitive to temperatures below an average of 15 °C, during pod set. The low yield reflected the suboptimal spring temperatures, which delayed pod development and reduced yield potential. The average temperature at Rankins Springs did not consistently exceed 15 °C until 19 October. This reduced the effective yield formation window, resulting in a relatively lower yield when compared with other pulse and legume species.

Table 7 Lentil variety evaluation experiment results at Rankins Springs in 2022.

Variety	Vigour score*	Date of 50% flowering	Flowering duration (days)	Maturity score**	Grain yield (t/ha)
PBA Hurricane XT	6.0	5 Sep	59.9	5.4	2.43
PBA Kelpie XT	6.4	28 Aug	67.6	3.5	2.41
PBA Highland XT	7.0	30 Aug	66.1	4.8	2.20
PBA Hallmark XT	7.2	1 Sep	63.0	5.8	2.11
PBA Jumbo2	6.2	2 Sep	60.7	5.2	2.01
PBA Greenfield	7.1	6 Sep	58.2	4.7	1.97
PBA Blitz	6.8	24 Aug	71.4	3.6	1.74
PBA Ace	6.4	8 Sep	56.6	5.3	1.66
PBA Flash	6.0	9 Sep	55.7	4.3	1.56
Nipper	6.0	12 Sep	51.9	3.6	1.55
PBA Bolt	6.5	28 Aug	67.5	4.1	1.03
Site mean	6.1	4 Sep	60.7	4.6	1.87
l.s.d. (*P*<0.05)	0.9	4.0	4.6	1.7	0.62

l.s.d. = least significant difference; *Vigour score: 1 = poor, 9 = excellent; **Maturity score: 1 = poor, 9 = excellent.
Data provided by Lentil Breeding Australia.

Table 8 Grain yield (t/ha) of chickpea cultivar experiments conducted at Rankins Springs from 2017 to 2022.

Variety	Grain yield (t/ha) (%SMY†)				
	2017	2019	2020	2021	2022
CBA Captain	*	1.38 (100)	2.59 (109)	2.44 (94)	3.03 (102)
Genesis090	*	1.41 (102)	*	*	*
Neelam	1.27 (109)	1.47 (107)	2.68 (113)	2.67 (102)	3.22 (109)
PBA Boundary	1.29 (111)	1.36 (99)	*	*	*
PBA Hat Trick	*	1.36 (98)	*	*	*
PBA Maiden	*	1.28 (93)	2.61 (110)	2.59 (99)	*
PBA Seamer	*	1.29 (93)	*	*	*
PBA Slasher	1.29 (111)	1.48 (107)	2.74 (115)	2.82 (108)	3.38 (114)
PBA Striker	1.27 (109)	1.50 (108)	2.66 (112)	2.74 (105)	3.17 (107)
Site mean	1.16 (100)	1.38 (100)	2.37 (100)	2.60 (100)	2.96 (100)

† Number in parenthesis in columns (%SMY) = percentage of grain yield compared to site mean yield;
* = variety not included in experiments that year.
Data provided by Chickpea Breeding Australia.

Pulses

Table 9 Kabuli chickpea variety evaluation experiment results at Rankins Springs in 2022.

Variety	Establishment (plants/m²)	Date of 50% flowering	Date of end of flowering	Flowering duration (days)	Grain yield (t/ha)	Seed weight (g/100 seeds)
PBA Royal	37.7	19 Sep	18 Dec	89.4	2.37	29.20
Genesis090	36.5	19 Sep	17 Dec	89.3	2.34	26.07
PBA Magnus	34.5	13 Sep	14 Dec	91.7	1.55	42.61
Site mean	36.2	17 Sep	16 Dec	90.2	2.09	32.63
l.s.d. (P<0.05)	n.s.	0.8	0.8	0.8	0.84	3.0

l.s.d. = least significant difference; n.s. = not significant.

Summary

The 2022 winter cropping season was long and wet with above average rainfall throughout the year resulting in overland flooding and waterlogging across the site in late spring. Mild temperatures and very high rainfall throughout the growing season resulted in substantial varietal biomass and ensuing fungal infections that required multiple applications to manage. Grain yields varied between the different species with the average faba bean yield (4.50 t/ha) being twice the average yield of the kabuli chickpea (2.09 t/ha). Vetch performed well with a site mean of 3.90 t/ha. Albus and narrow-leaf lupins achieved 3.38 t/ha and 3.11 t/ha, respectively. Low average air temperatures in spring and early summer delayed pod development in both desi and kabuli chickpea varieties when compared with the other species. Chickpea has limited tolerance to temperatures under 15 °C, where minimal pod and seed set occur, limiting yield potential. At Rankins Springs, the average air temperature did not consistently exceed 15 °C until 19 October delaying the beginning of pod and seed formation and leaving little time to accumulate grain yield. The average grain yield of both desi (2.96 t/ha) and kabuli (2.09 t/ha) chickpea was low when compared with the other pulse species.

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Faba bean, chickpea, lupin, lentil and field pea variety experiments – Methul 2022

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Key findings

- Mild wet conditions favoured higher yields in faba bean varieties (average yield of 5.35 t/ha) compared with the other pulse species evaluated.
- Average grain yields for field pea (3.44 t/ha), albus lupin (3.21 t/ha), narrow-leaf lupin (3.21 t/ha), desi chickpea (1.07 t/ha) and kabuli chickpea (0.31 t/ha) were achieved.
- Cool spring temperatures delayed pod formation and reduced yield potential for both desi and kabuli chickpea varieties, with average grain yields of 1.07 t/ha and 0.31 t/ha, respectively, well below expectations.

Pulses

Keywords Methul, 2022, pulses, variety, phenology, faba bean, lupin, lentil, chickpea, field pea, grain yield, seed weight, establishment

Introduction

Pulse variety experiments were conducted at Methul in 2022 to investigate crop phenology and grain yield responses for a range of commercially available varieties (Table 1). Data was collected to assess establishment, flowering date, maturity score, grain yield and seed weight within each species.

Site details

Location	Anglia, Methul (34° 37' 04.9"S, 147° 05' 08.2"E) NSW
Soil type	Red chromosol
Soil pH_{Ca}	4.8 (0–10 cm), 4.9 (10–20 cm), 5.7 (20–30 cm), 6.0 (30–60 cm), 6.3 (60–90 cm), 7.6 (90–120 cm)
Previous crop	Wheat
Rainfall	• Fallow (November 2021 – March 2022): 354 mm • Fallow LTA: 181 mm • In-crop (April–October): 489 mm • In-crop LTA: 283 mm
Fertiliser	100 kg/ha mono-ammonium phosphate (MAP) 50% and single super phosphate (SSP) 50% (blend) (nitrogen [N]:5; phosphorus [P]:15.4; potassium [K]:0; sulfur [S]:6.25)
Sowing and harvest date	See Table 2

Treatments

Varieties

Table 1 Pulse species and varieties evaluated at Methul in 2022.

Species	Type	Variety
Lupin	Albus	Luxor⸸, Murringo⸸, and Rosetta⸸
	Narrow-leaf	Mandelup⸸, PBA Bateman⸸, PBA Gunyidi⸸, PBA Jindalee⸸, PBA Jurien⸸, Wonga⸸
Faba bean		PBA Amberley⸸, PBA Bendoc⸸, PBA Marne⸸, PBA Nanu⸸, PBA Nasma⸸, PBA Samira⸸
Chickpea	Desi	CBA Captain⸸, PBA Boundary⸸, PBA Drummond⸸, PBA HatTrick, PBA Slasher⸸, PBA Striker⸸
	Kabuli	Genesis™090, PBA Magnus⸸, PBA Royal⸸
Field pea	Kaspa	PBA Butler⸸, PBA Taylor⸸, PBA Wharton⸸
	White	PBA Pearl⸸, Sturt⸸
	Dun	PBA Percy⸸, PBA Oura⸸
	Blue	PBA Noosa⸸
Lentil	Red	Nipper⸸, PBA Ace⸸, PBA Bolt⸸, PBA Hallmark XT⸸, PBA Highland XT⸸, PBA HurricaneXT⸸, PBA Jumbo2⸸, PBA Kelpie XT⸸
	Green	PBA Greenfield⸸

Table 2 Sowing and harvest dates for the different pulse species at Methul in 2022.

Pulse species	Sowing date	Harvest date
Lupin – narrow-leaf and albus	10 May 2022	6 January 2023
Faba bean	10 May 2022	6 January 2023
Chickpea – desi and kabuli	10 May 2022	6 January 2023
Field pea	20 May 2022	18 December 2022
Lentil	20 May 2022	9 January 2023

Seasonal conditions

The 2022 season started with above average stored soil water. Greater than 120 mm of rain fell in January, with further falls in excess of the LTA for March to May, and again from August to November (Figure 1). Plentiful rainfall, combined with a mild growing season, resulted in large biomass development in all crop species, which favoured fungal pathogens.

Below average spring temperatures delayed the start of pod formation and reduced the rate of seed development, especially in chickpea, which significantly reduced maximum yield potential. For other pulse species, such as faba bean, lupin and field pea, the milder spring conditions were conducive to increased yield potential.

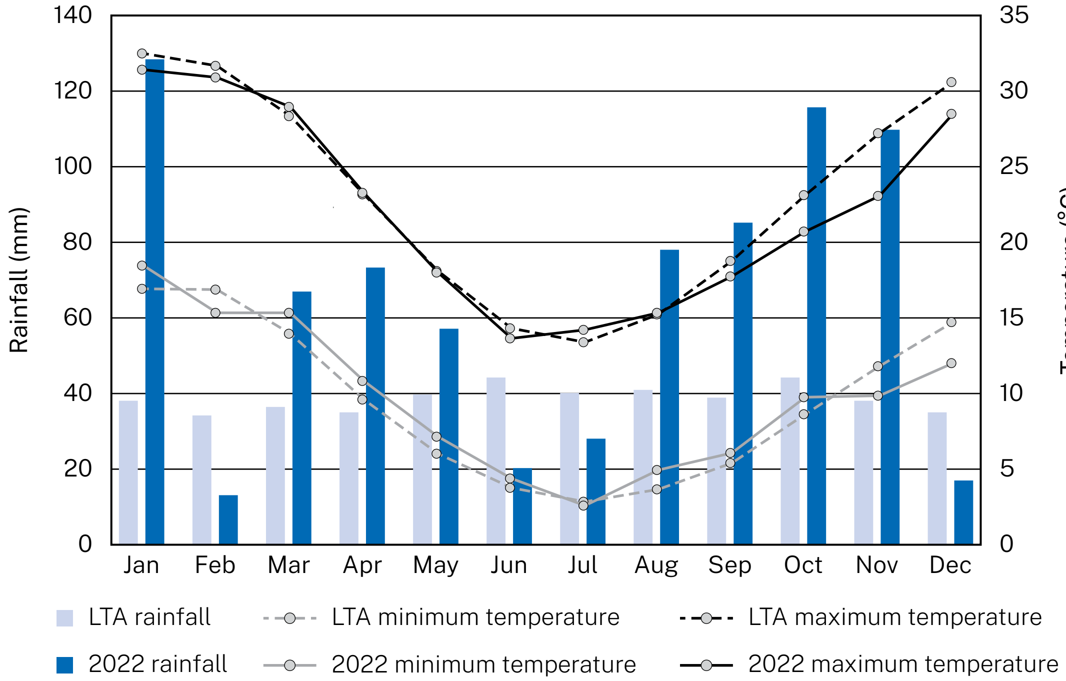

Figure 1 Monthly rainfall and temperature for Anglia, Methul for 2022 and associated long-term averages.

Results

Faba bean

Grain yield varied significantly. PBA Marne$^{\phi}$ and PBA Nanu$^{\phi}$ yielded 6.1 t/ha and 5.6 t/ha, respectively (Table 3). All other varieties except PBA Bendoc$^{\phi}$ exceeded 5 t/ha.

The optimal establishment rate for faba bean in southern NSW is between 20 plants/m^2 and 35 plants/m^2 depending on the sowing time. PBA Marne$^{\phi}$ had a higher establishment rate than other varieties at 36.6 plants/m^2 with all other varieties within the optimal range.

The early flowering lines PBA Nanu$^{\phi}$, PBA Nasma$^{\phi}$ and PBA Marne$^{\phi}$ reached 50% flowering before 12 August, while the late flowering lines PBA Amberley$^{\phi}$, PBA Bendoc$^{\phi}$ and PBA Samira$^{\phi}$ did not reach 50% flowering until 20 August.

PBA Nanu$^{\phi}$, PBA Nasma$^{\phi}$ and PBA Marne$^{\phi}$ had the longest flowering duration (all greater than 50 days), compared with the other 3 varieties (PBA Bendoc$^{\phi}$, PBA Samira$^{\phi}$ and PBA Amberley$^{\phi}$), which had flowering durations between 43 days and 45 days (Table 3).

Table 3 Faba bean variety evaluation experiment results at Methul in 2022.

Variety	Establishment (plants/m^2)	Date of 50% flowering	Flowering duration (days)	Harvest lodging score†	Grain yield (t/ha)	Seed weight (g/100 seeds)
PBA Marne	36.3	12 Aug	52.5	8.2	6.08	74.8
PBA Nanu	26.6	10 Aug	51.6	3.8	5.62	75.0
PBA Amberley	33.2	21 Aug	45.1	8.6	5.31	79.7
PBA Nasma	29.4	9 Aug	52.5	4.9	5.26	83.8
PBA Samira	27.9	22 Aug	44.8	7.6	5.22	82.8
PBA Bendoc	29.4	20 Aug	43.1	9.1	4.64	76.1
Site mean	30.5	16 Aug	48.3	7.0	5.35	78.7
l.s.d. (P<0.05)	5.8	1.1	2.3	2.9	0.55	2.5

l.s.d = least significant difference; †Harvest lodging score: 1 = no lodging, 9 = maximum lodging.

Albus lupin

Grain yield for all 3 albus lupin varieties was similar. The site mean was 3.21 t/ha (Table 4).

Plant establishment was also similar between the varieties. The site mean was 37.1 plants/m² and within the optimal range for southern NSW.

Murringo⟑ reached 50% flowering on 28 August, which was earlier than both Luxor⟑ (2 September) and Rosetta⟑ (6 September) respectively.

Flowering duration was significantly shorter for Rosetta⟑ at 82 days compared with Luxor⟑ and Murringo⟑, which both had similar flowering durations >91 days.

Table 4 Albus lupin variety evaluation experiment results at Methul in 2022.

Variety	Establishment (plants/m²)	Date of 50% flowering	Flowering duration (days)	Grain yield (t/ha)	Seed weight (g/100 seeds)
Rosetta	36.9	6 Sep	82.1	3.06	30.1
Luxor	37.7	2 Sep	94.1	3.25	30.2
Murringo	36.6	28 Aug	91.5	3.34	31.0
Site mean	37.1	1 Sep	89.2	3.21	30.4
l.s.d. (*P*<0.05)	n.s.	3.2	8.6	n.s.	n.s.

l.s.d = least significant difference; n.s. = not significant.

Narrow-leaf lupin

Establishment was similar across the 6 narrow-leaf lupin varieties, with an average of 43.6 plants/m² (Table 5).

The late flowering Jindalee⟑ was suited to the long season and had the highest yield (3.42 t/ha), similar to PBA Jurien⟑ (3.04 t/ha) and higher than all other varieties.

Table 5 Narrow-leaf lupin variety evaluation experiment results at Methul in 2022.

Variety	Establishment (plants/m²)	Grain yield (t/ha)	Seed weight (g/100 seeds)
Jindalee	44.6	3.42	12.5
PBA Jurien	46.4	3.04	13.5
PBA Gunyidi	45.3	3.00	13.6
Mandelup	39.4	2.87	13.4
PBA Bateman	45.1	2.86	14.5
Wonga	40.7	2.74	12.1
Site mean	43.6	2.99	13.3
l.s.d. (*P*<0.05)	n.s.	0.4	1.2

l.s.d = least significant difference; n.s. = not significant.

Lentil

The early flowering PBA Kelpie XT⟑ and PBA Highland XT⟑ reached 50% flowering on 9 September (Table 6), while the late flowering Nipper⟑ started on 20 September.

Nipper⟑ had the shortest flowering duration (50 days) and PBA Hallmark XT⟑ and PBA Kelpie XT⟑ had the longest flowering duration (65 days).

Grain yield varied significantly. PBA Greenfield⟑, PBA Hallmark XT⟑, PBA Highland XT⟑, PBA Hurricane XT⟑, PBA Jumbo2⟑ and PBA Kelpie XT⟑ had statistically similar yields with a mean yield of 3.52 t/ha. Nipper⟑, PBA Ace⟑ and PBA Bolt⟑ were significantly lower yielding than PBA Hallmark XT⟑ and PBA Hurricane XT⟑.

Table 6 Lentil variety evaluation experiment results at Methul in 2022.

Variety	Date of 50% flowering	Flowering duration (days)	Grain yield (t/ha)
PBA Hurricane XT	11 Sep	63.2	3.86
PBA Hallmark XT	12 Sep	64.9	3.83
PBA Kelpie XT	9 Sep	64.7	3.58
PBA Jumbo2	15 Sep	58.7	3.45
PBA Greenfield	16 Sep	57.5	3.24
PBA Highland XT	9 Sep	64.1	3.19
PBA Bolt	11 Sep	62.9	3.05
PBA Ace	16 Sep	56.3	2.70
Nipper	20 Sep	50.5	2.56
Site mean	13 Sep	59.8	3.32
l.s.d. (*P*<0.05)	2.60	7.72	0.68

l.s.d. = least significant difference.
Data provided by Lentil Breeding Australia.

Desi chickpea

Desi chickpea average grain yield (1.07 t/ha) was low when compared with the other pulse species. This was due to limited chilling tolerance in chickpea varieties, which rarely set pods or seeds when average daily temperatures are below 15 °C. During the 2022 growing season, the average daily temperature did not consistently rise above 15 °C until 18 October, and the ongoing sub-optimal temperatures throughout the spring significantly reduced yield potential.

The highest yielding variety was PBA Slasher$^{\phi}$ (1.37 t/ha), which was significantly higher than CBA Captain$^{\phi}$ and PBA Striker$^{\phi}$ (1.14 t/ha and 1.15 t/ha, respectively) (Table 7).

All but one variety (PBA Striker$^{\phi}$) achieved optimal establishment rates for desi chickpeas (between 35 plants/m^2 and 45 plants/m^2).

CBA Captain$^{\phi}$ was the first variety to flower (11 September), followed by PBA Boundary$^{\phi}$, PBA Slasher$^{\phi}$ and PBA Striker$^{\phi}$ (around 18 September). In contrast, PBA Drummond$^{\phi}$ and PBA HatTrick$^{\phi}$ flowered around 28 September.

Table 7 Desi chickpea variety evaluation experiment results at Methul in 2022.

Variety	Establishment (plants/m^2)	Date of 50% flowering	Flowering duration (days)	Grain yield (t/ha)	Seed weight (g/100 seeds)
PBA Slasher	35.8	18 Sep	77.5	1.37	20.8
PBA Striker	30.6	17 Sep	82.0	1.15	25.2
CBA Captain	45.4	11 Sep	81.3	1.14	22.1
PBA Boundary	39.9	18 Sep	77.7	0.94	21.5
PBA Drummond	34.8	28 Sep	66.5	0.93	23.2
PBA HatTrick	39.3	29 Sep	63.7	0.77	21.0
Site mean	37.6	20 Sep	74.8	1.07	22.3
l.s.d. (*P*<0.05)	7.2	1.80	4.1	0.2	0.9

l.s.d. = least significant difference.

Kabuli chickpea

The kabuli chickpea varieties had an average grain yield of 0.31 t/ha (Table 8). Low yields were due to flowering and pod development coinciding with unfavourable low average air temperatures throughout spring.

Flowering did not start until 27 September for PBA Magnus⁽ᵇ⁾ and 6 October for both Genesis™090 and PBA Royal⁽ᵇ⁾. Research has shown that mean daily temperatures below 15 °C limits chickpea seed development. Average air temperatures did not consistently rise above 15 °C until 18 October 2022 and the ongoing sub-optimal temperatures throughout the spring significantly reduced yield potential.

There was no difference in plant establishment between the 3 varieties. The site mean (33.7 plants/m^2) was within the optimal range (Table 8).

Table 8 Kabuli chickpea variety evaluation experiment results at Methul in 2022.

Variety	Establishment (plants/m^2)	Date of 50% flowering	Grain yield (t/ha)	Seed weight (g/100 seeds)
Genesis090	31.1	6 Oct	0.36	29.9
PBA Magnus	39.6	27 Sep	0.25	32.4
PBA Royal	30.3	6 Oct	0.31	31.0
Site mean	33.7	3 Oct	0.31	31.1
l.s.d. (P<0.05)	n.s.	3.4	n.s.	n.s.

l.s.d. = least significant difference; n.s. = not significant.

Field pea

Grain yield differed between field pea varieties. PBA Pearl⁽ᵇ⁾ had the highest yield (4.56 t/ha), which was significantly higher than all other varieties (Table 9). In contrast, the 5 lowest yielding varieties were similar: PBA Wharton⁽ᵇ⁾ (2.92 t/ha), Sturt⁽ᵇ⁾ (2.97 t/ha), PBA Oura⁽ᵇ⁾ (3.10 t/ha), PBA Taylor⁽ᵇ⁾ (3.32 t/ha) and PBA Percy⁽ᵇ⁾ (3.36 t/ha).

PBA Percy⁽ᵇ⁾ was the first variety to flower on 29 August, followed by PBA Oura⁽ᵇ⁾ and Sturt⁽ᵇ⁾ on 6 and 7 September, respectively. PBA Butler⁽ᵇ⁾ was last to flower on 14 September.

PBA Percy⁽ᵇ⁾ also spent the longest time flowering and developing pods (62.5 days). This was as 46% increase in flowering duration when compared with PBA Butler⁽ᵇ⁾ (42.8 days). However, the longer flowering period did not result in increased grain yield.

Table 9 Field pea variety evaluation experiment results at Methul in 2022.

Variety	Establishment (plants/m^2)	Date of 50% flowering	Flowering duration (days)	Day of maturity	Grain yield (t/ha)	Seed weight (g/100 seeds)
PBA Pearl	45.7	9 Sep	50.1	26 Nov	4.56	19.6
PBA Butler	45.9	14 Sep	42.8	23 Nov	3.88	20.3
PBA Noosa	43.1	9 Sep	50.1	25 Nov	3.44	20.2
PBA Percy	47.6	29 Aug	62.5	27 Nov	3.36	24.1
PBA Taylor	40.2	12 Sep	45.7	23 Nov	3.32	20.2
PBA Oura	48.0	6 Sep	50.4	24 Nov	3.10	21.8
Sturt	42.9	7 Sep	62.1	7 Dec	2.97	17.0
PBA Wharton	46.9	10 Sep	43.5	23 Nov	2.92	19.8
Site mean	45.0	8 Sep	50.9	26 Nov	3.44	20.4
l.s.d. (P<0.05)	n.s.	1.6	0.9	4.2	0.48	0.8

l.s.d. = least significant difference; n.s. = not significant.

Summary

High rainfall and mild temperatures in the 2022 winter growing season at Methul favoured large biomass accumulation. Consistent rainfall during spring and early summer created large, closed canopies which resulted in high disease levels, particularly in lentils and chickpea despite many fungicide applications.

Grain yields varied between the different pulse species. The average faba bean yield (5.35 t/ha) was 17 times the average yield of kabuli chickpea (0.31 t/ha). Faba bean varieties are known to be more adapted to high rainfall conditions, which were prevalent in 2022, compared with other pulse species. In contrast, the low average air temperatures delayed the beginning of yield formation in chickpea varieties reducing maximum potential. The average yield of both desi (1.07 t/ha) and kabuli (0.31 t/ha) chickpea was low compared with the other pulse species. All other pulse species had relatively high yields (faba bean, 5.35 t/ha; field pea, 3.44 t/ha; albus lupin, 3.21 t/ha; narrow-leaf lupin, 2.99 t/ha).

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Chickpea phenology and yield responses to environment and management practices – Wagga Wagga and Rankins Springs – 2022

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Key findings

- Average grain yield at Wagga Wagga was 2.43 t/ha and 2.31 t/ha at Rankins Springs.
- CBA Captain⁽ᴰ⁾ had the highest grain yield across locations; 2.84 t/ha at Wagga Wagga and 2.89 t/ha at Rankins Springs.
- Favourable seasonal conditions resulted in high peak biomass; 14.1 t/ha at Wagga Wagga and 11.9 t/ha at Rankins Springs.
- Challenging conditions, due to cooler-than-ideal spring temperatures, resulted in delayed pod set and reduced yield potential for both desi and kabuli chickpea varieties.

Keywords Wagga Wagga, Rankins Springs, 2022, chickpea, sowing date, phenology, grain yield, red kandosol, red chromosol, waterlogging, harvest index

Introduction

Pulses play a critical role in the Australian grains industry as they enhance the diversity and resilience of cropping systems that are currently dominated by cereals and canola. To maximise yield and profit while effectively managing production risks, it is essential to match well-adapted genotypes with the specific soil, climate, and management practices in each cropping region. This approach enables improved adaptation to optimise crop water use and minimise vulnerability to environmental constraints such as frost, heat, terminal drought and soil limitations.

These chickpea experiments are part of a nationwide project aimed at understanding the water-limited yield potential of pulses. The focus is on studying how these crops perform under best practice agronomy. Moreover, the project seeks to enhance our understanding of the relationships between phenology, water stress, temperature and the critical period for yield formation in pulses.

This report presents findings from the 2022 experiments conducted at the Wagga Wagga and Rankins Spring sites in southern NSW, outlining the interaction of phase development and environmental conditions in commercially available chickpea varieties.

Site details

Table 1 summarises the site conditions and experiment management.

Table 1 Summary of site conditions and experiment management.

Location: site	Wagga Wagga: WWAI	Rankins Springs: Hillview, Pulletop paddock
Soil type	Red kandosol	Red chromosol
Previous crop	Wheat	Barley
Rainfall		
Fallow (November 2021 – March 2022)	202 mm	297 mm
Fallow long-term average (LTA)	158 mm	131 mm
In-crop (April–October)	466 mm	449 mm
In-crop LTA	330 mm	233 mm
Starter fertiliser: mono-ammonium phosphate (MAP) 50% and single superphosphate (SSP) 50% (blend)	110 kg/ha	110 kg/ha

Treatments

Table 2 summarises the experiment treatments at each site.

Table 2 Summary of the experiment treatments at Wagga Wagga and Rankins Springs, 2022.

Location	Wagga Wagga	Rankins Springs
Variety	CBA Captain⍉ PBA Drummond⍉ PBA HatTrick⍉ PBA Striker⍉	CBA Captain⍉ PBA Boundary⍉ PBA Drummond⍉ PBA HatTrick⍉ PBA Slasher⍉ PBA Striker⍉
Sowing date (SD)	SD1: 11 May 2022 SD2: 15 June 2022	SD1: 9 May 2022 SD2: 9 June 2022
Maturity biomass cut date	4 January 2023	4 January 2023
Harvest date	6 January 2023	14 January 2023

Results

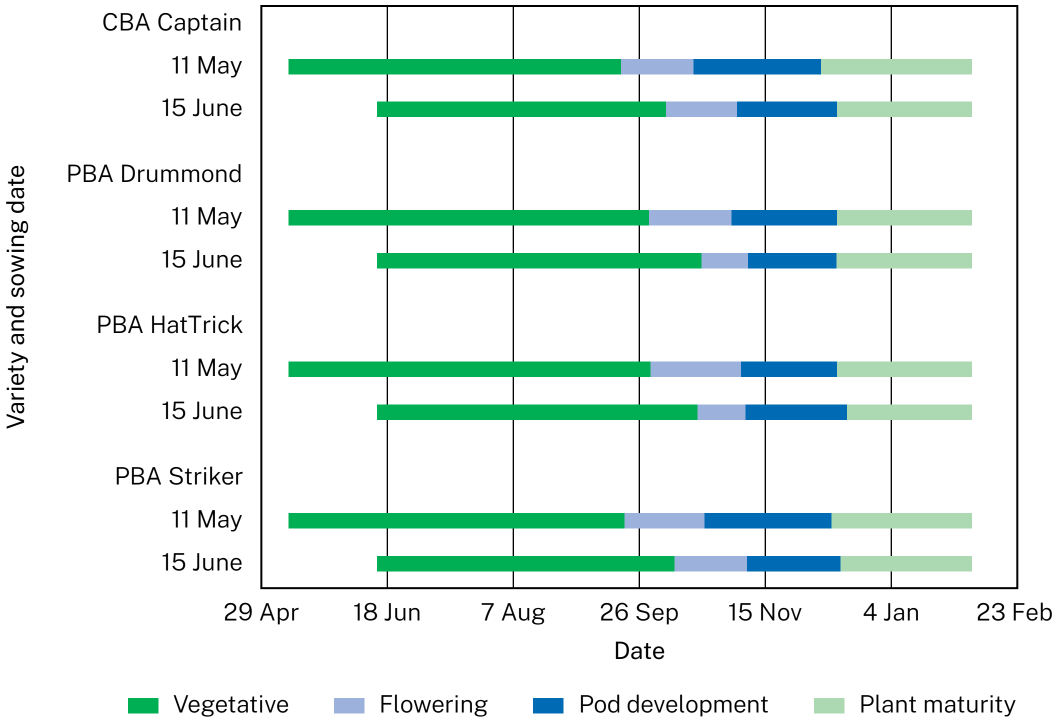
Seasonal conditions

In 2022, both locations had high pre-sowing soil water levels and above-average rainfall from August onwards. This resulted in extremely wet spring conditions. However, abundant rainfall in October caused overland flooding, which adversely affected grain yield in certain sections of the Rankins Springs experiment. The combination of ample water and mild weather conditions during the growing season led to the development of substantial crop biomass. Unfortunately, the wet crop canopy and mild temperatures created favourable conditions for the proliferation of fungal pathogens, making their control challenging throughout spring. Moreover, sub-optimal average air temperatures in spring caused a delay in pod formation, resulting in reduced yield potential as evidenced by the low harvest index.

Wagga Wagga

When crops were sown earlier (SD1: 11 May), the duration of each developmental stage was extended (Figure 1). The mild and wet growing season had a significant effect on the harvest, which took place in January 2023, approximately 5 weeks later than the usual timeframe. For instance, CBA Captain⍉ sown on 11 May began flowering on 20 September, while PBA HatTrick⍉ started flowering on 1 October. When sowing was delayed from 11 May to 15 June, there was a 17–21-day delay in the onset of flowering. At the Wagga Wagga site (Figure 1), CBA Captain⍉ was the first variety to flower for both sowing dates, followed by PBA Striker⍉, PBA Drummond⍉ and PBA HatTrick⍉.

Pulses



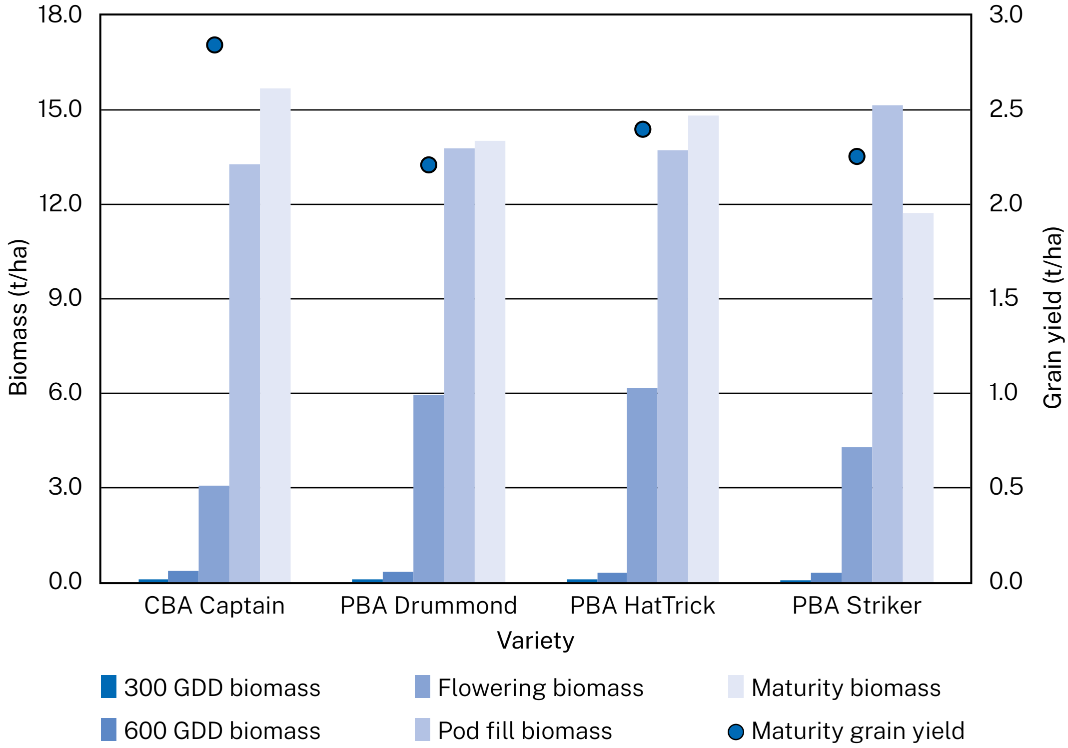
Flowering begins at the start of the flowering bar; podding commences at the start of the pod development bar and plant maturity is where the crops start to mature and dry for harvest.

Figure 1 Duration and/or transition between growth phases of 4 chickpea varieties for 2 sowing dates at Wagga Wagga, 2022.

The start of pod development for SD1 began on 18 October with CBA Captain⌽, followed by PBA Striker⌽ on 23 October, PBA Drummond⌽ on 2 November, and finally PBA HatTrick⌽ on 6 November (Figure 1). However, for SD2, the start of pod development for all 4 varieties occurred within a compressed timeframe, ranging from 4 to 9 November (Figure 1).

Throughout the growth stages, biomass accumulation differed among the 4 varieties, except for the first biomass harvest at 300 growing degree days (GDD) after sowing. GDD is calculated by adding the maximum and minimum air temperatures of a single day and then dividing that number by 2. It is a useful measure for estimating the timing of developmental phases in various crops. Chickpea is classified as an indeterminate crop, meaning biomass accumulation continues during flowering and pod development. Interestingly, PBA Striker⌽ achieved its maximum biomass accumulation during pod development, which was earlier than the other 3 varieties (Figure 2). This could have been influenced by the observed presence of sclerotinia within the experiment. PBA Striker⌽ appeared to be more severely infected with sclerotinia, causing more plant death and necrosis from mid spring onwards. This resulted in lower biomass at maturity than the other varieties. For the remaining 3 varieties, their peak biomass was observed when the pods had started changing colour.

The average grain yield at Wagga Wagga was 2.43 t/ha, while at Rankins Springs, it was slightly lower at 2.31 t/ha (tables 3 and 5). Surprisingly, there was no significant difference in grain yield between the 2 sowing dates at either location. This lack of distinction in yield could be attributed to the wet and mild spring. These conditions allowed for an extended grain filling period for crops sown on both dates, contributing to the similar yields observed at both sites.



l.s.d. (*P*<0.05) 300 GDD biomass = 0.01 t/ha

l.s.d. (*P*<0.05) 600 GDD biomass = 0.05 t/ha

l.s.d. (*P*<0.05) flowering biomass = 0.50 t/ha

l.s.d. (*P*<0.05) pod fill biomass = 1.22 t/ha

l.s.d. (*P*<0.05) maturity biomass = 1.71 t/ha

l.s.d. (*P*<0.05) maturity grain yield = 1.49 t/ha

Flower biomass was when 80% of plants had open flowers; pod fill biomass was when 80 % of plants had a pod with a fully formed seed inside; maturity biomass was when 90% of pods had turned brown and maturity grain yield was the yield obtained when the maturity biomass sample was threshed.
l.s.d. = least significant difference.

Figure 2 Biomass accumulation during the growing season and grain yield for the 4 chickpea varieties at Wagga Wagga, 2022.

Table 3 Plant establishment, maturity biomass, maturity grain yield, maturity harvest index and hundred seed weight response for 2 sowing dates at Wagga Wagga, 2022.

Sowing date	Plant establishment (plants/m²)	Maturity grain yield (t/ha)	Maturity biomass (t/ha)	Maturity harvest index	Seed weight (g/100 seeds)
11 May	37.6	2.22	14.0	0.16	23.4
15 June	41.1	2.63	14.1	0.18	23.8
Site mean	39.4	2.43	14.1	0.17	23.6
l.s.d. (*P*<0.05)	1.9	n.s.	n.s.	0.02	n.s.

l.s.d. = least significant difference, n.s. = not significant.

At Wagga Wagga there were significant differences in grain yield among the varieties, whereas at Rankins Springs, all varieties had similar yields. At both locations, CBA Captain⍉ had the highest yield, producing 2.84 t/ha at Wagga Wagga and 2.89 t/ha at Rankins Springs (tables 4 and 6). Moreover, at Wagga Wagga, both CBA Captain⍉ and PBA HatTrick⍉ had comparable yields, which were superior to PBA Striker⍉ (2.25 t/ha) and PBA Drummond⍉ (2.21 t/ha) (Table 4).

Plant establishment for SD1 at Wagga Wagga was 37.6 plants/m². This was 9% lower than the 41.1 plants/m² for SD2 (Table 3). However, there was no significant difference in establishment between SD1 and SD2 at Rankins Springs (Table 5). Optimal plant establishment rates for southern New South Wales are typically between 35 plants/m² and 45 plants/m². Interestingly, at both locations, the plant establishment for PBA Striker⍉

was lower than that of all other varieties and was slightly outside the optimal range at Wagga Wagga (tables 4 and 6).

The mild environmental conditions combined with excessive moisture, particularly during spring, fostered substantial crop biomass. Crop biomass had reached 14.1 t/ha at Wagga Wagga and 11.9 t/ha at Rankins Springs when the crops were harvested with 90% of pods turning brown (tables 3 and 5).

At Wagga Wagga, there was no difference in biomass at maturity between the 2 sowing dates, but variations were observed among the different varieties. CBA Captain⁽ᶦ⁾ had the highest biomass (15.7 t/ha) which was similar to PBA HatTrick⁽ᶦ⁾ (14.8 t/ha) and PBA Drummond⁽ᶦ⁾ (14.0 t/ha). However, PBA Striker⁽ᶦ⁾ had a significantly lower biomass (11.7 t/ha) (Table 4).

Table 4 Plant establishment, maturity biomass, maturity grain yield, maturity harvest index and hundred seed weight response for 4 chickpea varieties at Wagga Wagga, 2022.

Variety	Plant establishment (plants/m²)	Maturity grain yield (t/ha)	Maturity biomass (t/ha)	Maturity harvest index	Seed weight (g/100 seeds)
CBA Captain	41.1	2.84	15.7	0.18	23.3
PBA HatTrick	41.2	2.40	14.8	0.15	22.2
PBA Striker	34.8	2.25	11.7	0.18	24.3
PBA Drummond	40.3	2.21	14.0	0.15	24.5
Site mean	39.4	2.43	14.1	0.17	23.6
l.s.d. (P<0.05)	2.7	0.49	1.7	0.02	0.4

l.s.d. = least significant difference.

Rankins Springs

At Rankins Springs, sowing date played a crucial role in biomass at maturity. Maturity biomass was reduced from 13.4 t/ha for SD1 to 10.5 t/ha for SD2; a reduction of 20% (Table 5). However, there were no genotypic differences in accumulated biomass at plant maturity between the 6 varieties (Table 6).

Seed weight was influenced by sowing date and variety at Rankins Springs, yet solely by variety at Wagga Wagga (tables 3 and 5). On average, seed weight was higher at Wagga Wagga (site mean: 23.6 g/100 seeds) than at Rankins Springs (site mean: 21.3 g/100 seeds) (tables 3 and 5). This difference in seed weight could be attributed to overland flooding and waterlogging in October at Rankins Springs affecting overall plant health.

When the sowing was delayed from May (SD1) until June (SD2), the seed weight at Rankins Springs increased by 3% (Table 5).

Table 5 Plant establishment, maturity biomass, maturity grain yield, maturity harvest index and hundred seed weight responses for 2 sowing dates at Rankins Springs, 2022.

Sowing date	Plant establishment (plants/m²)	Maturity grain yield (t/ha)	Maturity biomass (t/ha)	Maturity harvest index	Seed weight (g/100 seeds)
9 May	40.4	2.13	13.4	0.15	20.9
9 June	39.9	2.48	10.5	0.22	21.6
Site mean	40.2	2.31	11.9	0.19	21.3
l.s.d. (P<0.05)	n.s.	n.s.	2.0	0.05	0.5

l.s.d. = least significant difference, n.s. = not significant.

At both Wagga Wagga and Rankins Springs, PBA Drummond$^{\phi}$ and PBA Striker$^{\phi}$ had the largest seed weight compared with the other varieties, while PBA HatTrick$^{\phi}$ had the smallest (tables 4 and 6). Interestingly, the similarity in seed weight ranking between Rankins Springs and Wagga Wagga suggests that large-seeded varieties consistently exhibit bigger seeds than small-seeded varieties, regardless of the growing location.

Table 6 Plant establishment, maturity biomass, maturity grain yield, maturity harvest index and hundred seed weight response for 6 chickpea varieties at Rankins Springs, 2022.

Variety	Plant establishment (plants/m²)	Maturity grain yield (t/ha)	Maturity biomass (t/ha)	Maturity harvest index	Seed weight (g/100 seeds)
CBA Captain	42.7	2.89	13.7	0.22	21.8
PBA Boundary	42.0	2.54	11.1	0.22	20.7
PBA Slasher	39.6	2.53	12.2	0.20	19.9
PBA Striker	36.0	2.24	11.1	0.20	22.5
PBA Drummond	41.3	1.86	12.1	0.15	22.3
PBA HatTrick	39.5	1.80	11.3	0.16	20.5
Site mean	40.2	2.31	11.9	0.19	21.3
l.s.d. (*P*<0.05)	4.2	n.s.	n.s.	0.04	0.9

l.s.d. = least significant difference, n.s. = not significant.

Summary

The average grain yield at Wagga Wagga was 2.43 t/ha, while at Rankins Springs, it was slightly lower at 2.31 t/ha. CBA Captain$^{\phi}$ stood out as the highest yielding variety at both experiment locations, achieving 2.89 t/ha and 2.84 t/ha, respectively. The stability in CBA Captain$^{\phi}$ grain yield across southern NSW in 2022 indicates consistent performance in different locations. It's important to note that the high yields from CBA Captain$^{\phi}$ might be due to the specific seasonal conditions in 2022, and differing results could be expected under varying conditions.

Plant establishment at Wagga Wagga and Rankins Springs generally fell within the optimal range for southern NSW, which is typically between 35 plants/m^2 and 45 plants/m^2. However, PBA Striker$^{\phi}$ had lower establishment rates than the other varieties at both locations.

Seed weight was slightly higher at Wagga Wagga (average of 23.6 g/100 seeds) compared with Rankins Springs (average of 21.3 g/100 seeds). This difference could be influenced, at least in part, by the overland flooding and waterlogging in October at Rankins Springs. These adverse conditions might have led to reduced productivity, affecting both yield and seed size due to plant damage or death.

In summary, CBA Captain$^{\phi}$ demonstrated its superiority as the highest yielding variety in both experiment locations, while PBA Striker$^{\phi}$ had the lowest establishment rate and PBA HatTrick$^{\phi}$ had the smallest seed weight. The observed differences in yield, establishment, and seed weight highlight the significance of seasonal conditions and their effect on crop performance.

Acknowledgements

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Lentil phenology and yield responses to management practices and environment – Wagga Wagga, Rankins Springs and Methul – 2022

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Key findings

- Maturity grain yield averaged 3.30 t/ha at Methul, 2.62 t/ha at Wagga Wagga and 2.45 t/ha at Rankins Springs.
- Grain yield increased by 27% and 21% at Wagga Wagga and Methul, respectively, when sowing was delayed to mid June, due to the extended growing season.
- PBA Hallmark XT⏀ showed broad adaptation, achieving comparable yields to the top yielding varieties at all locations.
- Wet spring conditions in combination with mild temperatures, were conducive to large crop biomass at all 3 locations with 8.6 t/ha at Methul, 8.4 t/ha at Wagga Wagga, and 7.6 t/ha at Rankins Springs.

Pulses

Keywords Wagga Wagga, Rankins Springs, Methul, 2022, lentil, variety, sowing date, phenology, flowering, grain yield, red chromosol, red kandosol, waterlogging

Introduction

Pulses are vital for the Australian grains industry, improving diversity and resilience in cropping systems dominated by cereals and canola. To maximise yield and manage risks, it's crucial to select adapted genotypes based on soil, climate and management practices. These lentil experiments are part of a national project exploring the water-limited yield potential of pulses in their traditional environments with best practice agronomy. This report presents the 2022 findings from the Wagga Wagga, Rankins Springs and Methul sites, studying the effect of developmental timing of commercially available lentil varieties and their interactions with environmental conditions.

Site details

Table 1 summarises the site conditions and experiment management.

Table 1 Summary of site conditions and experiment management.

Location: site	Wagga Wagga: WWAI	Rankins Springs: Hillview	Methul: Anglia
Soil type	Red kandosol	Red chromosol	Red chromosol
Previous crop	Wheat	Barley	Oats
Rainfall			
Fallow (November 2021 – March 2022)	202 mm	297 mm	334 mm
Fallow long-term average (LTA)	158 mm	131 mm	182 mm
In-crop (April–October)	466 mm	449 mm	489 mm
In-crop LTA	330 mm	233 mm	283 mm
Starter fertiliser: mono-ammonium phosphate (MAP) 50% and single superphosphate (SSP) 50% (blend)	100 kg/ha	100 kg/ha	100 kg/ha

Treatments

Table 2 summarises the experiment treatments at each site.

Table 2 Summary of the experiment treatments at Wagga Wagga, Rankins Springs and Methul, 2022.

Location	Wagga Wagga	Rankins Springs	Methul
Variety	PBA Bolt$^{\phi}$ PBA Hallmark XT$^{\phi}$ PBA Jumbo2$^{\phi}$ PBA Kelpie XT$^{\phi}$	PBA Ace$^{\phi}$ PBA Bolt$^{\phi}$ PBA Greenfield$^{\phi}$ PBA Hallmark XT$^{\phi}$ PBA Jumbo2$^{\phi}$ PBA Kelpie XT$^{\phi}$	PBA Ace$^{\phi}$ PBA Bolt$^{\phi}$ PBA Greenfield$^{\phi}$ PBA Hallmark XT$^{\phi}$ PBA Jumbo2$^{\phi}$ PBA Kelpie XT$^{\phi}$
Sowing date (SD)	SD1: 11 May SD2: 15 June	SD1: 9 May SD2: 9 June	SD1: 10 May SD2: 14 June
Maturity biomass cut date	SD1: 9 December 2022 SD2: 19 December 2022	30 November 2022	13 December 2022
Harvest date	13 December 2022	15 December 2022	27 December 2022

Results

Seasonal conditions

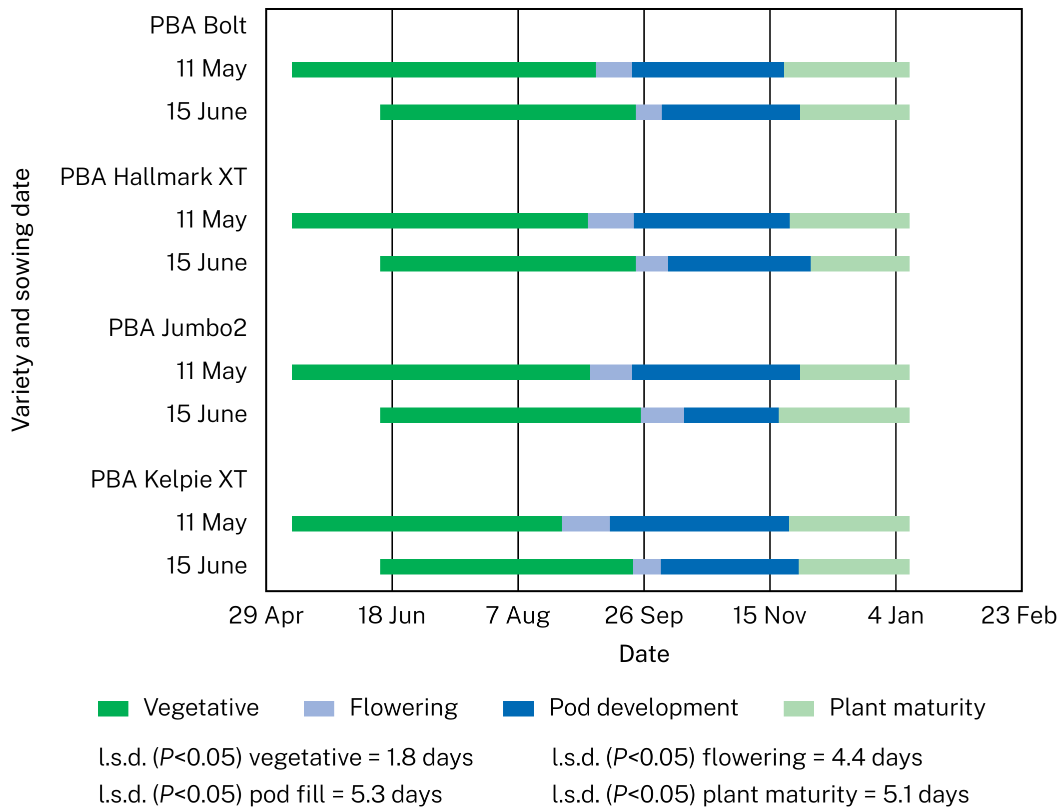
In 2022, all 3 locations had high pre-sowing soil water levels and above-average rainfall from August onwards, resulting in extremely wet spring conditions. Large crop biomass developed, favouring fungal pathogen infection such as botrytis grey mould and sclerotinia; the earlier sowing date had more severe disease. Cool summer temperatures slowed crop maturity and delayed harvest due to slow plant drying.

Heavy rainfall in late October resulted in overland flooding and waterlogging at Rankins Springs, and intermittent waterlogging at Methul and Wagga Wagga. These water-related challenges further delayed crop growth and development, which affected maturity and harvest timings.

Phasic development at Wagga Wagga

Timing of crop phases is vital for lentil yield potential. Favourable conditions during critical stages such as pod fill lead to high yields. However, environmental factors, such as cool temperatures during flowering and early pod fill, and high temperatures during late pod fill can decrease yield. Maintaining optimal soil moisture throughout the season is crucial, as inadequate, or excessive levels can affect overall grain yield.

Early sowing (SD1) of lentils resulted in earlier flowering, pod development, and crop dry down phases compared with later sowing (SD2) (Figure 1). Among the 4 varieties, PBA Kelpie XT$^{\phi}$ flowered first; PBA Bolt$^{\phi}$, PBA Hallmark XT$^{\phi}$, and PBA Jumbo2$^{\phi}$ followed around 10 days later.



The junction between the vegetative and flowering bars represents 10% flowering; the junction between flowering and pod development represents 80% of plants have a filled pod and the junction between pod development and plant maturity represents when 90% of pods have changed colour.
l.s.d. = least significant difference.

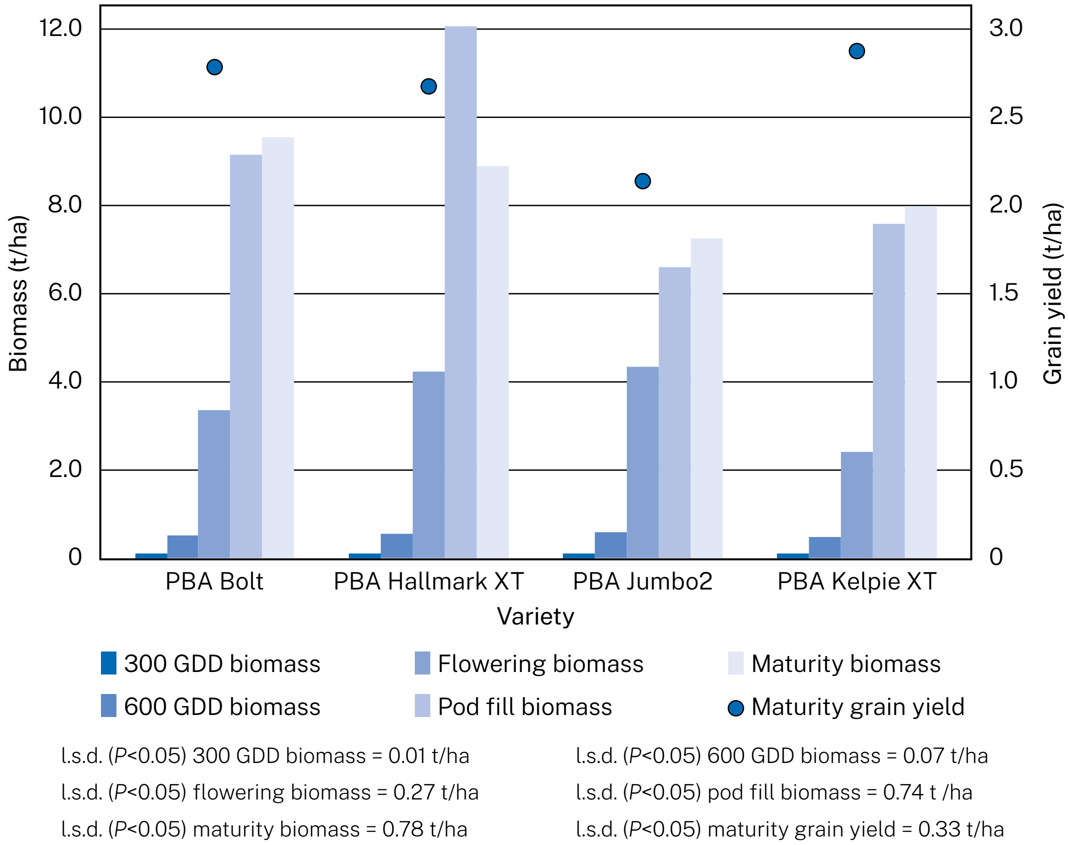
Figure 1 Duration and transition between growth phases of 4 lentil varieties for 2 sowing dates at Wagga Wagga, 2022.

Flowering date was significantly affected by sowing date, variety, and their interaction. The earlier sowing date (SD1: 11 May) flowered on 3 September when averaged over all varieties, 21 days earlier than the later sowing date (SD2: 15 June) on 24 September. Across the 2 sowing dates PBA Kelpie$^{\phi}$ was the first to flower on 9 September, 5 days earlier than the other varieties (data not shown). When sown early PBA Kelpie$^{\phi}$ was the first to flower on 26 August, 10 days before PBA Hallmark XT$^{\phi}$, yet when sown later PBA Kelpie$^{\phi}$ flowered on 23 September one day before both PBA Hallmark XT$^{\phi}$ and PBA Bolt$^{\phi}$ (Figure 1).

As with flowering, the start of pod development was also affected by sowing date, variety, and their interaction. Pod development started on 20 September in SD1, 17 days earlier than SD2 on 7 October. Across the sowing dates PBA Kelpie$^{\phi}$ was the first to set pods on 24 September, while PBA Bolt$^{\phi}$ (28 September), PBA Hallmark XT$^{\phi}$ (29 September), and PBA Jumbo2$^{\phi}$ (2 October) were later. PBA Kelpie$^{\phi}$ started podding earlier than the other 3 varieties for both sowing dates. In SD1 , PBA Kelpie$^{\phi}$ podded on 14 September, 8 days before PBA Jumbo2$^{\phi}$ and PBA Bolt$^{\phi}$ while PBA Hallmark XT$^{\phi}$ was another day later again. In SD2 both PBA Kelpie$^{\phi}$ and PBA Bolt$^{\phi}$ podded on 4 October, while PBA Hallmark XT$^{\phi}$ (6 October) and PBA Jumbo2$^{\phi}$ (13 October) were later (Figure 1).

Biomass accumulation at Wagga Wagga

Lentil varieties had different peak biomass stages. PBA Hallmark XT$^{\phi}$ reached its highest biomass of 12.1 t/ha at pod fill but this reduced by 24% to 8.9 t/ha at maturity, potentially due to sclerotinia infection later in the season (Figure 2). In contrast, PBA Bolt$^{\phi}$, PBA Kelpie XT⁽ᵈ⁾, and PBA Jumbo2⁽ᵈ⁾ continued to increase biomass until maturity, with maximum biomasses of 9.6 t/ha, 8.0 t/ha and 7.3 t/ha respectively.



Flowering biomass was when 80% of plants had open flowers; pod fill biomass was when 80% of plants had a pod with a fully formed seed inside; maturity biomass was when 90% of the pods had turned brown and maturity grain yield was the yield obtained when the biomass sample was threshed.
l.s.d. = least significant difference.

Figure 2 Biomass accumulation for 4 lentil varieties when averaged over the 2 sowing dates, during the growing season at Wagga Wagga, 2022.

Grain yield responses across sites

Methul had the highest grain yield at maturity with an average of 3.30 t/ha, while Wagga Wagga (2.62 t/ha) and Rankins Springs (2.45 t/ha) had lower yields (tables 3, 4, and 5). The lower yields at Rankins Springs were partly influenced by heavy rainfall in October that caused overland flooding and waterlogging.

Table 3 Plant establishment, maturity biomass, maturity grain yield, maturity harvest index and hundred seed weight response for 2 sowing dates at Methul, 2022.

Sowing date	Plant establishment (plants/m²)	Maturity grain yield (t/ha)	Maturity biomass (t/ha)	Maturity harvest index	Seed weight (g/100 seeds)
10 May	122.2	2.98	8.5	0.36	3.7
14 June	112.2	3.63	8.7	0.42	4.1
Site mean	112.2	3.30	8.6	0.39	3.9
l.s.d. (*P*<0.05)	n.s.	0.64	n.s.	0.05	0.05

l.s.d. = least significant difference, n.s. = not significant.

Table 4 Plant establishment, maturity biomass, harvest grain yield, maturity harvest index and hundred seed weight response for 2 sowing dates at Wagga Wagga, 2022.

Sowing date	Plant establishment (plants/m²)	Maturity grain yield (t/ha)	Maturity biomass (t/ha)	Maturity harvest index	Seed weight (g/100 seeds)
11 May	127.6	2.26	8.2	0.28	3.9
15 June	121.0	2.99	8.7	0.35	4.0
Site mean	124.3	2.62	8.4	0.31	3.9
l.s.d. (*P*<0.05)	6.1	0.34	n.s.	0.02	0.05

l.s.d. = least significant difference, n.s. = not significant.

Table 5 Plant establishment, maturity biomass, maturity grain yield, maturity harvest index and hundred seed weight response for 2 sowing dates at Rankins Springs, 2022.

Sowing date	Plant establishment (plants/m²)	Maturity grain yield (t/ha)	Maturity biomass (t/ha)	Maturity harvest index	Seed weight (g/100 seeds)
9 May	130.8	2.57	8.7	0.29	3.5
9 June	128.1	2.32	6.5	0.36	3.6
Site mean	129.5	2.45	7.6	0.33	3.6
l.s.d. (*P*<0.05)	n.s.	n.s.	1.2	0.05	n.s.

l.s.d. = least significant difference, n.s. = not significant.

Sowing date significantly affected grain yield at Methul and Wagga Wagga, with increased yields when sowing was delayed. At Methul, there was a 21% average increase to 3.63 t/ha for SD2 and at Wagga Wagga, there was a 27% average increase to 2.99 t/ha for SD2 (tables 3 and 4). This yield increase from later sowings might be due to higher fungal infection levels in SD1 and more favourable environmental conditions during yield development in SD2.

Varieties displayed differences in grain yield at each site. PBA Hallmark XT⁽ᵇ⁾ showed broad adaptability in 2022, with yields similar to the top-performing variety at each location (tables 6, 7, and 8). Other varieties showed varying responses to different locations. For instance, PBA Kelpie XT⁽ᵇ⁾ had the lowest yield at Wagga Wagga (2.14 t/ha) but the highest yield at Rankins Springs (2.74 t/ha) and Methul (3.93 t/ha) (tables 6, 7, and 8). Further assessments are needed to evaluate their yield potential under different environmental conditions in other years.

Table 6 Plant establishment, maturity biomass, harvest grain yield, maturity harvest index and hundred seed weight response for 4 lentil varieties at Wagga Wagga, 2022.

Variety	Plant establishment (plants/m²)	Maturity grain yield (t/ha)	Maturity biomass (t/ha)	Maturity harvest index	Seed weight (g/100 seeds)
PBA Jumbo2	126.5	2.88	7.3	0.29	4.2
PBA Bolt	125.5	2.79	9.6	0.29	3.9
PBA Hallmark XT	124.6	2.68	8.9	0.31	3.5
PBA Kelpie XT	120.7	2.14	8.0	0.36	4.1
Site mean	124.3	2.62	8.4	0.31	3.9
l.s.d. (*P*<0.05)	n.s.	0.33	0.8	0.03	0.06

l.s.d. = least significant difference, n.s. = not significant.

Table 7 Plant establishment, maturity biomass, maturity grain yield, maturity harvest index and hundred seed weight response for 6 lentil varieties at Rankins Springs, 2022.

Variety	Plant establishment (plants/m²)	Maturity grain yield (t/ha)	Maturity biomass (t/ha)	Maturity harvest index	Seed weight (g/100 seeds)
PBA Kelpie XT	135.0	2.74	6.2	0.41	3.9
PBA Jumbo2	129.0	2.70	8.1	0.35	3.9
PBA Hallmark XT	130.6	2.61	8.3	0.34	3.0
PBA Greenfield	133.2	2.34	7.6	0.30	3.9
PBA Bolt	124.6	2.24	6.9	0.31	3.3
PBA Ace	124.5	2.06	8.5	0.26	3.4
Site mean	129.5	2.45	7.6	0.33	3.6
l.s.d. (P<0.05)	7.5	0.43	1.4	0.04	0.1

l.s.d = least significant difference.

Table 8 Plant establishment, maturity biomass, maturity grain yield, maturity harvest index and hundred seed weight response for 6 lentil varieties at Methul, 2022.

Variety	Plant establishment (plants/m²)	Maturity grain yield (t/ha)	Maturity biomass (t/ha)	Maturity harvest index	Seed weight (g/100 seeds)
PBA Kelpie XT	114.2	3.93	8.9	0.46	4.3
PBA Hallmark XT	116.7	3.56	9.2	0.40	3.4
PBA Ace	113.4	3.45	10.2	0.34	3.7
PBA Jumbo2	106.2	3.14	8.7	0.35	4.4
PBA Bolt	106.7	3.08	8.1	0.38	3.6
PBA Greenfield	115.9	2.67	6.6	0.40	4.1
Site mean	112.2	3.30	8.6	0.39	3.9
l.s.d. (P<0.05)	9.1	0.55	0.9	0.05	0.1

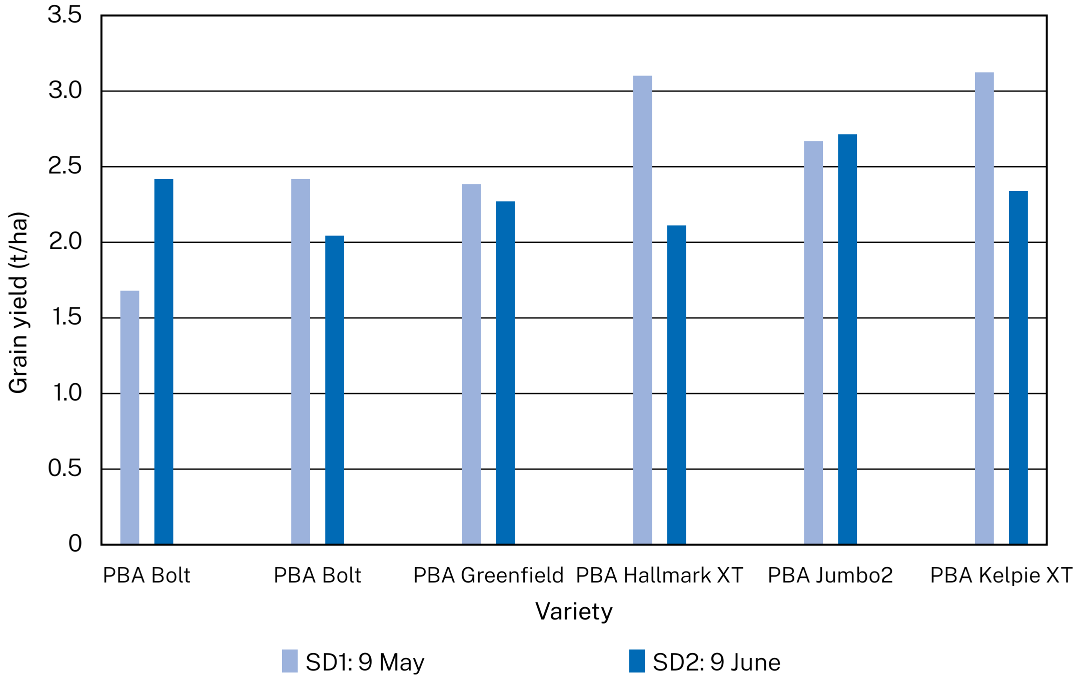
l.s.d. = least significant difference.

At Rankins Springs, there was a significant interaction between variety and sowing date for maturity grain yield, indicating that different varieties were more productive when sown at different times within the optimal window. PBA Hallmark XT⦶ and PBA Kelpie XT⦶ showed around 10% increased grain yield when sown early (SD1), within the optimal sowing window (Figure 3). Conversely, PBA Ace⦶ had higher maturity yield when sown later (SD2) in the optimal window, with a 7.5% increase over SD1. The other 3 varieties had similar maturity grain yields regardless of the sowing date. These results likely reflect the specific environmental conditions in 2022, and further testing is required to confirm these interactions over time.

Establishment responses across sites

At Wagga Wagga, Rankins Springs, and Methul, the average establishment rates were 124 plants/m², 129 plants/m² and 112 plants/m² respectively (tables 6, 7, and 8).

Sowing delays at Wagga Wagga resulted in a slight decrease in plant establishment, from 127.6 plants/m² to 121.0 plants/m² (Table 4). This represented a 5% reduction compared with SD1. However, at Rankins Springs and Methul, there was no significant difference in establishment in response to the sowing date (tables 5 and 6). This slight reduction in crop establishment at Wagga Wagga for SD2 could be due to differences in soil temperature and water content compared with SD1.



l.s.d. (*P*<0.05) sowing date × variety = 0.66 t/ha

Figure 3 Maturity grain yield for 6 lentil varieties for 2 sowing dates at Rankins Springs, 2022.

Seed weight responses across sites

There were significant differences in seed weight between locations, sowing dates, and varieties. Seed weight averaged 3.9 g/100 seeds at Methul and Wagga Wagga, which was larger than the 3.6 g/100 seeds recorded at Rankins Springs (tables 3, 4, and 5). The smaller seed weight at Rankins Springs could be due to overland flooding and waterlogging late in the season which damaged some plots and affected grain fill. Additionally, seed weight for SD2 was significantly greater than SD1 at all 3 sites, with increases of 0.4 g/100 seeds, 0.1 g/100 seeds, 0.1 g/100 seeds for Methul, Wagga Wagga and Rankins Springs respectively (tables 3, 4, and 5). The larger seed size in SD2 might be influenced by the mild temperatures, excessive rainfall, and higher disease presence observed in SD1.

Commercial lentil varieties are classified based on cotyledon colour and seed size. PBA Jumbo2⏀ and PBA Kelpie XT⏀ are classified as large red lentils, PBA Greenfield⏀ as a medium green lentil, and PBA Hallmark XT⏀, PBA Ace⏀, and PBA Bolt⏀ as medium red lentils. There were varietal differences in seed weight at each site, with the relative weight and ranking aligning with the varietal classification. PBA Jumbo2⏀ and PBA Kelpie XT⏀ had the largest seed weight, each over 3.9 g/100 seeds at every location, and PBA Greenfield⏀ had a similar weight, also over 3.9 g/100 seeds (tables 6, 7, and 8). Conversely, PBA Hallmark XT⏀, PBA Ace⏀, and PBA Bolt⏀, as medium red seeded lentils, had seed weights ranging from 3.0 g/100 seeds to 3.9 g/100 seeds at the 3 locations (tables 6, 7, and 8).

Summary

In 2022, lentil production was challenging due to abundant soil moisture during sowing and continuous rainfall throughout the season, which led to large crop biomass. These wet conditions increased the risk of fungal infections in the crop canopy. High intensity rainfall in late October resulted in overland flooding and waterlogging damage at Rankins Springs. Transient periods of waterlogging were observed at Wagga Wagga and Methul

Plant establishment in the experiments was generally even and within the optimal range for southern NSW. At Wagga Wagga, there was a slight reduction (5%) in plant establishment when sowing was delayed, which was probably due to lower soil temperatures and ample soil water in June.

Maturity grain yield varied across locations, with Methul recording the highest yield (3.30 t/ha), followed by Wagga Wagga (2.62 t/ha) and Rankins Springs (2.45 t/ha). Lower yields at Rankins Springs were attributed to the extremely high October rainfall event which caused overland flooding and waterlogging.

Sowing date significantly influenced average grain yield, with a 27% increase at Wagga Wagga and 21% at Methul when sowing was delayed until mid June. Later sowing dates were associated with lower fungal infections compared with earlier sowing dates.

Lentil varieties are classified based on cotyledon colour and seed size. PBA Jumbo2⏀ and PBA Kelpie XT⏀ are large red lentils, PBA Greenfield⏀ is a medium green lentil, and PBA Hallmark XT⏀, PBA Ace⏀, and PBA Bolt⏀ are medium red lentils. Hundred seed weight at each site aligned with these classifications, reflecting the size of each variety.

Acknowledgements

These experiments were conducted as part of the national 'Matching pulse crop designs to site and expected seasonal conditions to maximise yield and profit: a crop ecophysiology approach' project (CSP2107-011RTX), a joint investment by GRDC and NSW DPI, led by CSIRO.

We sincerely thank the Eckermann family, Hillside, Rankins Springs and the Graham family, Anglia, Methul for hosting the experiment sites and for their ongoing collaboration and support of pulse research.

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Interactive effects between phosphorus (P) placement and watering regimes on wheat grain yield

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Key findings

- Increase in wheat grain yield is attributed to the higher P rates rather than the placement strategies.
- Shallow P was as effective or more effective than dual P placement.
- P placement did not interact with watering regimes for wheat grain yield.
- Placing P deeper in the soil profile might not be a reliable way of improving crop performance in southern NSW.

Keywords Phosphorus placement, deep banded P, shallow P, dual P, rainout shelter

Introduction

Recent GRDC-invested research in the summer rainfall-dominated northern growing region of Australia has shown that grain yield can be increased by 6–40% by placing P ~20 cm deep and at 50 cm spacing instead of current farming practice, i.e. 5–10 kg P/ha applied in or around the seed row (Lester et al. 2022; Sands et al. 2022).

In contrast to the north, cropping in the southern growing region is dominated by winter rainfall. However, there are still periods of prolonged dry topsoils, particularly in drier years. These conditions, in addition to highly stratified surface P and low P reserves below the cultivated layer, led researchers to predict that dual P banding would be more efficient than current P placement strategies in or around the sowing rows.

In 2020, GRDC invested in a new project (Maximising the uptake of phosphorus by crops to optimise profit in central and southern NSW, Victoria and South Australia; DPI2001-033RTX) to investigate the effectiveness of dual placed P on crop performance. Prevailing wet conditions over the past 3 years have limited the incidence of favourable soil moisture conditions for deep P responses (i.e. dry surface with wet subsoil; Verburg et al. 2022). Therefore, a new experiment was established in 2022 at Tootool southern NSW, to impose a dry surface condition by excluding rain events greater than 5 mm using rainout shelters.

This paper reports experiment findings investigating the interactions between P placement strategies and watering regimes on grain yield of winter wheat.

Site details

Location	Tootool, southern NSW
Soil type	Red sodosol
Design	• Split-plot design with P treatment as the main plots and watering regimes as sub-plots • Replications: 4

Crop nutrition

Sowing	• Species: wheat (cv. Sunblade CL Plus⊕) • Seed rate: 71 kg/ha • Sowing date: 19 May 2022 • Spacing: 25 cm
Fertiliser	• Urea at 60 kg/ha at sowing to balance the P fertiliser applied as mono-ammonium phosphate (MAP) • Urea at 100 kg/ha at tillering
Rainfall	• Fallow (November 2021 – March 2022): 445 mm; long-term average = 195 mm • In-crop (April–October 2022): 583 mm; long-term average = 325 mm
Harvest date	16 December 2022 (header harvested)

Treatments

P treatments

Four P treatments: 5/0, 5/60, 20/0, and 20/60 (shallow/deep P kg/ha).

Phosphorus was either applied as a dual placement strategy or shallow only:

- dual placement – some under every seed row (shallow band) and some banded at approximately 20 cm below the surface in 50 cm spacings (deep band)
- shallow only – all placed under every seed row.

These 2 strategies are described as dual P (e.g. 5/60 and 20/60; shallow/deep P kg/ha) or shallow P (e.g. 5/0 and 20/0; shallow/deep P kg/ha), respectively.

All treatments (even where no deep P was applied for example 5/0 and 20/0) were disturbed to ~20 cm deep to account for any apparent ripping effect.

Watering regimes

Two watering regimes:

- control (rain-fed)
- dry conditions (using rainout shelters).

A custom-built rainout shelter (Figure 1) was used to create a contrasting watering regime to the rain-fed condition by excluding rain events (>5 mm). The cover of the rainout shelter was put on when >5 mm of rain was forecast but removed after the rain event to minimise shading effects. The rainout shelters were used from the second week of July until maturity.

Results

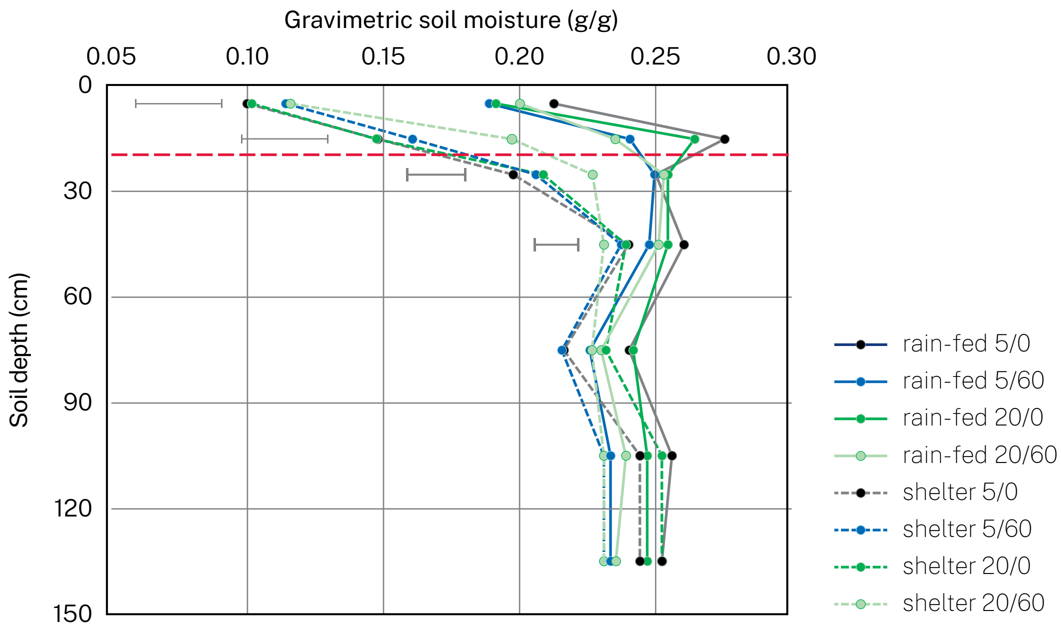
Growing conditions

The soil at the experiment site had stratified P. Colwell P was 26 mg/kg at the soil surface (0–10 cm) and 2.9 mg/kg in the subsoil (10–30 cm deep). The site had a potential alkaline sodicity constraint at depth (starting at 30–60 cm). Soil profile water content at sowing (up to 150 cm deep) was 605 mm indicating very high summer fallow rainfall. The site received well above average annual rainfall of 946 mm with 583 mm falling during the growing season (April–October).

Figure 1 Portable rainout shelters covering wheat plots to exclude rainwater at Tootool, southern NSW. Photos taken at anthesis showing wetter surface soil in the rain-fed plot (top right) compared to the plot with rainout shelter (bottom right).

Soil moisture content at anthesis

The gravimetric moisture content at different soil depths was determined by destructive soil coring at anthesis. The rainout shelters were effective at excluding rainwater and resulted in a significantly lower soil moisture content especially in the upper soil layers than in the rain-fed plots (Figure 2). The difference in surface soil moisture condition between the rain-fed and rainout shelter plots was also visible from the photos taken during soil coring at anthesis (Figure 1 top and bottom right). However, deeper in the soil profile (i.e. >60 cm deep) gravimetric soil moisture content did not significantly differ between the rain-fed and rainout shelter plots.

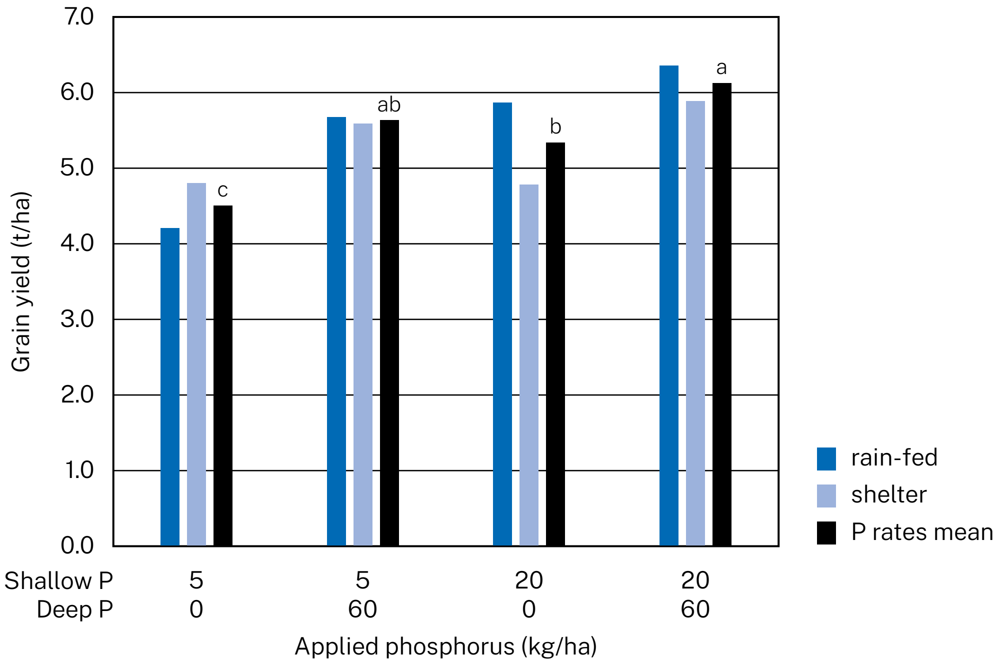


The horizontal dashed line (red) indicates deep P banding depth. All treatments had been disturbed to ~20 cm deep at 50 cm spacing at sowing in 2022 as part of the deep P application. At different soil depths, significant differences ($P<0.05$) between the watering regimes are indicated by horizontal lines. Gravimetric soil moisture content did not significantly differ ($P>0.05$) between the P placement strategies.

Figure 2 The effect of P placement strategy and watering regimes on gravimetric soil moisture content during wheat anthesis (cv. Sunblade CL Plus^(ϕ)) at Tootool, southern NSW in 2022.

Grain yield

Wheat grain yield was significantly ($P<0.001$) affected by the P placement strategy, but the effect of watering regimes was not significant ($P>0.05$). With a low rate of shallow P (i.e. 5 kg P/ha), deep banded 60 kg P/ha increased grain yield by 25%, whereas with a moderate rate of shallow P (i.e. 20 kg P/ha), the increase in grain yield was only 15% (Figure 3). A similar yield response between a total of 65 kg P/ha dual banded P (i.e. 5/60 shallow/deep kg P/ha) and only 20 kg P/ha shallow banded P (i.e. 20/0 shallow/deep kg P/ha) indicates that shallow P was more effective than dual P.



All treatments had been disturbed to ~20 cm deep at 50 cm spacing at sowing in 2022 as part of the deep P application. Each data point is a mean value of n = 4. Significantly different ($P<0.05$) wheat grain yield between P placement strategies (l.s.d. = 0.7 t/ha) is annotated by different letters.

Figure 3 The effect of shallow and dual banded P (kg/ha) on wheat (cv. Sunblade CL Plus$^{⊕}$) grain yield at Tootool, southern NSW in 2022.

Summary

Deep banding P has produced consistent grain yield in the northern growing region (Lester et al. 2022; Sands et al. 2022), but there is very limited evidence of an advantage of dual banded P over shallow banded P in the southern growing region (Uddin et al. 2023). Consistent with earlier findings from the southern growing region, the results from this experiment also support shallow banded P as a more effective strategy than dual P placement.

This experiment aimed to create favourable soil moisture conditions for deep P responses (dry surface soil at shallow banded P depth and wet subsurface soil at deep banded P depth) using rainout shelters. Soil moisture at anthesis showed that excessively using rainout shelters resulted in dry conditions both at shallow and deep banded P depths, thereby creating unfavourable soil moisture conditions for deep P responses. However, this once-off soil moisture measurement was unable to represent all growing season scenarios, as wheat grain yield still benefited from the higher rates of deep banded P. This highlights the importance of periodic soil moisture measurements.

The effectiveness of the shallow banded P compared with dual P placement under contrasting watering regimes indicates that placing P deeper in the profile might not be a reliable strategy to improve crop performance in southern NSW.

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Acknowledgements

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Does applying phosphorus (P) both deep and shallow produce better crops than shallow P alone in southern NSW?

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Key findings

- Fresh P fertiliser application outperformed the residual P effect in a P responsive site.
- Both surface and subsoil Colwell P interact with the prevailing rainfall conditions to determine dual P or shallow P responses.
- There was little evidence that dual P placement provided a yield advantage (only in one of the 3 data sets – wheat 2022 at French Park) compared with the same total P rate placed shallow.
- Responses to the residual dual P placement were also evident during the third cropping year (2022) from the initial application year (2020).

Keywords Phosphorus placement, deep banded P, shallow P, dual P, residual P

Introduction

Recent GRDC-invested research in the summer rainfall-dominated northern growing region of Australia has shown that grain yield can be increased by 6–40% by placing phosphorus (P) ~20 cm deep and at 50 cm spacing instead of current farming practices, i.e. 5–10 kg P/ha applied in or around the seed row (Lester et al. 2022; Sands et al. 2022). Furthermore, these experiments showed a residual benefit from deep banded P on grain yield in 5 consecutive crops (Sands et al. 2022).

There are however some fundamental differences in cropping systems between the northern and the southern growing regions of Australia. Winter crops in the north rely predominantly on water stored during summer fallows, and topsoils (where fertiliser and plant available soil P are concentrated) are often dry because of limited in-crop rainfall. Although nutrients also tend to be concentrated in the topsoil in south-eastern Australia as zero-tillage/conservation cropping practices become more common (Armstrong et al. 2015), cropping in the south is dominated by winter rainfall. Topsoil can remain wet for considerable lengths of time following sowing, or if rainfall is non-seasonal there can be some topsoil drying. Therefore, it is unclear whether crops will be as responsive to deep P in the southern regions, particularly in high rainfall years.

This paper reports experiment findings from southern NSW that tested the effectiveness of different combinations of shallow (~5 cm) and deep (~20 cm) banded P (dual P placement) in improving grain yield compared with shallow P placement alone.

Site details

Location	• French Park, southern NSW • Merriwagga, southern NSW
Soil type	• French Park: Red sodosol • Merriwagga: Red kandosol

Design	Experimental plots were arranged in a row-column design with 4 replications.
Sowing	• French Park – wheat (cv. Sunblade CL Plus⍉): 3 May 2022 with a seed rate of 71 kg/ha • French Park – lentil (cv. PBA Hallmark XT⍉): 3 May 2022 with a seed rate of 73 kg/ha • Merriwagga – canola (cv: Pioneer® 43Y92 CL): 29 April 2022 with a seed rate of 5 kg/ha • Merriwagga – field pea (cv. Sturt⍉): 24 May 2022 with a seed rate of 110 kg/ha
Rainfall	Fallow rainfall (November 2021 – March 2022) • French Park: 660 mm (long-term average = 195 mm) • Merriwagga: 282 mm (long-term average = 156 mm) In-crop rainfall (April–October 2022) • French Park: 553 mm (long-term average = 325 mm) • Merriwagga: 387 mm (long-term average = 225 mm)
Harvest date	• French Park – wheat: 16 December 2022 • Merriwagga – canola: 3 November 2022 • Merriwagga – field pea: 8 November 2022

Treatments

The experiments were established in 2020 with a range of P rates and 2 placement strategies.

Phosphorus was either applied as a dual placement strategy or shallow only:

- dual P placement – some under every seed row (shallow band) and some banded at approximately 20 cm below the surface in 50 cm spacings (deep band)
- shallow P only – all placed under every seed row.

These 2 strategies are described as dual P or shallow P, respectively. A very high rate of shallow banded P (60 kg P/ha or 80 kg P/ha) was included to estimate the severity of P deficiency for the site. An additional treatment where P was supplemented with Granulock®Z (referred by '+' with P rates) was included to cover any possible deficiencies in zinc and/or sulfur.

Phosphorus was applied as mono-ammonium phosphate (MAP) and balanced for nitrogen (N). All treatments were disturbed to ~20 cm deep to account for any apparent ripping effect. An additional control 0/0 undisturbed (no ripping) was included. At both sites, treatments were duplicated to include cereal, legumes and oilseed crops in rotations. In 2021 both sites received a blanket application of 5 kg P/ha.

In 2022, the original undisturbed 0/0 treatment (0UD/0) was treated with a shallow band of P at the maximum rate used in the initial experiment year (i.e. 60 kg P/ha or 80 kg P/ha) to examine fresh versus residual P effects. The remaining wheat plots were balanced for N only. However, for the legumes experiment, the additional P was applied as triple super phosphate (TSP) to avoid a high rate of N application from MAP.

Results

Growing conditions

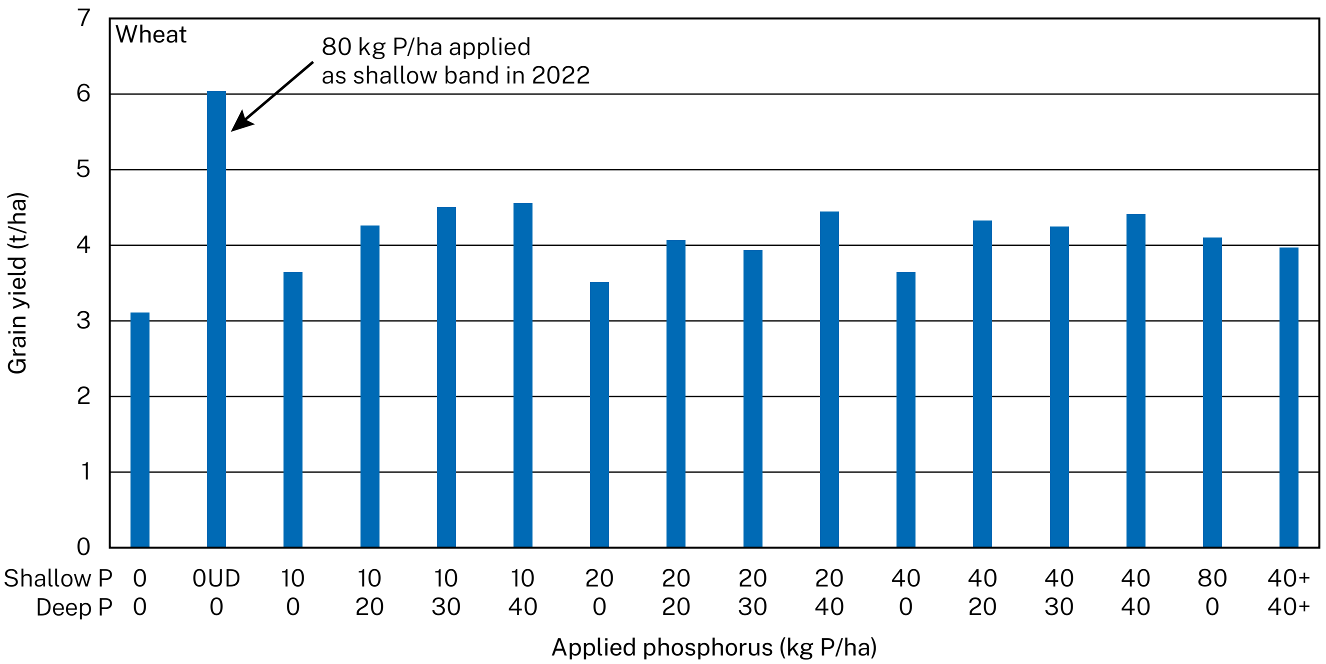
At French Park, the pre-sowing Colwell P for the 0–10 cm layer was 17 mg/kg. Soil profile water content at sowing (up to 120 cm deep) was 532 mm indicating very high summer fallow rainfall. The site received well above average annual rainfall of 1060 mm with 553 mm falling during the growing season (April–October). Although the lentils had an ideal start, higher than average rainfall, especially during spring severely affected the site and this experiment was lost to waterlogging stress. The wheat plots handled the waterlogged conditions better and were header harvested on 16 December 2022.

At Merriwagga, the pre-sowing Colwell P for the 0–10 cm layer was 36 mg/kg. Soil profile water content at sowing (up to 150 cm deep) was 487 mm indicating lower summer fallow rainfall than the French Park site. The site received 674 mm, which was well above the average annual rainfall of 381 mm.

Grain yield

At French Park, wheat yield in 2022 was significantly (*P*<0.001) increased following P fertiliser application in 2020 (Figure 1). Freshly applying 80 kg P/ha doubled wheat grain yield (6 t/ha) compared with the 0/0 P treatment (3.1 t/ha). The residual effect of different P fertiliser rates was evident during the third season with up to a 1.5 t/ha increase in grain yield. However, the fresh application of 80 kg P/ha (6 t/ha) outperformed the same rate of P that was applied back in 2020 (4.1 t/ha).

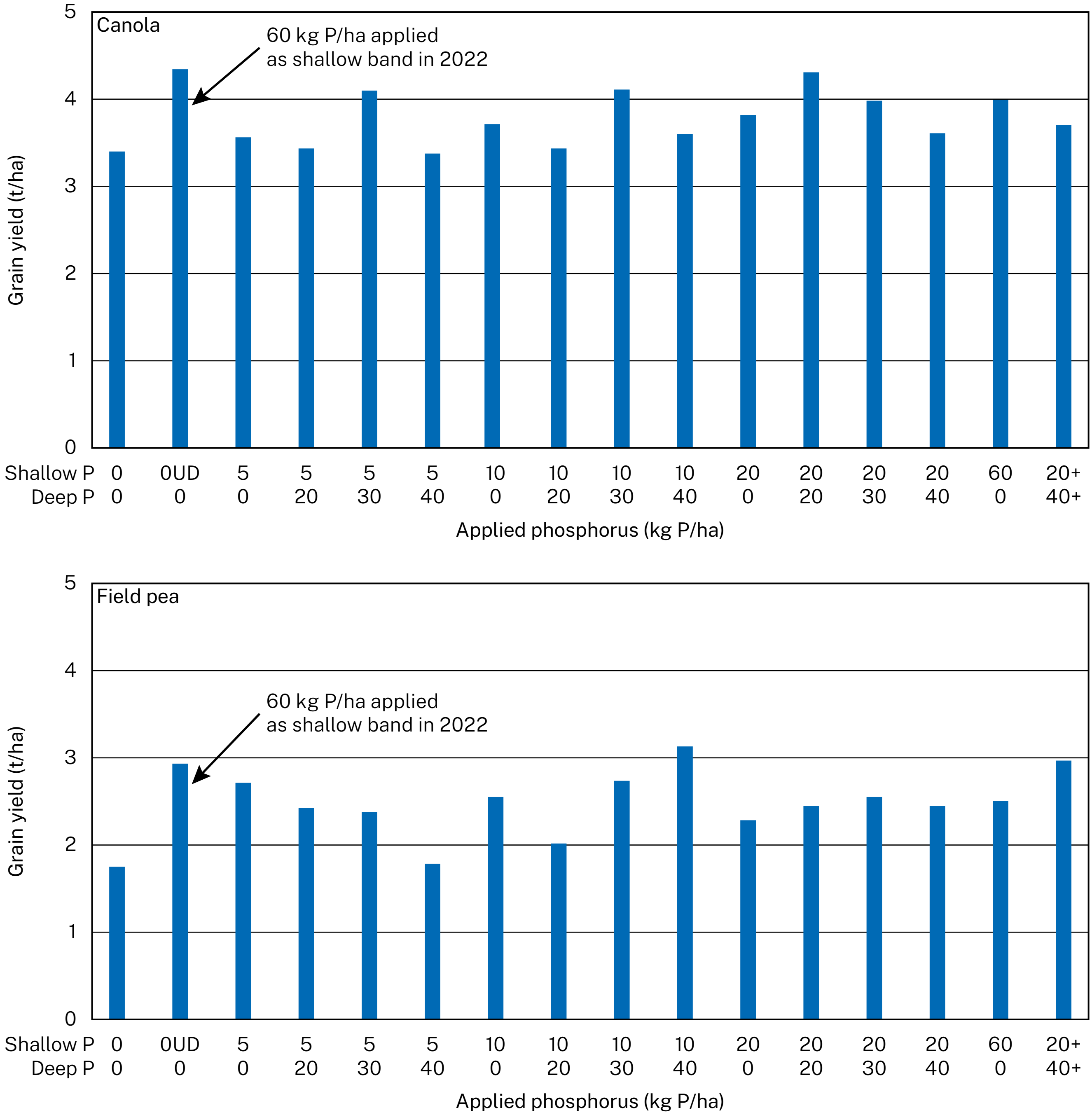
The 10/30 dual P application treatment (4.5 t/ha) yielded higher than the corresponding comparison of 40/0 (3.6 t/ha) indicating an advantage for dual placement. The yield difference of 0.9 t/ha approximated $288/ha assuming a wheat price of $320/t. However, the 40/40 dual P application treatment (4.4 t/ha) did not yield significantly higher than its corresponding comparison of 80/0 (4.1 t/ha).



Treatment with the '+' sign indicates P was supplemented with Granulock®Z fertiliser. All treatments except the 0UD/0 (UD = undisturbed control) had been disturbed to ~20 cm deep at 50 cm spacing in 2020 as part of the deep P application.
Each data point is the mean value of n = 4. l.s.d. (*P* = 0.05) = 0.7 t/ha.

Figure 1 The residual effect of shallow and dual banded P (kg/ha) on wheat grain yield (cv. Sunblade CL Plus⁽ᵈ⁾) during the third season (2022) after the initial P fertiliser application in 2020 at French Park, southern NSW.

At Merriwagga, neither canola nor field pea grain yield showed a significant response to residual P or even to the fresh P applied in 2022 (Figure 2). This observation is similar to the anthesis biomass in 2022 and the harvest yield results in the previous 2 years (2020 and 2021) for this site.



Treatment with the '+' sign indicates P was supplemented with Granulock®Z fertiliser. All treatments except the 0UD/0 (UD = undisturbed control) had been disturbed to ~20 cm deep at 50 cm spacing in 2020 as part of the deep P application. Each data point is the mean value of n = 4. The treatment effect was not statistically significant for canola (*P* = 0.88) or field pea (*P* = 0.89).

Figure 2 The residual effect of shallow and dual banded P (kg/ha) on canola grain yield (cv. Pioneer® 43Y92 CL) and field pea grain yield (cv. Sturt⁽ᶜ⁾) during the third season (2022) after the initial application of P fertiliser in 2020 at Merriwagga, southern NSW.

Crop nutrition

Summary

There was little evidence (one out of 3 datasets reported in this paper) of an advantage of dual placed P over shallow P. This might be due to the higher than average rainfall during the experiment years. This would have enhanced the plant availability of soil reserve P, particularly for a site like Merriwagga with high background Colwell P both at the surface (0–10 cm; 36 mg/kg) and in the subsoil (10–30 cm; 8 mg/kg) layers.

During the third growing season (2022) at French Park, despite having double the long-term average annual and growing season rainfall the residual benefit of dual P (i.e. 10/30 shallow/deep P kg/ha) was larger than its corresponding comparison of shallow banded P (i.e. 40/0 shallow/deep P kg/ha). This might be due to 660 mm of summer fallow rainfall combined with lower than average rainfall early in the growing season (June and July) creating favourable conditions for deep P responses (i.e. dry surface with wet subsoil; Verburg et al. 2022) and the very low subsoil Colwell P (<3 mg/kg) for this site.

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Cereal diseases – an autopsy of 2022 and management considerations for the 2023 season

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Key findings

- Favourable climatic conditions in 2022 increased the prevalence of a range of cereal diseases across NSW, in particular: fusarium head blight (FHB), stripe rust and septoria tritici blotch (STB).
- In combination with increased cereal stubble loads produced in 2022, pathogen levels are likely to be elevated again in 2023.
- High fungicide inputs inevitably increase selection for fungicide-resistant non-target pathogens such as STB and wheat powdery mildew (WPM), which might also be present at the time of application.
- Conditions led to an FHB epidemic which has not been seen since 2016 but was considerably more widespread across NSW than ever before.
- Multiple stripe rust pathotypes were prevalent across NSW in 2022 including a new mutation. Keep up to date with the latest varietal resistance ratings.
- Assess your risk. Commercial and industry providers are available to assess germination and vigour of seed being retained for sowing; and presence of pathogen loads in soil, stubble, and seed.
- Source clean seed for sowing in 2023, free of pathogens or with as low a level as possible.
- NSW DPI plant pathologists can assist with correct diagnosis, cereal stubble and seed testing, and advice on appropriate management options.

Crop protection

Keywords Correct diagnosis, leaf diseases, soil-borne diseases, fusarium head blight, stripe rust, septoria tritici blotch

Introduction

For many in the agricultural industry, 2022 was a challenging year, particularly for those involved in cropping. The year was characterised by extremely high rainfall, flooding events, waterlogging and crop loss. Paddock trafficability issues were also significant challenges to in-crop disease management and harvest. Additionally, the highly conducive environmental conditions were ideal for the development and spread of leaf and head diseases, making disease management a significant concern for growers and advisors. Despite these challenges, many were able to achieve high yields and excellent economic returns, making 2022 a year of mixed experiences.

This paper outlines some of the lessons learned from the challenges faced in 2022 and how we can improve cereal disease management for the upcoming 2023 season. The previous year's challenges have highlighted the importance of taking a proactive approach to cereal leaf disease management, especially given the unpredictable and extreme weather conditions that can occur. By learning from the experiences of the past year and implementing effective disease management strategies, we can better manage disease risks and improve the growers' probability of achieving potential yield and economic return.

Environmental and disease interactions associated with yield loss and pinched grain

In southern NSW (sNSW), many wheat crops did not meet their predicted yield potential. This yield reduction was mainly due to pinched or aborted grains in heads. It is unclear whether the cause was more due to management decisions, limited nutrition, environmental factors or diseases, but it is certain that all contributed to the yield loss to varying degrees. Yield potential of a cereal crop is set early with any number of factors influencing or reducing top end yield. There were many factors in 2022 that reduced crop yield and increased pinched grain.

Heavy rainfall and trafficability issues delayed sowing in many areas, resulting in seed germinating in cold, waterlogged soils. These conditions are not favourable for quick root development to depth, which enables the root systems to move below the bands of *Pythium* and *Rhizoctonia* in the soil. Early infections by these diseases, along with take-all and fusarium crown rot (FCR) compromised root systems, limiting growth above and below ground. This was more evident in cereal-on-cereal rotations and disc seeding systems.

The series of disease conducive cropping seasons and wet summers (2020–21) enabled disease inoculum to build-up to very high levels by sowing in 2022, in some cases to levels thus far unseen, such as with wheat stripe rust. High inoculum loads, combined with prolonged cooler temperatures, rainfall and humidity placed the 2022 cereal crop under enormous early disease pressure, particularly from foliar diseases.

In addition, paddock trafficability issues with ground application or availability of aerial application, delayed or prevented fungicide applications in some regions. This generally resulted in increased disease levels in unprotected susceptible varieties with significant loss of green leaf area on vital yield contributing leaves (Flag (F), F-1 and F-2). This compromised the photosynthetic ability of affected plants to physically produce and transport the required nutrients and water to the heads for grain fill.

The combination of factors such as waterlogging (shut down plants), compromised root systems (*Pythium* and *Rhizoctonia*), partially or fully blocked vascular systems (FCR and take-all), significant loss of green leaf area (foliar diseases) and head diseases (FHB) and lower than average solar radiation for sNSW (reduced carbohydrate and protein transportation) all potentially influenced abortion and pinching of grains to varying degrees leading to reduced yield, high screenings and quality downgrades in 2022.

Disease review of the 2022 season

Fusarium head blight

During 2022, FHB, a fungal disease that affects wheat and other cereal crops, was common at varying levels across southern Queensland (sQld), NSW, Victoria (Vic.) and South Australia (SA). The last major outbreak of FHB in NSW was in 2016 – a season with elevated levels of rainfall during flowering and grain filling, much like 2022.

FHB is caused by several species of the fungus *Fusarium*, with *F. pseudograminearum (Fp)* and *F. graminearum (Fg)* being the most common. Both species can produce toxins known as mycotoxins that can contaminate the grain and make it unsafe for human and stock consumption. FHB can reduce crop yield and quality and can also affect the germination and vigour of retained seed. Infection is favoured by prolonged periods of moisture (36–72 hours of greater than 80% humidity) and temperatures between 20 °C and 30 °C.

Infection occurs through the anthers during flowering and appears as bleached spikelets or partial or whole head bleaching. The defining diagnostic characteristic of FHB is rachis browning (stem within head). Any spikelets above this browning point will die or have shrivelled grain. Other characteristics include white or pink grains, or orange spore masses along the edge of the glumes.

It is important to identify which species of *Fusarium* is causing the FHB infection because this will determine the best management strategy and provide information about the potential risk of mycotoxins. If the infection is caused by *Fp*, it has come from basal tiller infection from FCR. Under humid conditions, macroconidia form around the nodes on the stem, which are then dispersed onto leaves and eventually into the head through raindrop splash. *Fp* does not have an airborne dispersal mechanism, so the underlying FCR levels must be managed before sowing future cereal crops through an integrated disease management (IDM) plan to minimise FCR inoculum and the potential for FHB infection.

The second *Fusarium* spp., *Fg*, as opposed to *Fp*, has an airborne dispersal mechanism and is hosted on grass species, cereal crops, maize and sorghum stubbles. The ascospores produced by *Fg* are highly suited to wind dispersal. Crop rotation, stubble management and grass weed control are the keys to reducing *Fg* risk.

Causal *Fusarium* spp. produce a range of mycotoxins, including deoxynivalenol (DON) and nivalenol (NIV). The toxicity of these mycotoxins can vary depending on the species of *Fusarium*. NIV is generally considered to be around 10 times more toxic than DON. There are 2 different forms of DON, with 3ADON being half as toxic as the 15ADON form. *Fp*, produces 3ADON, while *Fg* produces the more toxic 15ADON and NIV mycotoxins.

Care must be taken when feeding *Fusarium*-infected grain to stock. There are no specific Australian stock feed guidelines for mycotoxins. The US Food and Drug Administration (FDA) have advisory guidelines that state for the DON toxin, the maximum part per million (ppm) level for food products consumed is:

- 1 ppm for humans
- 10 ppm for ruminating beef and feedlot cattle older than 4 months (cannot exceed 50% of diet)
- 10 ppm for poultry (cannot exceed 50% of diet)
- 5 ppm for swine (cannot exceed 20% of diet)
- 5 ppm for all other animals (cannot exceed 40% of diet) (US FDA, 2010).

Species identification work, via quantitative PCR has been undertaken from diagnostic samples submitted during 2022. To date, 3 *Fusarium* spp. have been identified as the cause of FHB, being *Fp*, *Fg* and *Fusarium culmorum (Fc)*, with *Fp* being the most common. This indicates that a large proportion of NSW cropping regions have an underlying FCR issue, which needs to be managed with an IDM plan. *Eutiarosporella* spp., the causal pathogen of white grain disorder (WGD), has also been identified from infected heads. Unlike FHB, WGD does not produce a mycotoxin, but can reduce vigour and seed germination the following year. Both FHB and WGD can cause acceptance issues at grain receival sites if visual white grain numbers exceed delivery limits.

Wheat stripe rust

High inoculum levels combined with early opportunities for sowing winter wheat varieties kickstarted the epidemic for the 2022 cropping season. The first reported stripe infection for NSW was in mid May 2022. This detection was the second earliest infection date on record, with the historical average annual infection date being the third week of July.

The situation with wheat stripe rust in the eastern states' cropping regions has never been more complex with several pathotypes present in our environment. During 2021, Professor Robert Park of the Sydney University Australian Cereal Rust Survey identified 2 new mutations: 238 E191 A+ 17+ 33+ and 238 E191 A+ J+ T+ 17+. These mutations are thought to have come from hybridisation of the 198 E16 A+ J+ T+ 17+ (198) and 239 E237 A- 17+ 33+ (239) pathotypes. Some other pathotypes occurred in minor frequencies, with only 3 deemed predominant in NSW during 2022: 198, 238 E191 A+ 17+ 33+ (238) and 239, which comprised 98% of the pathotypes Professor Park and his team surveyed (personal communication, January 2022).

Each of these pathotypes can affect a particular variety (host) differently. This is due to the resistance genes within the plant and whether the individual pathotype is virulent or avirulent on those genes. It is important to stay up-to-date with the latest variety resistance ratings, as they can change from year to year. These ratings are developed through the National Variety Trial (NVT) pathology screening project and are released annually on the GRDC NVT website (https://nvt.grdc.com.au/) and in state-based sowing guides such as the NSW DPI winter crop variety sowing guide, (https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/nsw-winter-crop-variety-sowing-guide-2023).

Septoria tritici blotch

Septoria tritici blotch (STB) was particularly devastating to wheat crops that were not protected by fungicide in the high to medium rainfall zone of sNSW during 2022. Experiments previously conducted at Wagga Wagga Agricultural Institute (WWAI) found that a 19–49% yield loss from STB is possible in a susceptible wheat variety. Due to inoculum build up from previous seasons and optimal environmental conditions, STB became a serious issue in regions where it does not usually pose a threat to yield. In these areas, varieties that were rated as more resistant to stripe rust but more susceptible to STB (e.g. Beckom(D)), were adversely affected due to reduced fungicide use in these crops targeted at stripe rust management. In some cases, STB still reduced yield in crops that were protected by 1–2 fungicide applications, further highlighting that fungicide choice and timing is important for STB control.

STB has a fungal structure produced on wheat stubble (pseudothecia) that releases airborne spores (ascospores) under ideal environmental conditions. The ascospores can spread long distances to infect susceptible wheat, durum and triticale crops. Even after a non-host break crop (e.g. canola) is sown in a paddock, any remaining stubble residues from preceding wheat crops can still be a source of inoculum and infect a newly emerging wheat crop. This risk can remain for at least 2 years.

Stubble spore release experiments conducted at WWAI have shown that the resistance rating of the wheat variety grown has little influence on the ability of the pathogen to colonise senescent stubble and the inoculum level present on retained stubble, i.e. the number of spores released in the following season. Therefore, any infected wheat stubble must be considered a risk for the following wheat crop or crops located nearby. However, the variety's resistance rating is effective during the growing season in limiting STB infection within the canopy.

Stubble management experiments have shown that a net reduction in inoculum levels can be achieved by manipulating harvest cut height to reduce the standing straw available for the STB pathogen to colonise saprophytically after harvest. This experiment had 3 cut height treatments which were selected to lower straw length by one node on the main stem. Using the 32 cm cut height as a base level, lowering cut height to 24 cm reduced the number of ascospores produced by 84%. When comparing the 32 cm cut height to the 14 cm cut height, there was a 97% reduction in the number of ascospores released from the retained wheat stubble. However, excess stubble material must be removed from the paddock to result in a net reduction, otherwise the inoculum from the standing stubble is only relocated to the ground which maintains the same inoculum levels within the paddock. Bale or burn (narrow windrow or blanket burn) the straw to remove it. Some methods are less labour intensive than others, however, the cost–benefit risks of each method and other system effects must be weighed before being undertaken.

Ramularia leaf spot of barley

Ramularia leaf spot (RLS) of barley is caused by the pathogen *Ramularia collo-cygni*. It is a relatively new incursion into the NSW grain-growing belt; 2022 was the first season with relatively widespread expression in the medium- to high-rainfall zones of south-eastern NSW. RLS was first detected in Australia in 2016 in Tasmania, followed by Western Australia in 2018. Further surveys have confirmed the presence of RLS in NSW, Vic. and SA.

RLS can be transmitted via infected seed or wind dispersal. The pathogen grows for at least the start of its lifecycle as an endophyte, which means the fungus lives within the barley plant without causing disease symptoms or leaf damage. At some point after flowering, the pathogen can express toxins (rubellins) in the plant that cause characteristic rectangular lesions on the leaves and stems. These lesions lead to loss of green leaf area and subsequent loss of yield due to reduced grain filling. The exact triggers that cause the change from endophyte to pathogen are not well understood, however, the disease is likely to be more prevalent in the high rainfall cropping areas and more severe in years with higher rainfall at the end of the cropping season.

RLS can be difficult to differentiate from other barley leaf diseases such as the net-blotches and other physiological plant responses. RLS appears as small rectangular red–brown lesions surrounded by a yellow chlorotic margin, often in a speckled or chequer-plate pattern. Differing from the net-blotches, RLS lesions are restricted between leaf veins giving them a square or rectangular shape (Figure 1).

Figure 1 Barley plant infected with Ramularia leaf spot. Note loss of green leaf area (right).

Very little is known about the resistance levels to RLS in current barley varieties, fungicide resistance status or potential yield losses incurred under Australian environmental conditions. Internationally, yield losses up to 30% have been recorded, a figure that is consistent with the effect from other barley necrotrophic diseases. In overseas cropping systems, for example, in New Zealand and the United Kingdom, the pathogen has evolved and developed resistance to several fungicide chemistries (GRDC 2021). However, limited testing in Australia suggests all 3 major fungicide groups, Group 3, 7 and 11, are effective against RLS. International research suggests that application time should be between GS31 and GS49 (GRDC 2021). There are currently fungicides registered for RLS control in Australia. These products contain the actives benzovindiflupyr and propiconazole, with further products coming to the market in the future.

Disease risk in 2023

Climatic conditions (rainfall, temperature and humidity) play a significant role in initiating and driving disease epidemics. If 2023 approaches or reaches mean annual in-crop rainfall, there will be an elevated leaf disease risk. This is due to the extreme inoculum levels of many leaf disease pathogens that have developed from the disease-conducive 2020–22 seasons.

If 2023 is mild and wet, there is a higher risk of foliar disease epidemics. These include biotrophic diseases such as rusts and necrotrophic diseases such as STB and yellow leaf spot (YLS) in wheat, and RLS, the spot form of net-blotch, the net form of net-blotch and scald in barley. These conditions will also favour soil-borne diseases such as take-all and *Pythium*.

If the 2023 season is drier there is likely to be a reduction in foliar diseases and increase in root diseases, such as FCR and *Rhizoctonia,* where the drier conditions favour disease expression.

The final inoculum consideration is from seed-borne diseases and virus such as bacterial blight, smuts, bunts, *Fusarium*-infected grain and *Wheat streak mosaic virus*. Where possible, sourcing clean seed for sowing in 2023, that is, not from crops with moderate to high levels of infection in 2022, is important to reduce risk of these diseases. However, for the 2023 cropping year, this might not be easily done considering the widespread occurrence of FHB and poor-quality wheat grain i.e. pinched grain. *Fusarium*-infected grain in particular will be an issue for sowing in 2023.

Disease management for 2023

Managing diseases separately, stripe rust and septoria tritici blotch

One observation from 2022 was differences in fungicide management between varieties with more or less stripe rust resistance and the effects the level of fungicide use had on STB control. Most varieties grown in sNSW are moderately susceptible to susceptible (MS–S) to susceptible to very susceptible (S–VS) to STB. So, under the right conditions, STB infection will limit yields in most varieties.

STB caught a lot of growers and agronomists by surprise in the medium- to low-rainfall zones last year where this disease has not normally been an issue. This contrasts with the higher rainfall regions in sNSW, which are at risk of STB infections in most seasons and where management strategies are generally already planned for STB.

During 2022, varieties that are more susceptible to stripe rust often had better STB control than varieties with high resistance ratings for stripe rust. This resulted from using fungicides targeted to control stripe rust. Stripe-rust-susceptible varieties likely had 2–4 or more fungicide units applied to manage stripe rust. These would have had some efficacy on STB and helped keep it under control. However, 4 fungicide units is not a sustainable way to control stripe rust. It promotes both on- and off-target resistance development in diseases such as STB and wheat powdery mildew (WPM). Professor Park's new research has proven that individual pathotypes of both wheat and barley leaf rust within Australia have acquired resistance to Group 3 fungicides (DMI, triazoles); hence the need to judiciously apply fungicides in susceptible varieties to avoid stripe rust developing the same resistance or reduced sensitivity to fungicides.

On the other hand, varieties with improved stripe rust resistance levels (moderately resistant to moderately susceptible, MR–MS, and better) were generally more affected by STB as they only required one or maybe 2 fungicide units to manage stripe rust, generally around late tillering (GS30) or the start of stem elongation (GS31). The efficacy of early fungicides had diminished by GS39 and STB infection was well underway in some crops that had not been diagnosed. This later STB infection is what then caused yield loss and pinched grain in many situations. A single further fungicide application between GS39 and GS49, solely for STB, would have helped reduce the severity of late STB infection, protecting yield and reducing screenings.

So…what can we do better for 2023?

Firstly, grow more stripe rust resistant varieties as there is a big difference in fungicide stewardship of 1–2 fungicide units on a less susceptible rated stripe rust variety and 4 units on a susceptible (S) variety in conducive seasons. It also reduces the risk of yield loss if paddock trafficability within the season becomes an issue. For example, in 2022, many growers and advisors reported delayed foliar fungicide applications by ~10 days, related to paddock trafficability or access to aerial application. In more susceptible varieties and under the high inoculum loads of 2022, this delay resulted in up to 40% yield loss. This is a significant economic impact. Growing stripe rust susceptible varieties might have a yield benefit in some regions, but this needs to be balanced against the increased disease risk and reliance on the critical timing of fungicide applications.

All varieties, unless rated resistant (R), do have susceptibility to stripe rust infection at the seedling stage. Hence, more resistant varieties only need fungicide protection early until adult plant resistant (APR) genes become active (Table 1). APR is temperature and growth stage sensitive, and the timing of full expression can vary from year to year. After these growth stages, the APR genes can be relied on to control further stripe rust development. Moderately susceptible to susceptible (MS–S) or S varieties have little APR and by the time it expresses after grain fill, there is likely to be severe yield loss if not controlled using in-crop fungicides, therefore, there is a critical need to fully manage these varieties throughout the season with multiple fungicide applications.

Fungicide management for 2023 will depend on the variety's resistance rating to stripe rust and STB. Table 2 displays a suggested fungicide plan for sNSW if 2023 is conducive to leaf disease development. However, not all applications will be needed depending on seasonal conditions. If an S or worse-rated variety is to be sown, the planned fungicide regime should consider including an up-front fungicide such as adding flutriafol to the starter fertiliser at sowing, followed by a GS31 and GS39 in-crop fungicide application. If the conducive conditions persist later into the season, a GS59 fungicide application could also be needed. Reducing the time between applications to no more than 3–4 weeks might also need to be considered, as under high inoculum pressure the protective component of fungicides will be running out leaving the plants unprotected, which is what occurred in 2022.

Table 1 Stripe rust resistance rating and the associated growth stage of adult plant resistance expression.

Stripe rust resistance rating	Growth stage (GS) adult plant resistance is expressed
MR	GS30–32
MR–MS	GS37–39
MS	GS49–60
MS–S	GS61–75

MR = moderately resistant, MR–MS = moderately resistant–moderately susceptible, MS = moderately susceptible, MS–S = moderately susceptible–susceptible.

Table 2 Fungicide management strategy to protect against stripe rust and STB in sNSW if 2023 is another highly conducive year for these leaf diseases.

Stripe rust resistance rating	Suggested fungicide application(s) for stripe rust	Suggested additional fungicide application(s) for STB
MR	GS31	GS39–49
MS	GS31, GS39-49	GS59
S	GS31, GS39, GS59	Nil

MR = moderately resistant, MS = moderately susceptible, S = susceptible.

Alternatively, if an up-front fungicide is not used, a minimum of 2 in-crop fungicide applications should be planned, timed at GS31 and GS39 for an S-rated variety, with the likelihood of a further GS59 application under conducive conditions. Earlier in-crop intervention might be needed if stripe rust appears before GS31. These control programs, combined with fungicide choice, will also help protect against STB infection. This is a high input and high risk strategy that will potentially increase selection for fungicide resistance within the stripe rust population, but which will also select for resistance in other fungal pathogens such as STB and WPM, which could also be present when the fungicide is applied.

For varieties with better levels of stripe rust resistance (R–MR, MR, MR–MS), early protection up-front from flutriafol with the fertiliser, depending on the season, might be enough to protect the plants from stripe rust until APR becomes active. Alternatively, if flutriafol is not an option, apply fungicide around the start of stem elongation (GS31) to control early stripe rust infections. If the season is conducive, apply fungicide again around GS39–49 to protect against STB. If the STB season is severe like 2022, a third application around GS59 might be necessary. However, in most seasons it will not be needed.

The intermediate rated varieties, MS and MS–S to stripe rust, depending on the season, are likely to need a management package meshing components from each management plan discussed above. The minimum planned strategy should include 2 fungicide applications.

It should be noted that even in high stripe rust pressure years, there is very little data showing a yield benefit from using fungicides before stem elongation starts. That said, any sprays applied before stem elongation starts will at best only have a suppressive effect on inoculum load, as none of the leaves that contribute significantly to grain yield emerge until after this growth stage. Therefore, crops that include a fungicide with the herbicide application during tillering (GS25) still require a dedicated stripe rust fungicide spray at GS31–32 to protect the F-2 leaf. In susceptible varieties the gap is simply too long between GS25 and the flag leaf (GS39) second application timing, which can result in significant stripe development on the unprotected F-2 and F-1 leaves during this period.

Fungicide applications can be altered to suit another key growth stage such as flowering, seasonal conditions and outlook along with yield potential. Fungicide resistance management through rotating modes of action (MoA) and individual triazole actives within season should also be considered (refer to the Australian Fungicide Resistance Extension Network [AFREN] website, https://afren.com.au/).

Lastly, not all fungicide active ingredients are the same when it comes to controlling STB; fungicide choice is becoming increasingly important. Group 3 (DMI, triazoles) fungicides with active ingredients such as tebuconazole and propiconazole will readily control stripe rust, but have poorer activity against STB. Prothioconazole and epoxiconazole are more robust and better options for targeted STB control. They are also effective on stripe rust.

Group 7 (SDHI) and Group 11 (QoIs, strobilurins) fungicides are mainly protectants, with some of the Group 3 actives they are paired with being poorer curatively on STB so they should be applied to plants with minimal infection. Do not spray the same Group 3 active ingredient more than twice in one season and once for Group 7 and Group 11. Use mixtures with multiple active ingredients to minimise fungicide resistance development, rotate actives and groups (especially between consecutive applications), and be mindful of label instructions and withholding periods.

Fusarium head blight

Fusarium head blight was prevalent across NSW during 2022. The carryover of *Fusarium* spp. in seed from crops infected with FHB in 2022, which have been retained for sowing this season is a concern.

Using seed that has moderate *Fusarium* infection levels can:

- affect seed germination and vigour
- cause seedling blight of young wheat plants, stunting their growth and causing death
- introduce FCR into otherwise FCR-free paddocks.

It is critical to test seed retained from any crop known to have FHB or where white grains were detected at harvest for the *Fusarium* infection level well in advance of sowing. Testing will identify if a cleaner seed source or a fungicide seed treatment is required. It is important to get seed sources tested, as infection can be higher than the visual number of white/pink grains in the sample. This is due to later infections of FHB which might not have discoloured the seed.

If you have a known *Fusarium*-infected seed source, it should be tested for germination and vigour as *Fusarium* can affect these traits. There are commercial providers that provide this service. This will allow you to adjust your seeding rates at sowing accordingly or find a different seed source.

In high-risk situations, applying Prosaro® when flowering starts is an option to reduce FHB levels. These situations can include:

- conducive weather conditions (prolonged high >80% humidity during flowering and early grain fill)
- overhead irrigation
- presence of maize or sorghum stubbles
- high underlying FCR levels or high risk durum wheat paddocks.

Prosaro® needs to be applied at the start of flowering as the anthers are the primary infection site for FHB. There is a big distinction between FHB and stripe rust fungicide timing to limit head infections. Effective stripe rust control needs to be carried out at least 2–3 weeks before flowering. This allows time for the spores to die so they are not blown into the head at flowering. Whereas with FHB, the fungicide needs to be timed specifically at flowering to protect the anthers. Note, in North America, strobilurin fungicides (also known as Group 11 or QoIs in Australia) are not recommended from booting (GS45) onwards in paddocks with FHB risk, as this can increase mycotoxin accumulation in infected grain (Chilvers et al. 2016). The risk of mycotoxin accumulation and the need to control other diseases will need to be considered.

Fungicide application for FHB is a dedicated spray, set up differently than for stripe rust, as coverage of heads is critical. Factors include:

- timing (start of flowering, GS61)
- high water rates (minimum 100 L/ha) by ground rig
- twin angled nozzles to allow coverage on both sides of the head (required)
- Prosaro® is the only registered product in Australia
- efficacy is considerably reduced with aerial application.

At harvest, it is best to separate out grain from infected and uninfected paddocks to maximise market opportunities. Harvest the least infected paddocks first, open header sieves and increase fan speed to blow out infected grains if they are pinched and lighter to reduce the number of white/pink grains in the sample. This is only an option if the other grain is full, otherwise non-infected grain will also be blown out the back of the header.

FHB requires extended periods (>36 hours) of high humidity (>80%) at a very specific growth stage (flowering) to initiate infections so relies heavily on these conditions coming together. Considerable differences in FHB levels between varieties within a location that flowered 2 weeks apart were common in 2022 even though under the same inoculum pressure. Hence, the risk of FHB again in 2023 needs to be kept in perspective. The key underlying message is that in many regions, the FHB infection in 2022 was related to basal infections from FCR. A hot and dry seasonal finish in 2022 would have prevented FHB infection, but would likely have led to widespread yield loss from FCR, which is exacerbated by stress during grain filling. FCR risk across much of NSW is at an all-time high following 3 consecutive wet seasons; moisture favours infection, but limits expression and yield loss from whiteheads. Do NOT ignore the signs from FHB in 2022. Test paddocks with any level of FHB for their level of FCR inoculum in retained stubble, especially if considering another cereal crop in 2023.

Cereal root diseases

With the risk of cereal root disease elevated for 2023, consider the risk associated with cereal-on-cereal rotations. Root diseases are difficult to control as you cannot apply fungicides once they appear to limit further development. An IDM plan must be implemented to manage the underlying pathogen loads, which could take more than one season.

Rhizoctonia, *Pythium*, take-all and FCR were all prevalent during 2022. If a cereal-on-cereal sequence is necessary, be proactive instead of reactive. Consult paddock notes, management plans and rotation sequences from previous years to identify known and potential disease issues. Gain an understanding of underlying inoculum levels through PreDicta®B DNA-based testing, which quantifies a wide range of pathogen levels and provides an associated risk level.

Management of fusarium crown rot

If moderate to high *Fusarium* levels are identified in cereal stubble or PreDicta®B testing, consider growing a non-host break crop (i.e. pulses, canola or grass-free pasture legumes such as lucerne). This will allow time for the infected cereal stubble to decompose, reducing survival of the FCR fungus. Solid rotations incorporating non-consecutive cereals and diverse break crops create an environment that will reduce the likelihood of significant root diseases including FCR.

Varieties and crop species can differ in their resistance and tolerance to FCR. So crop and variety choice can be used as a 'band aid' solution if you are forced to grow a cereal under moderate FCR risk. For FCR, in the order of most susceptible to least susceptible is: durum wheat>triticale>bread wheat>barley>oats.

Under moderate FCR risk, consider barley or oats instead of bread wheat and avoid durum. Barley tends to have less yield loss from FCR as it generally fills grain earlier in the season compared with wheat. This provides some escape from heat and moisture stress, which exacerbates disease expression. However, barley is still a very good host of the FCR fungus. Growing a cereal crop will still build or maintain FCR inoculum within paddocks, so you are just buying time and not addressing the underlying FCR issue.

There are other management options at sowing that can reduce the level of FCR infection and expression during grain filling. These include:

- inter-row sowing to place the cereal seedling furthest away from the inoculum held in previous cereal rows
- fungicide seed treatments, which are available, but they must be used in an integrated management plan, they are not a magic bullet
- sowing at the start of the recommended window for each variety in your area to reduce heat/water stress at flowering
- matching nitrogen fertiliser applications to stored soil water at sowing and predicted seasonal conditions.

Controlling grass weeds and volunteer cereal plants is vital, especially in break crops, as most grass weeds are alternative hosts of winter cereal pathogens, including the FCR fungus. Controlling weeds and cereal volunteers over summer also maximises soil moisture storage and reduces the carryover of other pathogens including rust and insect virus vectors.

Summary

The 2022 season was a challenging cropping year for many in the face of high rainfall, devastating floods and high sustained cereal disease pressure. The authors thoughts are with those who were affected and we wish them a quick recovery. However, for many, the season was still very successful with excellent grain yields. The 2023 season is already shaping as another favourable year for crop production with high soil moisture levels at depth already accumulated in many areas. In-crop rainfall will be required to germinate the crop and ensure it can access the sub-soil moisture i.e. join up the moisture bands. Cereal disease risk is likely to be higher due to ongoing pathogen build-up between 2020 and 2022. Well-planned integrated management strategies will help to minimise disease levels whilst maximising profit.

If 2022 has taught us anything, it is that we cannot control the weather. However, growers still need to focus on managing the controllable in 2023. This starts with ensuring the quality of seed for sowing and committing added attention to identifying and managing cereal disease risk such as FCR within individual paddocks. NSW DPI is here to support growers with pre-season testing, correct diagnosis and discussion of management options before sowing and as required throughout the season.

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Cereal disease related diagnostic activities across NSW during the 2022 cropping season

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Key findings

- Favourable climatic conditions in 2022 increased the prevalence of a range of cereal diseases across NSW, in particular: fusarium head blight (FHB), stripe rust and septoria tritici blotch (STB).
- There was a 42% increase in demand for cereal disease diagnostic activities during 2022 compared with 2021.
- Eleven percent of samples submitted as disease were identified as non-disease issues such as plant physiological responses to stress, frost damage, herbicide injury, related to crop nutritional issues or other non-disease issues.
- Complexes of physiological and disease symptoms in wheat heads were prominent late in the 2022 cropping season.
- NSW DPI plant pathologists supported growers with correct diagnosis, cereal stubble and seed testing and advice on appropriate management options.

Keywords Correct diagnosis, leaf diseases, soil-borne diseases, fusarium head blight, stripe rust, septoria tritici blotch

Introduction

A diagnostic service for cereal growers and their advisers in NSW is provided at no charge through project code DPI2207-002RTX (previously BLG207 and BLG208). This service uses evidence-based methods, including visual symptoms and the laboratory identification of pathogens to confirm a diagnosis. Any samples that are suspected to be viruses are confirmed using ELISA testing at the NSW DPI Elizabeth Macarthur Agricultural Institute. This free diagnostic service is part of a partnership between NSW Department of Primary Industries (DPI) and the Grains Research and Development Corporation (GRDC).

Samples of wheat, barley, and oat rusts (such as stripe, leaf, and stem rust) are sent to the Australian Cereal Rust Control Program (ACRCP). This helps track the spread of rust pathotypes across NSW and Australia. The ACRCP regularly updates an interactive map (https://www.sydney.edu.au/science/our-research/research-areas/life-and-environmental-sciences/cereal-rust-research/rust-reports.html), showing which pathotypes are dominant in different regions, enabling growers and advisors to be aware of what is happening during the growing season.

The project also keeps track of disease enquiries received from growers and advisers throughout the season. This information is used to support cereal producers in obtaining correct disease diagnosis and independent management advice. Getting the right

Crop protection

diagnosis can help limit the economic impact of diseases as growers can implement effective management strategies or reduce unnecessary in-crop fungicide use.

Results

The demand for diagnostic support for cereal crops in NSW is strongly influenced by different seasonal conditions. In the 2022 season, the most common issues faced by growers and advisors were foliar diseases and head infections (Figure 1). Additionally, there was a significant increase (42%) in demand for diagnostic support in 2022 compared with 2021 (Table 1). This increase was mainly due to 3 consecutive seasons that favoured the development of various cereal leaf and head diseases.

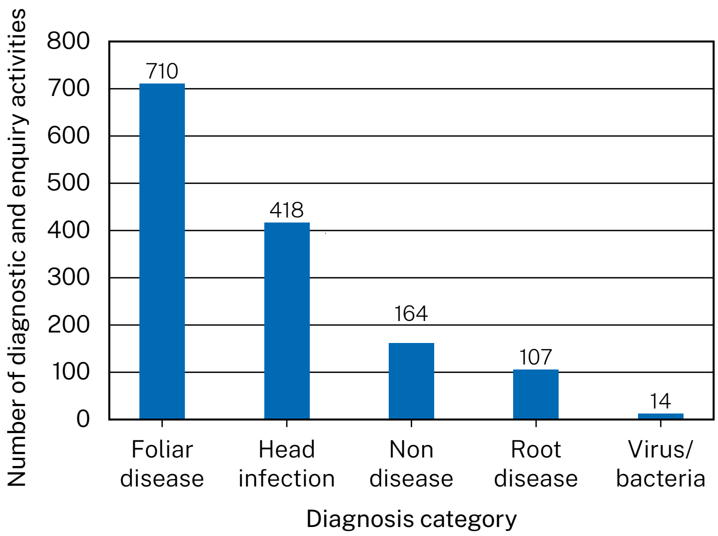

Figure 1 Diagnostics and enquiries across NSW in 2022 by category.

Fusarium head blight replaced wheat stripe rust as the most diagnosed and queried cereal disease in 2022 contributing 28% of the total diagnosis activities. Stripe rust was the most queried disease during 2020 and 2021, but was second during 2022 with 27% of activities (Table 1). Septoria tritici blotch (STB) remained the third most queried disease for the second year running; fusarium crown rot (FCR) was fourth in 2022. This is not surprising considering *Fusarium* species were the main source of inoculum for FHB infections in 2022. It also reinforces the fact that root and stem diseases such as FCR do not disappear during wet seasons.

On the other hand, it was surprising that diagnostic activities such as plant diagnosis, and management advice for diseases such as barley scald and take-all remained low, despite the 2022 season being favourable for their expression. This trend has been observed consistently, especially for barley scald, which has declined from higher levels in 2020 in both 2021 and again in the 2022 season. Diagnostic activities for *Rhizoctonia*, which is favoured by dry conditions, were also relatively low during wetter 2020 to 2022 seasons. There was a general decrease in diagnostic activities for cereal virus and bacterial diseases in the 2022 season (Table 1).

Importantly, 11% of plant diagnostics undertaken in 2022, 13% in 2021, 21% in 2020 and 28% in 2019 were not related to disease. In 2022, 164 samples were submitted as suspected of having disease issues, yet these were either diagnosed as plant physiological responses to stress, frost damage, herbicide injury, related to crop nutritional issues or other non-disease issues (Table 1). The decline in misdiagnosed disease from 2019 through 2022 could be explained through increased industry awareness, increased sample size and a general increase in actual disease incidence between the 2019 and 2022 cropping seasons.

Table 1 Cereal diagnostics and enquiries processed across NSW between 2019 and 2022.

Disease issue*	2022	2021	2020	2019
Fusarium head blight	389	18	10	0
Stripe rust (wheat)	379	343	194	13
Septoria tritici blotch (wheat)	104	56	17	13
Fusarium crown rot	89	99	61	14
Physiological/melanism	68	20	65	10
Wheat powdery mildew	53	17	53	1
Yellow leaf spot (wheat)	49	56	10	4
Other non-disease (e.g. soil constraint, leaf blotching/ mottling)	42	53	34	24
Spot form of net blotch (barley)	30	50	65	32
Herbicide	27	7	28	6
Leaf rust (wheat)	21	37	35	2
Rusts crown and stem (oats)	21	24	29	4
White grain disorder (*Eutiarosporella* spp.)	21	1	1	0
Environmental (e.g. frost damage, waterlogging)	16	24	45	4
Net form of net blotch (barley)	11	20	23	0
Nutrition	11	18	16	2
Barley powdery mildew	9	8	12	0
Scald (barley)	9	7	65	4
Loose smut	8	11	9	1
Bacterial blight (other cereals)	8	4	30	0
Leaf rust (barley)	8	3	0	0
Take-all	6	33	16	1
Seedling root disease complex (*Pythium*, crown rot, *Rhizoctonia*, take-all)	6	13	8	2
Barley grass stripe rust	6	2	20	1
Ring spot	5	2	0	1
Other oat foliar diseases (red leather leaf, septoria blotch, bacterial blight)	4	9	26	12
Common root rot	3	26	2	3
Wheat streak mosaic virus	3	23	3	1
Rhizoctonia	3	9	12	7
Barley yellow dwarf virus	3	4	19	1
Other minor diseases	1	1	4	2
Total	1413	998	912	165

* Disease/issues are ranked in order of frequency in 2022.

During 2022, weather conditions were ideal for physiological issue expression, including melanism, in certain wheat varieties with 68 individual queries received. Melanism, which is also known as pseudo black chaff, is a physiological response in wheat associated with carrying a stem rust resistance gene Sr2. Not all wheat varieties carry Sr2, so expression is variety-specific. This response results in the over production of a pigment called a melanoid, which can cause the glumes to turn brown in wheat heads, but can also appear on wheat stems. High humidity and ultraviolet light (UV) are necessary for melanism development, which can be mistaken for FCR if it is found on the stem, or for FHB if it is found on or below the head or on glumes. The defining diagnostic feature of melanism is that it causes browning from a node downwards, which differs from FCR which results in stem browning from a node upwards.

This highlights the ongoing importance of the diagnostic service provided by these projects to NSW growers and their advisers to support correct identification and implementation of appropriate management strategies. A second opinion from a plant pathologist ensures the correct diagnosis. Contact details for NSW DPI cereal pathologists are provided below.

Summary

The disease surveillance and related diagnostics project for the Australian grains industry in NSW is a joint investment by NSW DPI and GRDC. It provides crucial diagnostic support and independent management advice to the NSW cereal industry. In the past 4 years, NSW DPI cereal pathologists have conducted a total of 3,491 individual diagnostic activities (excluding 2023). Out of these, 520 (15%) were classified as non-disease, which saves industry significant time, labour, machinery and monetary investment in fungicide applications that would not have yielded an economic return. This approach helps reduce the development of target and non-target fungicide resistance in pathogens such as powdery mildew and STB by eliminating unnecessary fungicide sprays. The project also allows cereal pathologists to gain an accurate understanding of the dynamic nature of disease complexes in our cropping regions throughout the year and across seasons. This knowledge provides forewarning of disease issues and management advice for upcoming seasons.

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

DAN00213: Grains Agronomy and Pathology Partnership (GAPP) – A strategic partnership between GRDC and NSW DPI (projects BLG208 and BLG207 – completed).

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Glyphosate resistance in Australian cotton farming systems: what are the surveys telling us? The then and now.

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Key findings

- Glyphosate resistance is increasing in 6 common weeds of cotton: annual ryegrass, barnyard grass, feathertop Rhodes grass, fleabane, sowthistle and windmill grass.
- Species shift has occurred from pre-GM cotton to 2020.
- An increase in zero tillage in dryland cotton has resulted in more surface germinating weeds.
- Over 90% of fleabane seed collected was glyphosate resistant.
- Glyphosate resistance levels are also increasing in sowthistle, windmill grass and barnyard grass.
- Feathertop Rhodes grass resistance is increasing quickly.
- Over 80% of annual ryegrass samples tested were glyphosate resistant.

Keywords Herbicide resistance, cotton, weeds, integrated weed management, glyphosate resistance

Introduction

In the 1990s Australian cotton farmers relied on a range of chemical and mechanical tools to control weeds in their fields. Weed control relied on large inputs of mostly residual herbicides followed by the inevitable hand chipping to control escapes or survivors. Charles (1991) reported that weed control costs for NSW cotton growers in 1989 averaged $187 per hectare, with herbicides accounting for $76 and chipping $67. The *2018 Australian Cotton Comparative Analysis* reported herbicide costs were $134 per hectare and chipping was $4 per hectare (Boyce 2019). The relative reduction in costs can be attributed to Roundup Ready® cotton being introduced in the early 2000s. This system evolved quickly to a relatively simple weed management plan heavily reliant on glyphosate, but the impressive control it provided could also turn out to be its Achilles heel. Early results were remarkable with many problem weeds disappearing from the cotton farming landscape and chipping crews no longer required in most fields.

Fast forward 20 years and most, if not all farms have some level of resistant weeds. In 2016 an industry survey found that many growers (approximately 74%) suspected glyphosate resistance but resistance testing was relatively low (30%). In a follow up survey in 2019, the number of growers that suspected glyphosate resistance had increased to 85%. Subsequent industry surveys support these observations, with 52% of growers confirming glyphosate-resistant weeds (CCA 2021).

The move to genetically modified (GM) crops around the world has seen a shift in weed species composition (Culpepper 2006). The Australian cotton industry has followed a similar pattern with broadleaf weeds replaced by grass weeds as the most problematic and hard to control.

What did we do?

During the 2015–16 season we conducted a random survey of 144 fields on 50 farms across 7 cotton farming regions in Queensland and NSW. We collected seed, after post-emergent glyphosate was applied, from surviving populations and recorded other weed species present at each site. This was followed by targeted surveys in the 2016–17 (43 fields) and 2017–18 (31 fields) seasons. COVID-19 travel restrictions prevented sampling in 2019 and samples were received by mail from consultants instead (results not reported here). The surveys also recorded the 3 most common weeds in each field in a similar manner to Graham Charles's 1990 surveys.

We added seeds from these populations to plastic pots (25 cm in diameter) that had been pre-filled with potting mix and topped with 2 cm of field soil. The seeds were placed on the soil surface, watered, covered with paper towel and maintained in a glasshouse. Plants from each pot were transplanted to trays with the same peat substrate (6 alternating spots on the tray) at the 2- to 4-leaf stage. Each population had 18 experimental units (6 plants or units per replication).

The seedlings were sprayed at the rosette stage (8–10 cm diameter for broadleaf weeds and early tillering for grass weeds) with 0.68 kg ai/ha of glyphosate. This is a commonly used rate for general fallow weed control in Australia (Walker et al. 2011).

The herbicides were applied using an automated laboratory sized cabinet sprayer with a moving boom applying a water volume of 77 L/h equivalent from a flat fan nozzle at 300 kPa pressure. The irrigation was turned off one day before spraying and turned back on one day after spraying. Trays were arranged in a completely randomised design with 3 replications. Weed control ratings were assessed visually at 2, 7, 14 and 28 days after treatment (DAT) using a scale ranging from 0% (no control or injury) to 100% (complete control or plant death). The total number of survived plants for each population was counted and converted as percentage value at 28 DAT. Populations with plant survival after spraying:

- >20% were considered resistant
- 10% to 20% were considered to be developing resistance
- <10%, or with plant death and necrosis >80%, were considered susceptible.

What did we find?

Results from the 2015 survey were concerning. Just over 20% of sowthistle samples were assessed as resistant or developing resistance to glyphosate. Sowthistle is an emerging problem in grains farming systems and is now a weed of concern in both winter and summer cropping. This glyphosate resistance level is consistent with surveys conducted in the broadacre grains industry (John Broster, personal communication, 21 February 2019). Very high glyphosate resistance levels (>95%) were recorded in fleabane and it appears to have a naturally high tolerance to glyphosate (Table 1).

Windmill grass, feathertop Rhodes grass and barnyard grass are either developing or have resistance to glyphosate (Table 1).

The biggest concern from the 2 surveys was the increase in glyphosate resistance in feathertop Rhodes grass samples. This rose from 20% to 40% in 3 seasons (Table 1).

From the historical to the most recent surveys there has been a significant shift in species from the broadleaf weeds of the pre-Roundup Ready® era to an increase in grass weeds (Table 2). The 3 most common weeds found in fields were recorded during all surveys, from the 1990s to current, allowing this comparison. The increase in glyphosate resistance in grass weeds follows a similar pattern to that observed in minimum till broadacre grain systems in northern NSW. Findings from the latest surveys show that fleabane and sowthistle are becoming hard to control, especially in dryland cotton systems where minimum or zero tillage dominates.

Table 1 Percentage of populations of 6 problem weeds resistant to glyphosate from surveys in 2015 to 2018.

Weeds	Populations resistant to glyphosate (%)		
	2015–16	2016–17	2017–18
Annual ryegrass	Not tested	Not tested	83 (12)
Barnyard grass	72 (24)	65 (23)	57 (23)
Feathertop Rhodes grass	20 (20)	35 (13)	40 (25)
Fleabane	97 (37)	75 (25)	Not tested
Sowthistle	22 (37)	10 (37)	28 (11)
Windmill grass	90 (24)	45 (11)	44 (16)

Numbers in brackets = number of plants tested.

Table 2 Species shift through time in Australian cotton fields.

1991	2001	2012	2016
noogoora burr	peachvine	flaxleaf fleabane	feathertop Rhodes grass
Cyperus spp	bladder ketmia	sowthistle	awnless barnyard grass
Bathurst burr	nutgrass	peachvine	windmill grass

How do we use the information? What are the implications for industry?

The Cotton Research and Development Corporation (CRDC) Herbicide Technical Panel is worried that glyphosate resistance could rise rapidly, especially in dryland northern cotton farming systems where fallow weed control is important for moisture conservation. The weed surveys highlighted weed species that are developing glyphosate resistance. Many weeds are proving difficult to control in a glyphosate-dominant system. Over 80% of growers are using glyphosate as the only knockdown herbicide before planting, coupled with in-crop applications. This strategy relies on glyphosate to do all the heavy lifting for weed control. Consequently, there has been a switch to include a more integrated approach to weed management that incorporates pre-emergent and in-crop residual herbicides.

The weed survey results are important to guide decision making now and into the future as industry grapples with developing glyphosate resistance. Early results are encouraging, growers are responding to the resistance issue.

Crop Consultants Australia (CCA) (2021) reported that almost 70% of growers are applying a pre plant residual (i.e. just before planting) and 43% are applying a residual herbicide at planting. Additionally, 64% of growers are incorporating more than 2 or 3 other modes of action (MoA) into their weed control program. However, what is concerning is that 33% of growers are still using glyphosate together with only one other MoA herbicide. The introduction of Xtend Flex® cotton, which has herbicide tolerance to glufosinate and dicamba, into Australia from the 2023–24 season will provide growers with additional herbicide MoA for weed control. The availability of different MoA provides options for growers with difficult to control weeds. As with any herbicide program the key to longevity is a diverse approach to weed control and mixing up weed control tactics to delay herbicide resistance.

The Australian cotton industry has been very proactive in developing a stewardship program around integrated weed management. It is just as important to target the non-cropping phase of the rotation and implement robust and diverse tactics for weed control, including using at least 2 non-glyphosate herbicides in fallow and in-crop (Thornby et al. 2013). Adding in-crop tillage can also help to control late emerging weeds in-crop and herbicide application survivors. This approach is the cornerstone of the herbicide resistance management strategy (HRMS) developed by the cotton industry.

As a result of the HRMS stewardship program and its adoption by Australian cotton growers there is still good efficacy with glyphosate, even though there are reportedly increasing levels of herbicide resistance. Various pre-emergent, in-crop and layby herbicides with different MoA are available and when added to targeted tillage, shrouded sprayers and emerging optical technology the system is very diverse and robust.

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NSW DPI technical staff assistance with collecting and preparing samples is appreciated. The role of CottonInfo Regional Extension Officers enabled field selection and grower access.

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Southern NSW soybean breeding experiments – Leeton 2021–22

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Key finding

- Two new soybean lines resulting from backcrossing Burrinjuck⟬ have been identified as suitable for release in the southern and northern NSW soybean growing regions.

Keywords Plant breeding, soybean

Introduction

Soybeans are photoperiod sensitive (responsive to day length). A short planting window from mid November to mid December is recommended to achieve maximum yields. Later planting results in less time for biomass accumulation before flowering begins. Delaying planting from mid November to mid December will typically reduce yield by 10–20% for all soybean varieties. For this reason, most commercial soybean growers in southern NSW and northern Victoria aim to plant early (mid November) when targeting higher yields. Later planting (mid December) is more common in a double crop system as soybean planting can only start after the winter cereal crop has been harvested.

Yanco Agricultural Institute (YAI) is part of the National Soybean Breeding Program. The program evaluates new lines for southern soybean growing regions to suit both single and double cropping. In 2020, the program released Burrinjuck⟬ as a replacement for Snowy⟬. Burrinjuck⟬ is well suited to the human consumption market with excellent seed quality and agronomic characteristics. It has a significantly higher grain yield and protein content than any other locally grown soybean variety. Soy milk processors have recently approved Burrinjuck⟬ as a preferred variety.

In 2021–22, the Soybean Breeding Program at YAI focused on evaluating Burrinjuck⟬ backcrosses with powdery mildew and *Phytophthora* resistance combined with resistance to sulfonylurea herbicides.

Site details

Location	Leeton Field Station (LFS), part of Yanoco Agricultural Institute
Soil type	Grey vertosol
Previous crop	Sorghum (2020–21)
Starter fertiliser	100 kg/ha Rustica Plus (pulse fertiliser mix – nitrogen [N]:12; phosphorus [P]:5; potassium [K]:14)
Planting dates	Early planted (early) experiment – 22 November 2021 Late planted (late) experiment – 21 December 2021
Harvest dates	Early experiment: 9 May 2022 Late experiment: 11 May 2022

Treatments and establishment

Two experiments were established to evaluate Burrinjuck$^{\phi}$ backcrosses and identify superior genotypes suitable for early planted conventional systems and later planted double cropping systems.

Both experiments (early and late) included:

- 14 entries: 9 breeding lines and 5 commercial varieties (Burrinjuck$^{\phi}$, Djakal, Snowy$^{\phi}$, Bidgee$^{\phi}$ and Bowyer)
- 4 replicates in a randomised block design.

Both experiments were planted on raised beds with 1.83 m centres. Two rows per bed were planted with a row spacing of 0.915 m. Plots were 1 bed wide by 10 m long for a total of 18.3 m^2 per plot.

Assessments

All plots were assessed twice weekly for physiological maturity before harvest. Plots were recorded as mature when 95% of pods had changed from a green to yellow colour (expressed as P95). Plant height and powdery mildew severity was also assessed before harvest. Powdery mildew was visually assessed and rated (0 = no disease to 5 = severe disease). A plot header was used to collect seed from the entire plot to calculate the yield. Header seed samples were then subsampled and used to determine grain protein, grain moisture, oil content, seed size and hilum colour. Grain yield was calculated at 12% grain moisture and grain protein was calculated on a dry matter basis (DMB).

Results

Early planted experiment

Grain yield averaged 2.80 t/ha across all cultivars (Table 1). Cultivar 2J89D225 had the highest grain yield (3.25 t/ha). No new cultivars had a significantly higher grain yield than Burrinjuck$^{\phi}$.

Grain protein concentration averaged 46.24% across all cultivars. Cultivar 2J89D221 had the highest grain protein (48.05%). It was the only new cultivar to achieve a grain protein concentration significantly higher than Burrinjuck$^{\phi}$. All other new cultivars had a grain protein concentration statistically similar to Burrinjuck$^{\phi}$.

Burrinjuck$^{\phi}$ had a maturity time of 135.3 days, which was similar to Snowy$^{\phi}$ (137.0 days) and Djakal (134.3 days). All new cultivars had a statistically longer maturity time than Burrinjuck$^{\phi}$, taking from 5.2 days to 11.5 days longer to mature.

Burrinjuck$^{\phi}$ had a powdery mildew severity rating of 4.0, confirming that it is susceptible to the disease. One new cultivar (2J89D225) had a powdery mildew severity rating of 2.0, indicating that it is also susceptible to the disease. All other new cultivars had a powdery mildew severity rating of 0.0, indicating strong disease resistance.

Burrinjuck$^{\phi}$ and all new cultivars had a clear hilum indicating that they could be suitable for the human consumption market. Varieties with a black or brown coloured hilum are generally not as suitable for the human consumption market and are therefore usually grown for the lower valued crushing market.

Table 1 Assessment results for the LFS early planted variety evaluation experiment, 2021–22.

Cultivar	Grain yield (t/ha)	Grain protein (%)	Days to maturity (P95)	Powdery mildew (0 = no disease to 5 = severe)	Hilum colour
2J89D225	3.25[a]	46.81[a]	140.5	2.0	Clear
2J89D212	3.08[a]	46.15	141.0	0.0[a]	Clear
Burrinjuck	2.99[a]	46.13	135.3	4.0	Clear
Djakal	2.97[a]	43.70	134.3	0.0[a]	Dark brown
2J89D207	2.97[a]	46.97[a]	141.3	0.0[a]	Clear
2J89D201	2.96[a]	47.14[a]	141.8	0.0[a]	Clear
2J89D221	2.95[a]	48.05[a]	141.3	0.0[a]	Clear
2J89D033	2.88[a]	45.76	140.5	0.0[a]	Clear
2J89D167	2.88[a]	45.53	141.5	0.0[a]	Clear
2J89D195	2.82[a]	46.55	142.5	0.0[a]	Clear
Bidgee	2.59	45.52	126.5[a]	4.8	Clear
Snowy	2.57	45.74	137.0	5.0	Clear
Bowyer	2.33	46.42	141.5	0.0[a]	Light brown
2J89D009	1.98	46.95[a]	146.8	0.0[a]	Clear
Average	2.80	46.24	139.4		
l.s.d.	0.589	1.387	3.34	0.77	

Numbers in the same column sharing the letter 'a' are in the top grouping and are not significantly different by l.s.d. (least significant difference) test at *P* = 0.05.

Late planted experiment

Grain yield averaged 2.65 t/ha across all cultivars (Table 2). All new cultivars had a significantly higher grain yield than Burrinjuck$^{\phi}$ (1.86 t/ha).

Grain protein concentration averaged 41.47% across all cultivars. Cultivar 2J89D009 had the highest grain protein (43.73%). Burrinjuck$^{\phi}$ had a protein concentration of 41.44%, which was statistically similar to all new cultivars.

Burrinjuck$^{\phi}$ had a maturity time of 108.8 days, which was statistically similar to all new breeding cultivars except 2J89D009, which had a maturity time of 114.5 days (5.7 days longer).

Powdery mildew results in the late planting experiment were similar to the early planting experiment. Burrinjuck$^{\phi}$ and one new cultivar (2J89D225) both demonstrated susceptibility to the disease with severity ratings of 3.3 and 2.3 respectively. All remaining new breeding cultivars had a powdery mildew severity rating of 0.0, demonstrating strong resistance.

The late planting experiment also had similar results to the early planting experiment for hilum colour. Burrinjuck$^{\phi}$ and all new cultivars had a clear hilum, indicating their suitability for the human consumption market.

Table 2 Assessment results for the LFS late planted variety evaluation experiment, 2021–22.

Cultivar	Grain yield (t/ha)	Grain protein (%)	Days to maturity (P95)	Powdery mildew (0 = no disease to 5 = severe)	Hilum colour
2J89D221	3.12[a]	41.99[a]	108.3	0.0[a]	Clear
2J89D201	2.99[a]	40.96[a]	108.8	0.0[a]	Clear
2J89D225	2.97[a]	41.67[a]	109.0	2.3	Clear
2J89D195	2.93[a]	41.77[a]	109.5	0.0[a]	Clear
2J89D212	2.85[a]	42.14[a]	108.5	0.0[a]	Clear
2J89D033	2.80[a]	42.01[a]	109.5	0.0[a]	Clear
Djakal	2.78[a]	38.99	105.5[a]	0.0[a]	Dark brown
2J89D207	2.78[a]	41.03[a]	109.8	0.0[a]	Clear
Snowy	2.75[a]	41.00[a]	111.5	5.0	Clear
2J89D167	2.74[a]	42.46[a]	109.3	0.0[a]	Clear
2J89D009	2.68[a]	43.73[a]	114.5	0.0[a]	Clear
Bowyer	2.61[a]	41.63[a]	112.5	0.0[a]	Light brown
Burrinjuck	1.86	41.44[a]	108.8	3.3	Clear
Bidgee	1.18	39.77	104.0[a]	4.6	Clear
Average	2.65	41.47	109.2		
l.s.d.	0.599	2.928	2.231	0.81	

Numbers in the same column sharing the letter 'a' are in the top grouping and are not significantly different by l.s.d. (least significant difference) test at $P = 0.05$.

Discussion

To progress in the breeding program new cultivars needed to have:

- a high grain yield and high grain protein concentration
- a maturity similar to current industry standards
- resistance to powdery mildew
- a clear hilum.

The late planting experiment demonstrated that all 9 new crosses had a higher grain yield than Burrinjuck⦶. The early planting experiment demonstrated that 8 of the 9 new crosses had a similar grain yield to Burrinjuck⦶. The new breeding cross 2J89D009 was the only cultivar with a lower grain yield than Burrinjuck⦶ in the early planting experiment. Consequently, with an inferior yield to Burrinjuck⦶, it was not considered for progression in the breeding program.

The late planting experiment demonstrated that all 9 new crosses had a similar grain protein concentration to Burrinjuck⦶. The early planting experiment demonstrated that 8 of the 9 new crosses had a similar grain protein concentration to Burrinjuck⦶. The new breeding cross 2J89D221 was the only cultivar with a higher grain protein concentration than Burrinjuck⦶.

The late planting experiment demonstrated that all 9 new crosses had a similar maturity time to Burrinjuck⦶ (between 108 to 114 days). The early planting experiment demonstrated that all 9 new crosses had a longer maturity time than Burrinjuck⦶ (between 5.2 to 11.5 days longer). Any new cultivar with a maturity time 6.0 days or longer than Burrinjuck⦶ was not considered for progression in the breeding program. Based on this criterion, 3 of the 9 new cultivars (2J89D225, 2J89D033 and 2J89D212) were considered for progression in the breeding program (maturity times 5.2, 5.7 and 5.7 days longer than Burrinjuck⦶ respectively).

Only new cultivars with a demonstrated resistance to powdery mildew and having a clear hilum in both experiments were considered for progression in the breeding program. As 2J89D225 demonstrated susceptibility to powdery mildew in both experiments, it was not considered for progression in the breeding program.

Both the early and late planting experiments identified 2J89D033 and 2J89D2122 as suitable for progression in the breeding program. These 2 cultivars satisfied all criteria, having a similar grain yield and grain protein concentration to Burrinjuck⁽ᴾ⁾, a maturity time less than 6.0 days longer than Burrinjuck⁽ᴾ⁾, demonstrated resistance to powdery mildew and a clear hilum.

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