NSW GOVERNMENT

Department of Primary Industries

Southern NSW research results 2021

RESEARCH & DEVELOPMENT – INDEPENDENT RESEARCH FOR INDUSTRY

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an initiative of Southern Cropping Systems

Editors: Deb Slinger, Director Southern Cropping and Institute Director Wagga Wagga Agricultural Institute, NSW DPI, Wagga Wagga; Tania Moore, Project Officer, NSW DPI, Griffith and Carey Martin, Development Officer Information Delivery, NSW DPI Orange.

Reviewers: Dr Aaron Preston, Research Agronomist (Pulses); Andrew Carmichael, Leader South (Agronomy and Crop Protection); Dr Ben Ovenden, Plant Pathologist; Dr Bert Collard, Technical Specialist (Rice Breeding and Research); Craig Whiting, Leader (Crop Genetics and Low Rainfall Agronomy); David Troldahl, Leader (Southern Irrigated Systems); Don McCaffery, Technical Specialist (Oils and Pulses); Eric Koetz, Research Agronomist (Cotton); Dr Felicity Harris, Research Scientist (Crop Physiology); Dr Harsh Raman, Research Scientist (Molecular); Dr Iain Hume, Research Officer; Mark Evans, Director (Pasture Systems); Mark Richards, Research Agronomist (Pulses); Dr Md Asaduzzaman (Asad), Research Officer (Weeds); Peter Matthews, Technical Specialist (Grain Services); Dr Polychronis Rempoulakis, Leader (Plant Biosecurity Entomology); Richard Hayes, Senior Research Scientist; Dr Shihab Uddin, Research Scientist (Soils); Dr Susan Orgill, Leader (Soil Research and Development); Dr Warwick Badgery Leader (Rangelands and Tropical Pastures) and Dr Warwick Dougherty, Director (Soil and Water Research and Development) – all NSW DPI.

Cover images: main: faba beans, Dr Aaron Preston; inset left: cotton seedlings, Gabby Panazzolo; inset centre: canola frost shelters, Dr Rajneet Uppal; inset right: early sown wheat experiment, Dr Felicity Harris.

ISSN: 2652-6948

jn 17023

Published by NSW Department of Primary Industries, a part of the Department of Regional New South Wales.

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Foreword

NSW Department of Primary Industries (NSW DPI) welcomes you to the Southern NSW research results 2021. 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 soils, climate, weeds, farming systems, pastures, water and irrigation.

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 clients you work with.

Special thanks to 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 also encourage feedback to help us produce improved editions in future years.

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

Contents

The season

Agronomy–cereals

Agronomy–canola

Agronomy–pulses

Agronomy–summer crops

Agronomy–pastures

Crop protection

Nutrition & soils

Irrigation & climate

Other research

Seasonal conditions 2020

Scott Wallace, Seasonal Conditions Coordinator, NSW DPI Climate Branch

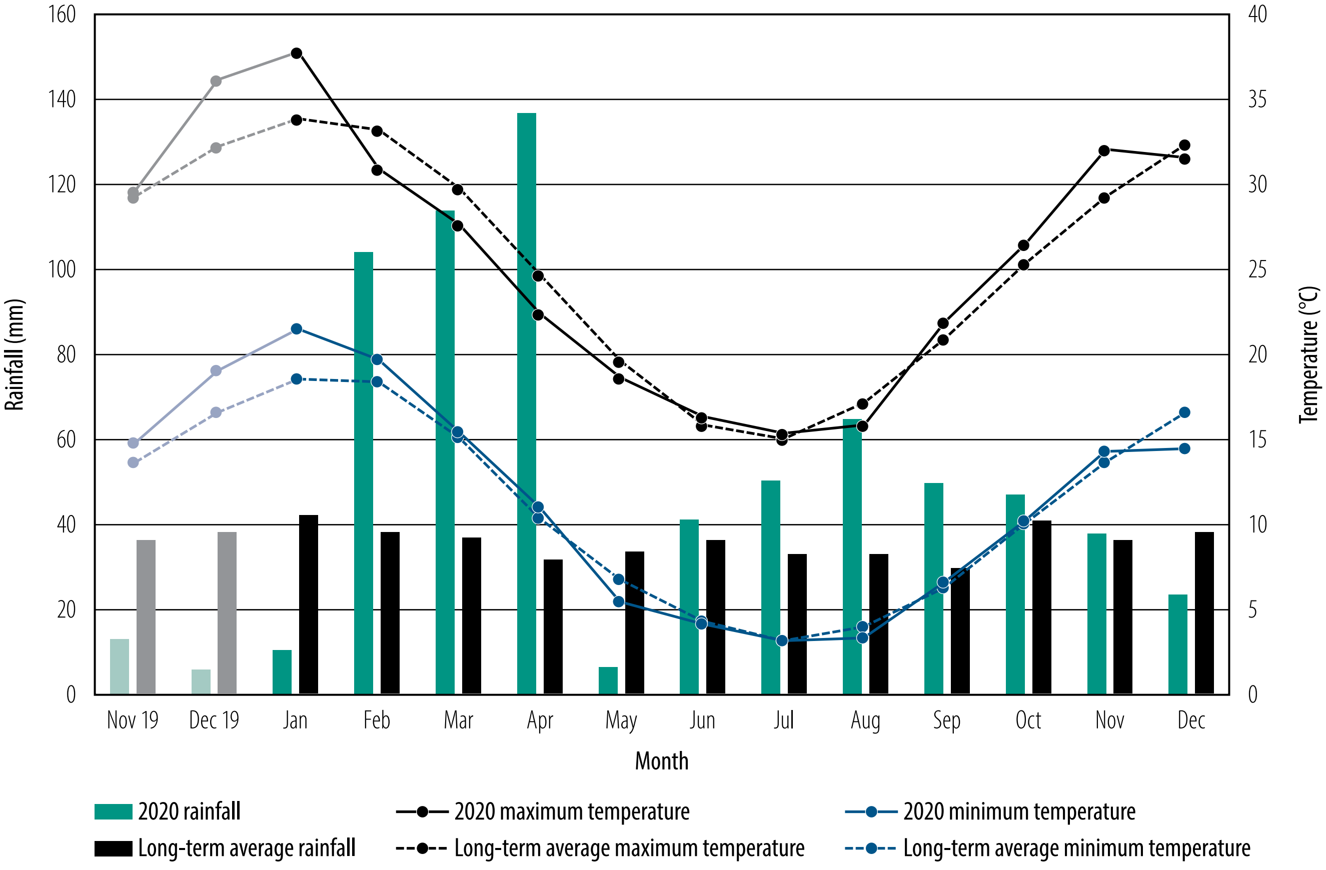
Climate summary

Condobolin Agricultural Research and Advisory Station

Minimum temperatures at Condobolin were close to or above the long-term monthly average (LTA) for most of 2020 (Figure 1). May and August were exceptions in the growing season with minimum temperatures falling below the LTA. December 2020 (post 2020 winter crop growing season) was also an exception with the average minimum temperature below the LTA.

Maximum temperatures during the first part of the 2019–20 fallow period (November 2019 to January 2020) were much higher than the LTA. Maximum temperatures then fell below the LTA for the remainder of the fallow period (February to May 2020), which reduced soil water evaporation potential later in the period. The 2020 winter maximum temperatures were close to the LTA and became warmer than the LTA during the 2020 spring.

Generally, both the minimum and maximum temperatures were close to the LTA during the growing season (May to October 2020).



Source: SILO (Scientific Information for Land Owners) Patched Point Data, Queensland Government.

Figure 1 Average monthly minimum and maximum temperature in 2020, total monthly rainfall in 2020, and long-term averages at Condobolin Agricultural Research and Advisory Station, including the November and December 2019 summer fallow period.

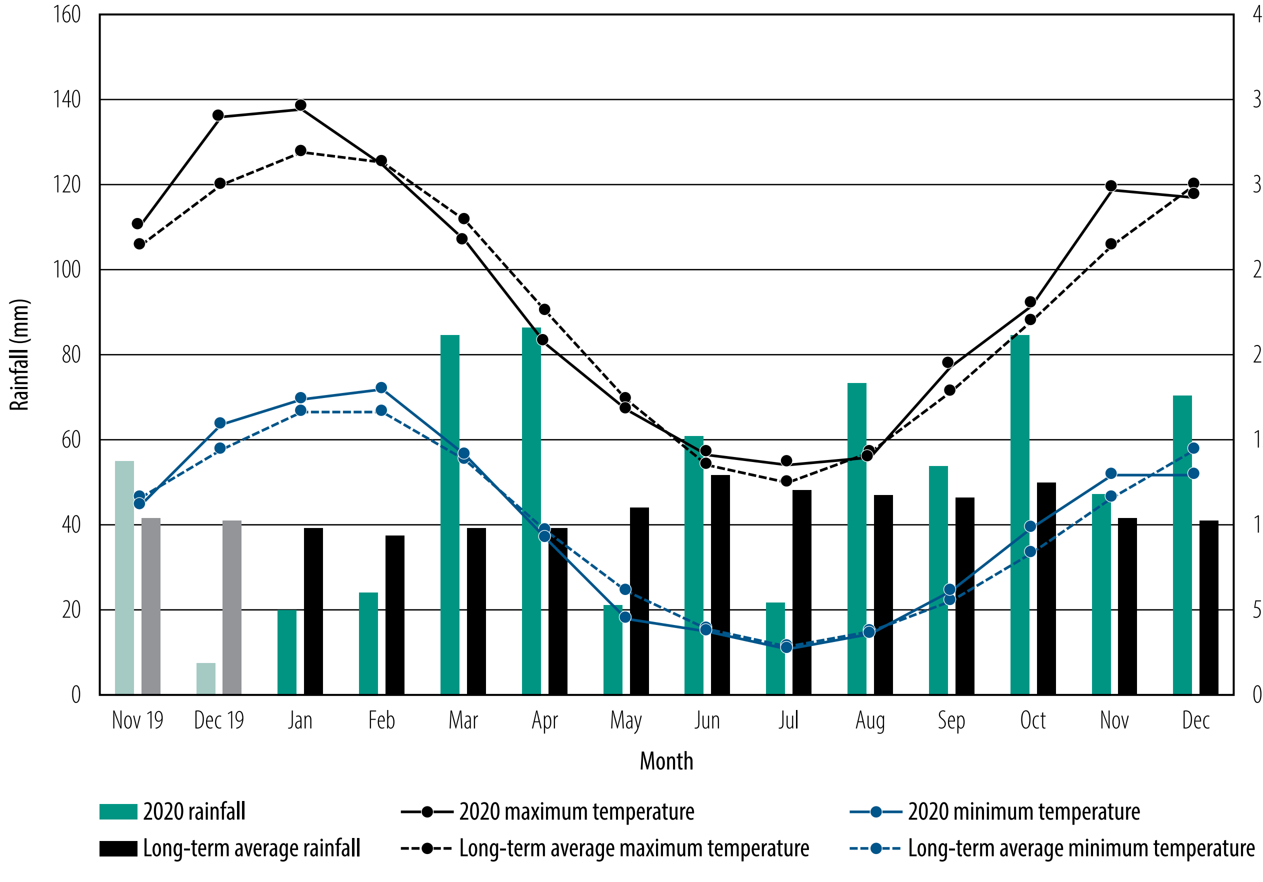
Rainfall in the first part of the fallow period (November 2019 to January 2020) was well below average (Figure 1), this extended long-term drought conditions at Condobolin. Well above average rainfall was then recorded in the second part of the fallow period over three consecutive months from February 2020. This rainfall provided increased confidence and higher soil moisture levels in the lead up to the May sowing window. Except for May, rainfall was above the LTA for all months during the growing season. The combination of late fallow soil moisture and growing season rainfall provided a good foundation for high crop yield potential.

Wagga Wagga Agricultural Institute

Minimum temperatures at Wagga Wagga were close to or above the LTA for most of 2020 (Figure 2). May and December 2020 were exceptions where minimum temperatures were much cooler than the LTA.

Maximum temperatures during the first part of the 2019–20 fallow period (November 2019 to January 2020) were much higher than the LTA. Maximum temperatures were then near to below the LTA for the remainder of the fallow period (February to May 2020). The 2020 winter maximum temperatures were close to the LTA and became warmer than the LTA during the 2020 spring.

Except for May 2020, both the minimum and maximum temperatures were close to or higher than the LTA during the growing season (May to October 2020).



Source: SILO (Scientific Information for Land Owners) Patched Point Data, Queensland Government.

Figure 2 Average monthly minimum and maximum temperature in 2020, total monthly rainfall in 2020, and long-term averages at Wagga Wagga Agricultural Institute, including the November and December 2019 summer fallow period.

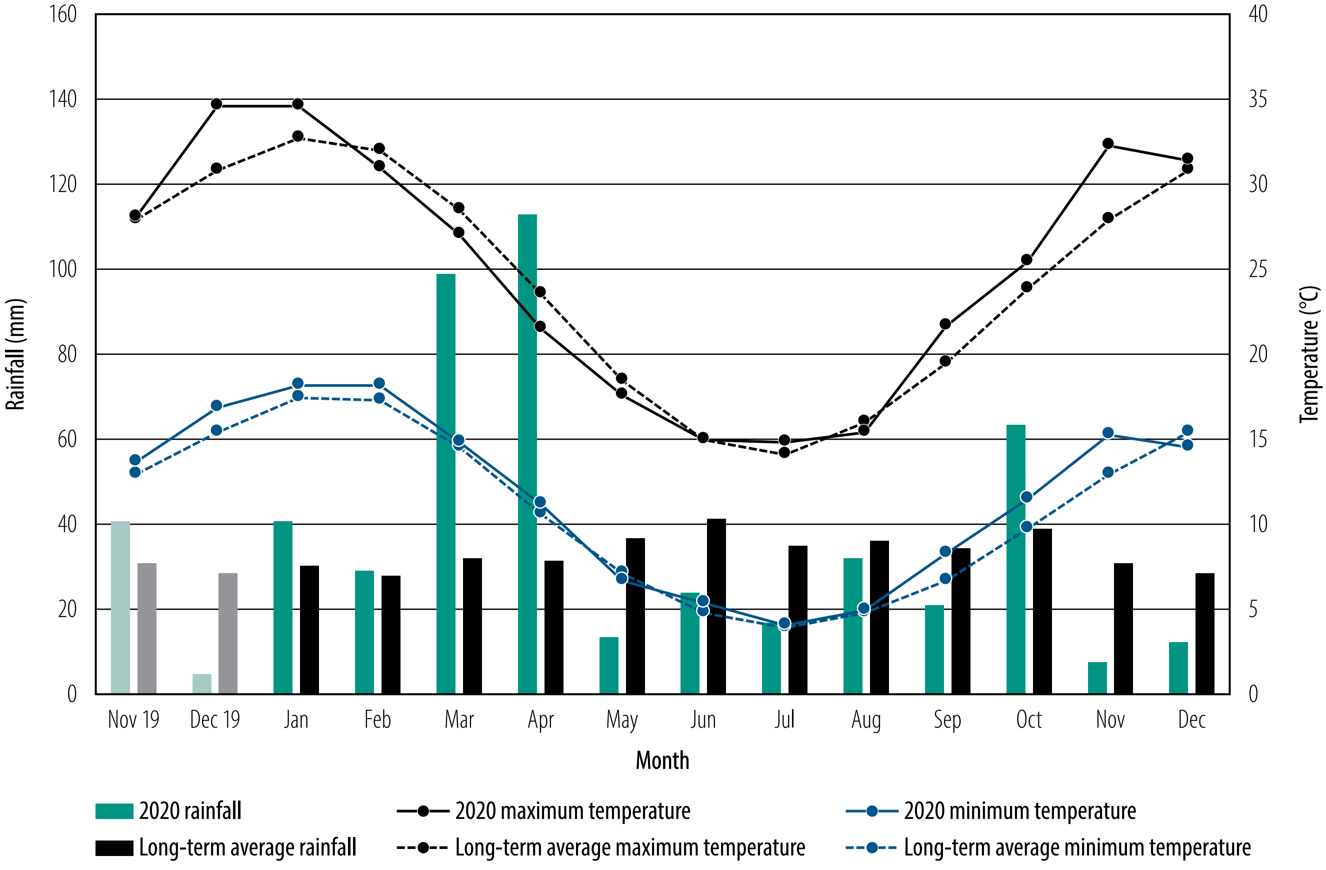
Except for November 2019, rainfall in the first part of the fallow period (November 2019 to February 2020) was well below average (Figure 2). Well above average rainfall was then recorded in the final two months of the fallow period (March and April 2020). This rainfall was timely and increased confidence with improved stored soil moisture levels before the sowing period. Rainfall was above the LTA for all months during the growing season, except May and July. Generally, the seasonal conditions in 2020 were conducive to above average grain yield for winter crops.

Yanco Agricultural Institute

Minimum temperatures at Yanco were close to or above the LTA for most of 2020 (Figure 3). December 2020 (post 2020 winter crop growing season) was an exception when the minimum temperature was slightly cooler than the LTA.

Maximum temperatures during the first part of the 2019–20 fallow period (November 2019 to January 2020) were much higher than the LTA. Maximum temperatures then fell below the LTA for the remainder of the fallow period (February to May 2020). The cooler conditions helped preserve subsoil moisture later in the fallow period. The 2020 winter maximum temperatures were close to the LTA, but became much warmer than the LTA during the 2020 spring.

Generally, both the minimum and maximum temperatures were close to the LTA during the growing season (May to October 2020). Higher than average maximum temperatures in spring could have affected crop potential due to stress during grain fill and maturity. The warmer temperatures in October and November provided an excellent start for the summer cropping experiments.



Source: SILO (Scientific Information for Land Owners) Patched Point Data, Queensland Government.

Figure 3 Average monthly minimum and maximum temperature in 2020, total monthly rainfall in 2020, and long-term averages at Yanco Agricultural Institute, including the November and December 2019 summer fallow period.

Apart from December 2019, rainfall during the fallow period (November 2019 to April 2020) was close to or well above average (Figure 3). Rainfall in March and April 2020 was well above average and provided a confident start to the growing season with improved soil moisture stores. The March/April rainfall provided an excellent start for the winter pulse and canola experiments. The winter crop growing season rainfall (May to October 2020) was generally below average. Due to the lower than average rainfall from May until October, all winter cropping experiments at Yanco Agricultural Institute had at least one or two spring irrigations. October was an exception when rainfall was higher than the LTA. The effect of this late season rainfall would depend on the crops' maturity, with decreasing yield response as the crop approaches later stages in development. The 60 mm+ rainfall in October provided good soil moisture for establishing the summer cropping experiments.

Disease

Winter cereals

Improved growing conditions characterised the 2020 season in southern NSW compared with the extensive drought in 2019. The higher rainfall and earlier sowing opportunities affected disease development across the whole state with high levels of leaf diseases observed. The winter cereal disease survey results reflected these environmental influences.

A paper discussing highlights from the 2020 Grains Agronomy and Pathology Partnership (GAPP) survey was presented at the Wagga Wagga GRDC update in February 2021. This paper discussed preliminary results from the southern NSW 2020 survey of 32 barley and 54 wheat paddocks, which are part of the GRDC and NSW DPI joint investment into the northern region GAPP disease investment. This is the second year of the survey with uniform methods across the northern region and trends are emerging from the data that can help agronomists and growers improve their rotation decisions to reduce disease risk. The survey data reflected the influence of improved growing conditions with higher leaf disease levels and, as predicted in 2019, the necrotrophic disease such as Septoria tritici blotch (STB), yellow leaf spot (YLS), the spot form net blotch (SFNB) and scald were able to recover from the previous dry conditions quickly in 2020. Root diseases such as crown rot, which are favoured by a dry season, were still common and did reach yield-robbing levels in some paddocks. Take-all was a feature in southern NSW promoted by the above average rainfall in August to October. The '198' strain of wheat stripe rust discovered during 2019 became the dominant pathotype in 2020, causing large areas of susceptible wheats to require fungicide protection.

In total, 912 diagnostic activities were provided across NSW between the Wagga Wagga and Tamworth cereal pathology groups. Dr Steven Simpfendorfer and Dr Andrew Milgate produced a combined GRDC northern region report on the diagnostic activities for publication at the 2021 NSW GRDC updates. This was a large increase in diagnostic/advice delivered through the two GAPP projects in 2020 compared with 165 in total during 2019. The wheat stripe rust epidemic was the dominant feature, while other leaf pathogens such as barley scald, powdery mildew (wheat and barley) also had significantly higher levels in grower paddocks across southern NSW. Take-all also caused levels of yield loss in paddocks that has not been seen widely for many years.

Winter pulse and oilseed

The return of wet conditions in winter and spring in 2020 resulted in significantly elevated disease development in pulse and oilseed crops across the region, especially foliar diseases. Diagnostic samples received at Wagga Wagga included a confirmation of various diseases, herbicide injury symptoms and decision-making related to fungicide application.

Surveys of commercial pulse (lupin, chickpea, faba bean, lentil, field pea) and canola crops across the region found above average levels of foliar disease compared with the previous two seasons. Virtually every crop inspected had disease present as a result of the favourable conditions.

- Significant levels of sclerotinia disease was found across all pulse crops inspected. Narrow-leaf lupin had the highest levels of disease.
- Botrytis grey mould is rarely seen in lupin crops in southern NSW, however, the disease was widespread in 2020. Dense crop canopy growth in combination with senescent plant tissue and frequent rainfall all combined to favour its development.
- Every canola crop inspected had blackleg present causing varying levels of injury. Symptoms ranged from lower leaf infection to significant levels of stem cankering and plant death.
- Compared with 2018 and 2019, low levels of frost injury were observed. Frequent rainfall and warmer night temperatures due to cloud cover significantly reduced the number and severity of frosts.

- Symptoms of virus infection were widespread across all pulse crops in 2020. An early break to the season and mild winter temperatures allowed aphid populations to build up and be maintained in autumn and winter resulting in widespread symptom expression in spring.

Despite low levels of disease being observed in commercial crops in 2019, highly favourable conditions for rapid crop growth and frequent rainfall in 2020 resulted in epidemic levels of disease developing quickly. This makes crop monitoring and disease control important for grains producers in 2021.

Acknowledgements

Thank you to contributors David Burch, Tony Napier, Mark Richards, Dr Andrew Milgate and Dr Kurt Lindbeck, and Don McCaffery for review.

Wheat phenology and yield responses to sowing time – Harefield 2020

Dr Felicity Harris, Hugh Kanaley, Mary Matthews, Jess Simpson, Jordan Bathgate, Dean Turner and Ian Menz

NSW DPI, Wagga Wagga

Key findings

- In the high yielding 2020 season, flowering earlier than the optimal flowering period resulted in significant yield penalties.
- Grain yield responses varied in response to sowing date, and the highest yields occurred when varietal phenology was matched with the recommended sowing windows.
- A key recommendation for growers is to remain disciplined with sowing dates.

Introduction

The 'Optimising yield potential of winter cereals in the northern grains region (NGR)' project has been a GRDC and NSW DPI joint investment under the Grains Agronomy and Pathology Partnership (GAPP) in collaboration with the Queensland Department of Agriculture and Fisheries (QDAF). From 2017–20, field experiments were sown across 10 locations in New South Wales and Queensland where annual rainfall ranged from 184 mm to 853 mm and grain yields ranged from 0.2 t/ha to 10 t/ha. The project aimed to provide a better understanding of wheat phenology and yield responses across different environments to refine sowing recommendations and improve yield stability and profitability of growers in the NGR.

This paper presents results from the Harefield site (southern NSW) in 2020 and discusses the influence of sowing date (SD) on the phenology and grain yield responses of a core set of 36 wheat genotypes.

Site details

Location	Harefield NSW
Soil type	Red chromosol
Previous crop	Canola
Sowing	Direct drilled with DBS tynes spaced at 240 mm using a GPS auto-steer system.
Target plant density	140 plants/m^2.
Soil pH$_{Ca}$	4.9 (0–10 cm); 5.7 (10–30 cm)
Mineral nitrogen (N)	155 kg N/ha at sowing (1.5 m depth)
Fertiliser	• 92 kg/ha mono-ammonium phosphate (MAP) (sowing). • 42 kg N/ha applied as urea (10 July and 4 August).
Weed control	• **Knockdown**: Weedmaster® DST® (470 g/L glyphosate) 2.5 L/ha, Revolver® (135 g/L paraquat and 115 g/L diquat) 2 L/ha. • **Pre-emergent**: Sakura® (850 g/ka pyroxasulfone) 118 g/ha + Avadex® Xtra (500 g/L tri-allate) 1.6 L/ha + trifluralin (480 g/L) 0.8 L/ha.

- **In-crop**: LVE MCPA (570 g/L) 600 mL/ha + Paradigm® (200 g/kg halauxifen and 200 g/kg florasulam) 25 g/ha (applied 22 May to SD1 and SD2 only).

Disease and pest management

- **Seed treatment**: Hombre® Ultra (360 g/L imidacloprid and 12.5 g/L tebuconazole) 200 mL/100 kg and Gaucho® 600 (600 g/L imidacloprid)120 mL/100 kg.
- **Fertiliser treatment**: Flutriafol (250 g/L) 400 mL/ha.
- **Foliar fungicide:** Prosaro® 420 SC (210 g/L prothioconazole and 210 g/L tebuconazole) 300 mL/ha 19 June (SD1 and SD2), 3 August, 18 September.

Rainfall

In-crop (April–October): 408 mm

Severe temperature events

- No heat stress events (days >30 °C), during the growing season.
- 11 frosts (days <0 °C), including –2.3 (5 August), –2.8 (6 August), –1 (26 August) and –1.1 (28 September).

Harvest date

26 November 2020

Treatments

Genotype

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

Sowing date (SD)

SD1: 6 April

SD2: 21 April

SD3: 6 May

SD4: 19 May

Table 1 Expected phenology responses of the 2020 experiment genotypes.

Phenology type	Genotypes
Winter (W)	Longsword$^{\phi}$ (Quick), LongReach Kittyhawk$^{\phi}$ (Mid), EGA Wedgetail$^{\phi}$ (Mid), DS Bennett$^{\phi}$ (Mid–slow), RGT Accroc (Slow), Manning$^{\phi}$ (Slow)
Very slow (VS)	EGA Eaglehawk$^{\phi}$, RGT Zanzibar, **LongReach Nighthawk**$^{\phi}$
Slow (S)	Sunmax$^{\phi}$, Cutlass$^{\phi}$, Sunlamb$^{\phi}$
Mid (M)	Mitch$^{\phi}$, LongReach Lancer$^{\phi}$, Coolah$^{\phi}$, DS Pascal$^{\phi}$, EGA Gregory$^{\phi}$, LongReach Trojan$^{\phi}$, **Catapult**$^{\phi}$, **Rockstar**$^{\phi}$
Mid–quick (MQ)	Janz, Beckom$^{\phi}$, Sunvale$^{\phi}$, Suntop$^{\phi}$ LongReach Reliant$^{\phi}$
Quick (Q)	Scepter$^{\phi}$, Corack$^{\phi}$, Mace$^{\phi}$, LongReach Mustang$^{\phi}$, LongReach Spitfire$^{\phi}$, Sunprime$^{\phi}$, **LongReach Hellfire**$^{\phi}$
Very quick (VQ)	Condo$^{\phi}$, LongReach Dart$^{\phi}$, H45$^{\phi}$, Vixen$^{\phi}$

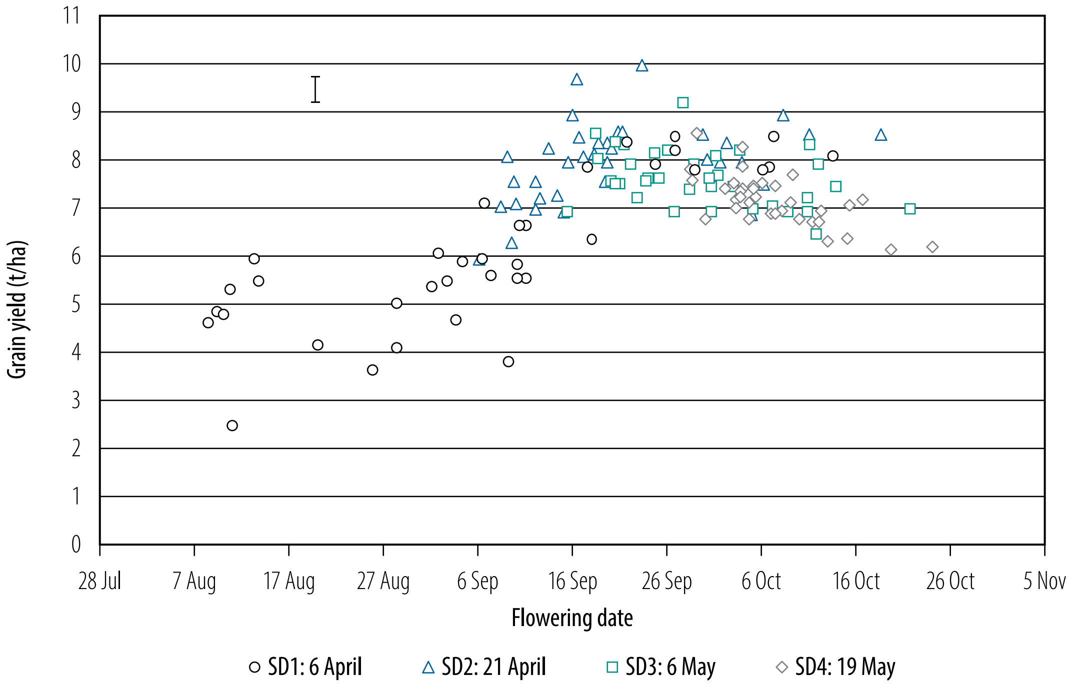
New releases in **bold**.

Results

Phasic development

The consistent messages presented from the project to date have centred around synchronising crop development (phenology) with seasonal conditions to ensure that the optimal flowering period (OFP) is matched to the growing environment. In 2020, the flowering window spanned from 8 August to 24 October (Figure 1). Mild temperatures, combined with unlimited soil moisture in autumn–early winter, resulted in optimal conditions for both growth and crop development, and as such many winter and slow spring types were able to meet their vernalisation (cold temperature) requirements very quickly, progressing to stem elongation and flowering ~7–14 days earlier than recorded in previous years (Harris et al. 2018; 2019; 2020).

Favorable seasonal conditions resulted in high yields across a wide flowering window, and mild spring temperatures meant that there was no significant yield penalty associated with later flowering (in contrast to long-term data). However, there was a significant yield decline when flowering occurred earlier than mid September (Figure 1) associated with some minor frost, that coincided with critical development stages.



I Vertical error bar represents l.s.d. (*P* = 0.05).

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

There were significant variations in phenology responses to sowing date amongst spring types from 2017–20. When sown early (when temperatures are warmer and days longer) flowering can be unpredictable and varies substantially across seasons. The earlier flowering dates were recorded in quick developing spring types that progressed quickly when sown on SD1 and SD2, and flowered significantly earlier than the OFP. For example, Vixen$^{\Phi}$ (SD1: 6 April) flowered on 8 August, however, when sown on SD4 (19 May), which aligns with its recommended sowing window, Vixen$^{\Phi}$ flowered on 29 September and within the OFP (Figure 2). The earlier flowering in SD1 also resulted in a 53% yield reduction compared with SD4 (SD1: 4.54 t/ha and SD4: 8.56 t/ha, Table 2). In contrast, the winter types had more stable flowering behaviour across sowing dates despite the earlier flowering dates recorded in 2020 compared with previous years (Harris et al. 2018; 2019; 2020).

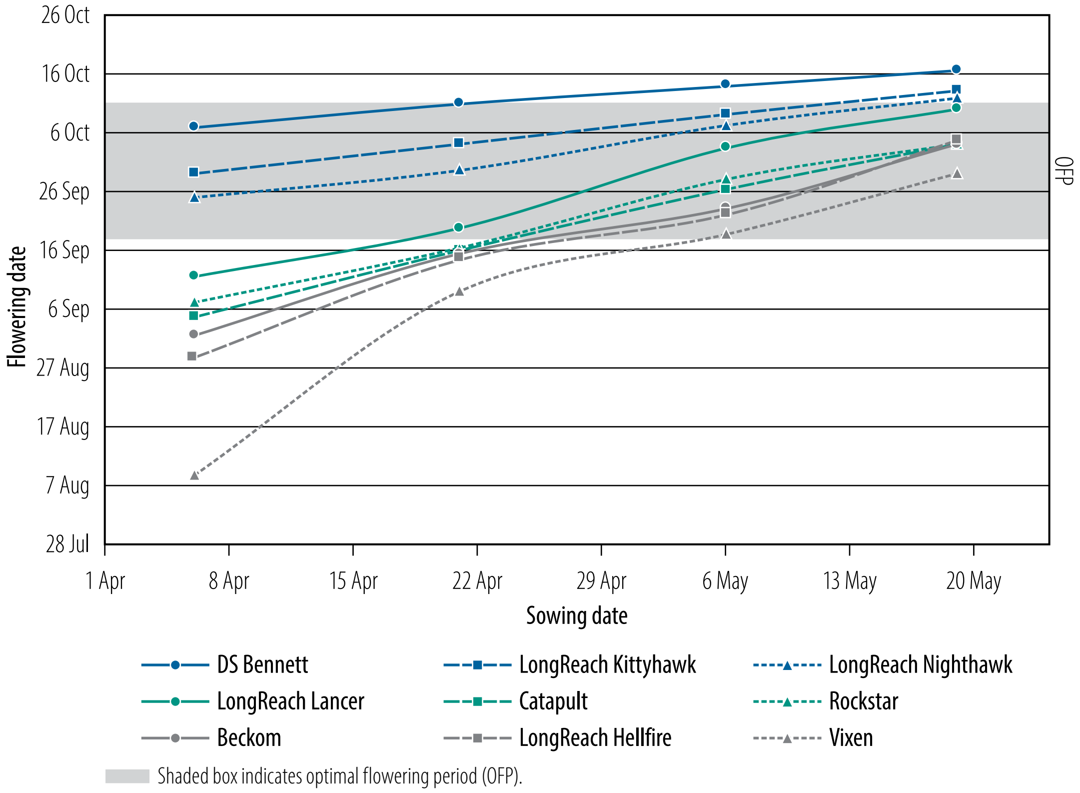


Figure 2 Influence of sowing date on flowering of selected genotypes sown on four dates at Harefield, 2020.

Grain yield

Grain yields and genotype rankings varied significantly across the sowing dates (early April to late May) (Table 2), reinforcing the key project finding that varietal phenology needs to be matched to sowing date. In 2020, slower developing spring types (e.g. RGT Zanzibar, Rockstar$^{\Phi}$, Catapult$^{\Phi}$) and some winter types (e.g. RGT Accroc) in SD2 (21 April) achieved the highest grain yields; quick spring types ranked highest in SD2 and SD3 (e.g. Scepter$^{\Phi}$, Vixen$^{\Phi}$) (Table 2). While mean yield was reduced when sowing was delayed after early May, there were significant yield penalties when quick developing spring wheats were sown in early April (SD1), associated with rapid development and exposure to frost damage and reduced biomass accumulation in a high yield potential season (Figure 3).

Important note: while all seasons are unique, it is important to consider long-term phenology and yield data to determine varietal responses and adaptation to growing environment.

Table 2 Grain yield of genotypes across four sowing dates at Harefield, 2020.

Genotype	Grain yield (t/ha) (rank)							
	SD1: 6 April		SD2: 21 April		SD3: 6 May		SD4: 19 May	
Beckom	5.31	(25)	7.96	(23)	8.23	(5)	7.84	(3)
Catapult	5.84	(18)	8.92	(3)	8.16	(7)	7.37	(13)
Condo	4.80	(28)	7.04	(31)	7.99	(10)	7.80	(4)
Coolah	6.60	(12)	8.59	(5)	7.36	(24)	6.94	(25)
Corack	2.43	(36)	6.28	(35)	7.47	(19)	7.57	(6)
Cutlass	3.74	(34)	7.96	(22)	8.25	(4)	7.49	(8)
DS Bennett	7.80	(7)	8.51	(9)	7.38	(23)	7.16	(19)
DS Pascal	6.56	(13)	7.97	(21)	7.59	(14)	7.11	(20)
EGA Eaglehawk	**8.42**	**(1)**	6.89	(34)	6.88	(33)	6.36	(33)
EGA Gregory	5.76	(19)	8.09	(17)	7.35	(25)	7.21	(17)
EGA Wedgetail	8.11	(4)	8.04	(19)	6.95	(29)	6.71	(31)
H45	5.44	(23)	7.09	(30)	7.47	(20)	7.40	(12)
Janz	4.62	(30)	8.12	(16)	7.56	(17)	7.09	(21)
Longsword	6.32	(14)	8.58	(6)	8.01	(9)	7.37	(14)
LongReach Dart	4.74	(29)	5.96	(36)	6.87	(34)	6.77	(28)
LongReach Hellfire	4.02	(33)	7.25	(28)	7.48	(18)	6.76	(29)
LongReach Kittyhawk	7.73	(9)	7.97	(20)	6.85	(35)	6.28	(34)
LongReach Lancer	5.50	(22)	8.34	(13)	7.40	(22)	6.72	(30)
LongReach Mustang	5.25	(26)	7.23	(29)	7.18	(26)	6.99	(23)
LongReach Nighthawk	7.82	(6)	8.55	(7)	6.97	(28)	6.67	(32)
LongReach Reliant	5.41	(24)	6.94	(33)	6.90	(31)	7.31	(15)
LongReach Spitfire	4.08	(32)	7.58	(24)	7.57	(16)	7.16	(18)
LongReach Trojan	5.55	(20)	8.47	(10)	8.11	(8)	7.44	(9)
Mace	3.60	(35)	7.01	(32)	7.85	(11)	7.52	(7)
Manning	8.04	(5)	8.53	(8)	6.94	(30)	6.18	(35)
Mitch	6.01	(15)	8.28	(14)	7.85	(12)	7.42	(10)
RGT Accroc	**8.41**	**(2)**	8.92	(4)	7.84	(13)	7.06	(22)
RGT Zanzibar	7.80	(8)	**10.00**	**(1)**	8.16	(6)	7.69	(5)
Rockstar	7.02	(11)	**9.67**	**(2)**	**9.13**	**(1)**	**8.27**	**(2)**
Scepter	4.96	(27)	8.25	(15)	8.29	(3)	7.41	(11)
Sunlamb	7.72	(10)	7.53	(27)	6.41	(36)	6.15	(36)
Sunmax	**8.31**	**(3)**	8.37	(11)	7.18	(27)	6.94	(24)
Sunprime	5.91	(16)	7.58	(25)	7.43	(21)	7.22	(16)
Suntop	5.91	(17)	8.34	(12)	7.58	(15)	6.88	(27)
Sunvale	5.51	(21)	7.57	(26)	6.90	(32)	6.89	(26)
Vixen	4.54	(31)	8.07	(18)	8.51	(2)	**8.56**	**(1)**
Mean	5.99		7.96		7.56		7.16	
l.s.d. Genotype	0.26							
l.s.d. SD	0.09							
l.s.d. Genotype × SD	0.53							

Yield ranking according to sowing date treatment in parentheses, **bold** text indicates highest yielding treatments.

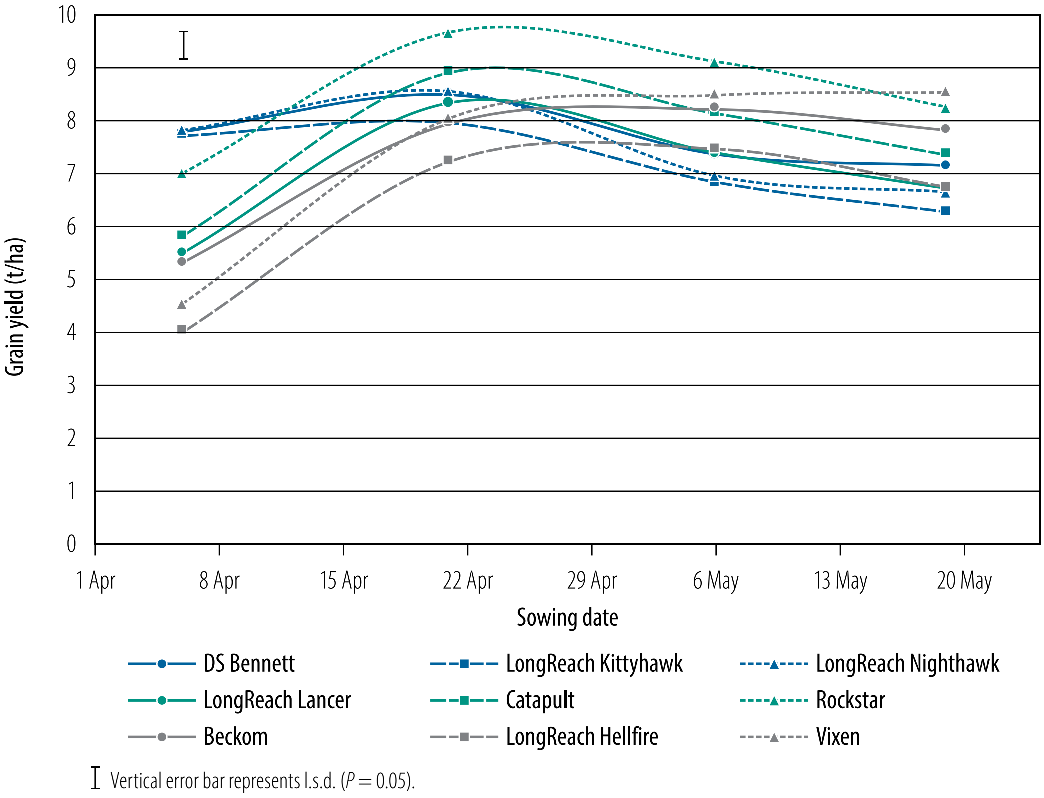


Figure 3 Grain yield of selected genotypes for four sowing dates at Harefield, 2020.

Grain quality

There were significant differences within genotype, sowing date and the interaction between genotype and sowing date on grain quality in 2020 (Table 3). All commercial genotypes achieved greater than 11.5% grain protein in their recommended sowing windows, except for DS Bennett⁽ᵖ⁾ (Australian Standard White – ASW), Manning⁽ᵖ⁾ (Australian Feed – FEED), RGT Accroc (FEED) and RGT Zanzibar (FEED), which recorded low grain protein across all sowing dates. Most genotypes achieved a test weight of >76 kg/hL, with the exception of those significantly affected by frost (SD1 Corack⁽ᵖ⁾, Cutlass⁽ᵖ⁾, Mace⁽ᵖ⁾ and Spitfire⁽ᵖ⁾) and Manning⁽ᵖ⁾ at the later sowing dates (SD3 and SD4). Generally, most genotype × sowing date combinations recorded low screenings, however RGT Zanzibar recorded high screenings (>5%) across all sowing dates.

Table 3 Grain protein (GP), screenings (SCRN) and test weight (TWT) of genotypes across four sowing dates at Harefield, 2020.

Genotype	SD1: 6 April			SD2: 21 April			SD3: 6 May			SD4: 19 May		
	GP (%)	SCRN (%)	TWT (kg/hL)	GP (%)	SCRN (%)	TWT (kg/hL)	GP (%)	SCRN (%)	TWT (kg/hL)	GP (%)	SCRN (%)	TWT (kg/hL)
Beckom	14.6	1.7	79.1	12.2	1.1	80.5	11.3	2.0	80.1	11.6	2.4	80.7
Catapult	13.8	3.1	79.2	11.6	1.7	81.5	10.8	3.4	81.6	11.9	3.0	80.8
Condo	17.1	2.2	80.1	14.4	2.9	82.9	13.0	2.6	83.5	12.4	4.1	83.7
Coolah	13.2	2.5	79.5	11.4	2.2	79.6	11.2	2.0	80.8	11.8	2.4	80.6
Corack	17.0	3.4	64.5	14.1	1.5	79.6	12.8	1.3	82.1	12.6	1.8	81.8
Cutlass	16.0	2.5	70.9	12.5	1.6	81.4	11.5	2.1	82.3	11.7	1.9	81.9
DS Bennett	8.9	2.8	81.3	9.7	2.8	81.1	9.5	4.7	81.9	10.6	6.3	80.2
DS Pascal	13.7	1.1	77.8	11.8	1.2	80.2	11.4	1.9	80.7	12.2	2.3	81.8
EGA Eaglehawk	11.1	3.3	81.0	11.8	4.2	81.0	11.2	3.4	82.6	12.5	4.0	81.7
EGA Gregory	14.6	2.2	79.5	12.6	1.9	81.5	12.1	2.4	82.5	12.2	2.5	82.4
EGA Wedgetail	12.4	2.2	78.0	12.3	1.8	77.0	12.7	1.7	78.5	12.4	1.9	78.2
H45	14.8	1.3	79.6	12.1	1.2	80.1	11.4	1.5	82.4	11.2	2.1	81.6
Janz	15.4	1.7	77.5	12.5	1.2	79.9	12.2	1.9	81.1	12.4	2.8	80.3
Longsword	14.4	0.7	77.5	12.4	0.7	81.0	11.7	1.4	82.1	12.2	1.4	82.4
LongReach Dart	16.7	2.1	77.3	16.0	1.8	77.2	13.9	1.9	80.7	12.8	4.3	78.7
LongReach Hellfire	17.4	2.4	77.2	15.0	1.5	82.3	13.7	2.6	84.0	14.3	2.4	81.8
LongReach Kittyhawk	10.6	2.8	83.3	11.4	2.4	83.5	12.1	2.6	83.6	12.4	2.3	83.7
LongReach Lancer	15.5	2.2	75.8	13.2	2.0	80.8	13.0	2.0	82.8	12.9	2.1	82.5
LongReach Mustang	14.3	2.8	78.8	13.7	2.4	78.7	12.6	4.1	80.4	12.0	4.1	81.7
LongReach Nighthawk	11.6	1.6	81.2	11.4	1.4	82.2	11.3	2.3	82.7	11.2	1.8	83.1
LongReach Reliant	15.2	2.8	77.2	13.0	3.5	80.7	12.0	3.9	81.4	11.8	3.3	83.4
LongReach Spitfire	17.3	2.5	74.8	15.0	2.4	81.4	13.3	3.2	84.0	13.4	3.0	82.5
LongReach Trojan	14.6	1.3	79.2	12.0	1.2	81.4	11.8	2.4	82.1	11.8	2.6	82.3
Mace	17.3	2.3	70.4	13.5	1.1	80.1	12.4	1.8	81.3	12.4	2.6	80.1
Manning	9.4	3.9	78.3	10.1	4.1	77.9	10.7	6.1	75.2	12.0	8.3	72.3
Mitch	13.9	2.1	81.4	11.3	2.0	79.5	10.5	2.1	80.7	10.8	2.1	80.9
RGT Accroc	10.5	2.0	78.5	10.5	2.0	79.1	11.3	2.2	78.4	11.2	2.9	76.8
RGT Zanzibar	11.5	10.7	78.8	11.2	7.1	79.6	11.4	5.2	81.5	11.4	5.4	81.6
Rockstar	13.7	3.0	77.3	11.6	2.1	81.7	11.0	3.0	81.3	11.2	2.8	79.8
Scepter	15.3	3.0	77.2	12.4	2.0	81.5	11.7	2.2	82.8	11.6	3.1	81.2
Sunlamb	12.1	5.1	78.4	12.4	4.0	79.7	13.0	4.9	80.9	13.0	4.7	81.1
Sunmax	11.0	4.4	79.3	11.8	5.3	79.1	11.4	5.6	80.1	12.2	5.5	80.0
Sunprime	14.7	1.7	79.5	13.0	2.3	80.1	12.4	3.1	80.4	12.2	3.4	80.8
Suntop	14.2	2.7	80.2	12.2	1.9	81.2	11.9	2.1	82.3	12.2	2.9	81.9
Sunvale	15.3	1.3	78.0	13.2	1.0	80.8	12.9	1.5	82.5	13.1	1.4	83.6
Vixen	17.4	2.0	75.7	13.7	1.9	79.6	12.3	1.8	81.4	11.7	3.1	80.8
Mean	14.1	2.7	77.9	12.5	2.3	80.4	11.9	2.7	81.5	12.1	3.1	81.1
l.s.d. Genotype	0.3	0.4	1.1									
l.s.d. SD	0.1	0.1	0.4									
l.s.d. Genotype × SD	0.6	0.8	2.2									

Summary

Seasonal conditions significantly influenced phenology, yield and grain quality responses to sowing date in 2020. Mild temperatures, combined with unlimited soil moisture throughout the growing season provided optimal conditions for crop development and growth, resulting in a very high yield potential and some varied phenology responses. While vernalisation responsive winter types flowered ~7–14 days earlier than recorded in previous years, they were still able to flower within the OFP. Quick developing spring types sown in early April suffered significant yield penalties as critical development stages coincided with frosts in August. These results reinforce the key phenology findings and highlight the importance for growers to consider long-term responses when determining cultivar selection and sowing time decisions.

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Acknowledgements

This experiment was part of the 'Optimising grain yield potential of winter cereals in the northern grains region', project BLG104, 2017–20, a joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

We sincerely thank Eugene, Michele, Simon and Sophie Moloney, Tambea, for hosting the field experiment and acknowledge the technical support of Chris Leywood, Ella Bent and Curtis Targett.

Contact

Dr Felicity Harris
Wagga Wagga Agricultural Institute, Wagga Wagga
felicity.harris@dpi.nsw.gov.au
0458 243 350

Influence of sowing date on wheat phenology and grain yield – Cudal 2019

Peter Roberts[1], Peter Matthews[2], Dr Felicity Harris[3], Jess Perry[1] and Jennifer Pumpa[3]

[1] NSW DPI, Cowra
[2] NSW DPI, Orange
[3] NSW DPI, Wagga Wagga

Key findings

- The 2019 dry spring conditions affected genotype performance, influencing flowering time and grain yield responses.
- Current varieties were not broadly adapted across sowing dates from mid April to late May.
- Highest grain yields were achieved across phenology types in response to sowing dates, with very slow spring types maximising yield from the mid April sowing date (SD), with later sowing dates favouring faster developing spring genotypes, which achieved the highest grain yields in 2019.

Introduction

In 2019, field experiments were conducted across various sites in the GRDC northern grains region (NGR) to determine how phenology influences grain yield responses for a diverse set of wheat genotypes. This paper presents results from the Cudal site (central eastern NSW) and discusses the sowing date influence on the phenology and grain yield responses from a core set of 36 wheat genotypes.

Site details

Location	South Bowen Park, Cudal NSW
Soil type	Red–brown chromosol
Previous crop	Canola
Sowing	Direct drilled with Horwood Bagshaw seeding units, spaced at 220 mm using a GPS auto-steer system.
Target plant density	160 plants/m^2
Soil pH$_{Ca}$	5.2 (0–10 cm); 5.2 (10–30 cm)
Mineral nitrogen (N)	192 kg N/ha at sowing (1.5 m depth)
Fertiliser	• 100 kg/ha mono-ammonium phosphate (MAP) (sowing) • 150 kg/ha urea (sowing)
Weed control	• **Knockdown**: Glyphosate (450 g/L) 2.0 L/ha • **Pre-sowing**: Sakura® (850 g/ka pyroxasulfone) 118 g/ha + Avadex® Xtra (500 g/L tri-allate) 1.6 L/ha + trifluralin (480 g/L) 1.6 L/ha (SD1: 17 April, SD2: 6 May and SD3: 20 May)

	• **In-crop**: Axial® (100 g/L pinoxaden and 25 g/L cloquintocet-methyl) 300 mL/ha + Precept® (125 g/L MCPA and 25 g/L pyrasulfotole) 2 L/ha + Adigor® (adjuvant) 500 mL per 100 L water (18 June)
Disease management	• **Seed treatment**: Hombre® Ultra (360 g/L imidacloprid and 12.5 g/L tebuconazole) 200 mL/100 kg seed • **Fertiliser treatment**: Flutriafol (250 g/L) 400 mL/ha • **In-crop**: Prosaro® 420 SC (210 g/L prothioconazole and 210 g/L tebuconazole) 300 mL/ha (15 August)
Pest management	• Talstar® 250 EC (250 g/L bifenthrin) 80 mL/ha (23 May) • Aphidex® WG (500 g/kg pirimicarb) 250 g/ha (15 August and 17 September) • Fastac® Duo (100 g/L alpha-cypermethrin) 100 mL/ha (17 September)
Rainfall	In-crop (April–October): 145 mm; long-term average: 353 mm
In-crop supplementary irrigation (sprinkler)	• 10 mm: SD1 only post sowing (29 April) • 20 mm: all sowing dates (5 August) • 20 mm: all sowing dates (24 September)
Severe temperature events	• Four heat stress events (days >30 °C) during October including a 32.5 °C day (6 October) and 11 heat stress events during November. • Four frost events (days <0 °C), 5 August 0°C, 6 August –1.5 °C, 14 August 0 °C and 10 September –1.0 °C.
Harvest date	28 November 2019

Treatments

Genotype

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

Sowing date (SD)

- SD1: 17 April 2019
- SD2: 6 May 2019
- SD3: 20 May 2019

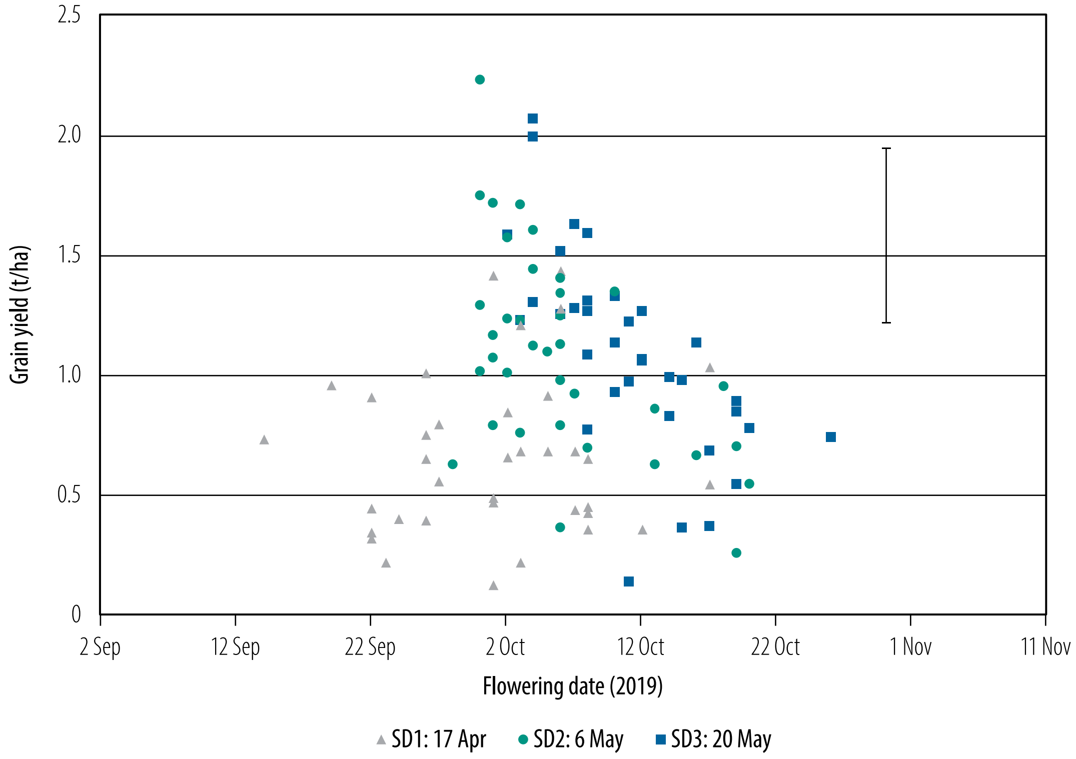
Results

Phasic development

The optimal flowering period (OFP) for Cudal derived from modelling using long-term climatic data occurs in the second and third week of October, where risk from frost, heat and moisture stress on grain yield is minimised. In 2019, the flowering window spanned from 13 September to 18 October. This window was shorter than previous seasons as the slow winter types, Manning$^{\Phi}$ and RGT Accroc, did not flower and set grain from the 20 May sowing (SD3) because of the spring drought conditions. Additionally, frosts in August coincided with sensitive reproductive stages in the very fast and fast spring types, causing stem death and delayed flowering dates. Genotype × sowing date combinations, which flowered in the window from late-September to early-October, achieved the highest grain yields in the 2019 season – two weeks earlier than the OFP for Cudal (Figure 1).

Table 1 Expected phenology responses of the 2019 experiment genotypes.

Phenology type	Sub-category	Genotypes
Winter	Slow	Manning⌽, RGT Accroc
	Mid–slow	DS Bennett⌽
	Mid	EGA Wedgetail⌽, LongReach Kittyhawk⌽
	Fast	Longsword⌽
Spring	Very slow	EGA Eaglehawk⌽, LongReach Nighthawk⌽, RGT Zanzibar, Sunlamb⌽, Sunmax⌽
	Slow	Cutlass⌽
	Mid–slow	Catapult⌽, Coolah⌽, DS Pascal⌽, EGA Gregory⌽, LongReach Lancer⌽, LongReach Trojan⌽, Mitch⌽
	Mid	Beckom⌽, Janz, Sunvale⌽
	Mid–fast	LongReach Reliant⌽, Suntop⌽
	Fast	Corack⌽, LongReach Hellfire⌽, LongReach Mustang⌽, LongReach Spitfire⌽, Mace⌽, Scepter⌽, Sunprime⌽
	Very fast	Condo⌽, H45⌽, LongReach Dart⌽, TenFour⌽, Vixen⌽



I Vertical bar represents l.s.d. (*P* = 0.05) = 0.73 t/ha.

Figure 1 Relationship between flowering date and grain yield for 36 genotypes sown on three dates at Cudal, 2019.

Early phasic development highlighted the speed of the very fast and fast spring types (Figure 2), with Vixen⌽ and Scepter⌽ reaching growth stage 30 (GS30) on the 9 June and 11 June for SD1 compared with LongReach Nighthawk⌽ (25 June), EGA Wedgetail⌽ (30 June) and DS Bennett⌽ (16 July). The slower development through growth stages following GS30 between the very fast spring wheat Vixen⌽ and a long season spring LongReach Nighthawk⌽ was emphasised with Vixen⌽ recording a grain yield of 0.32 t/ha for SD1 and LongReach Nighthawk⌽, the third highest yielding genotype in SD1, 1.27 t/ha. Frost damage through the critical stem elongation phase in August and early September severely affected Vixen⌽.

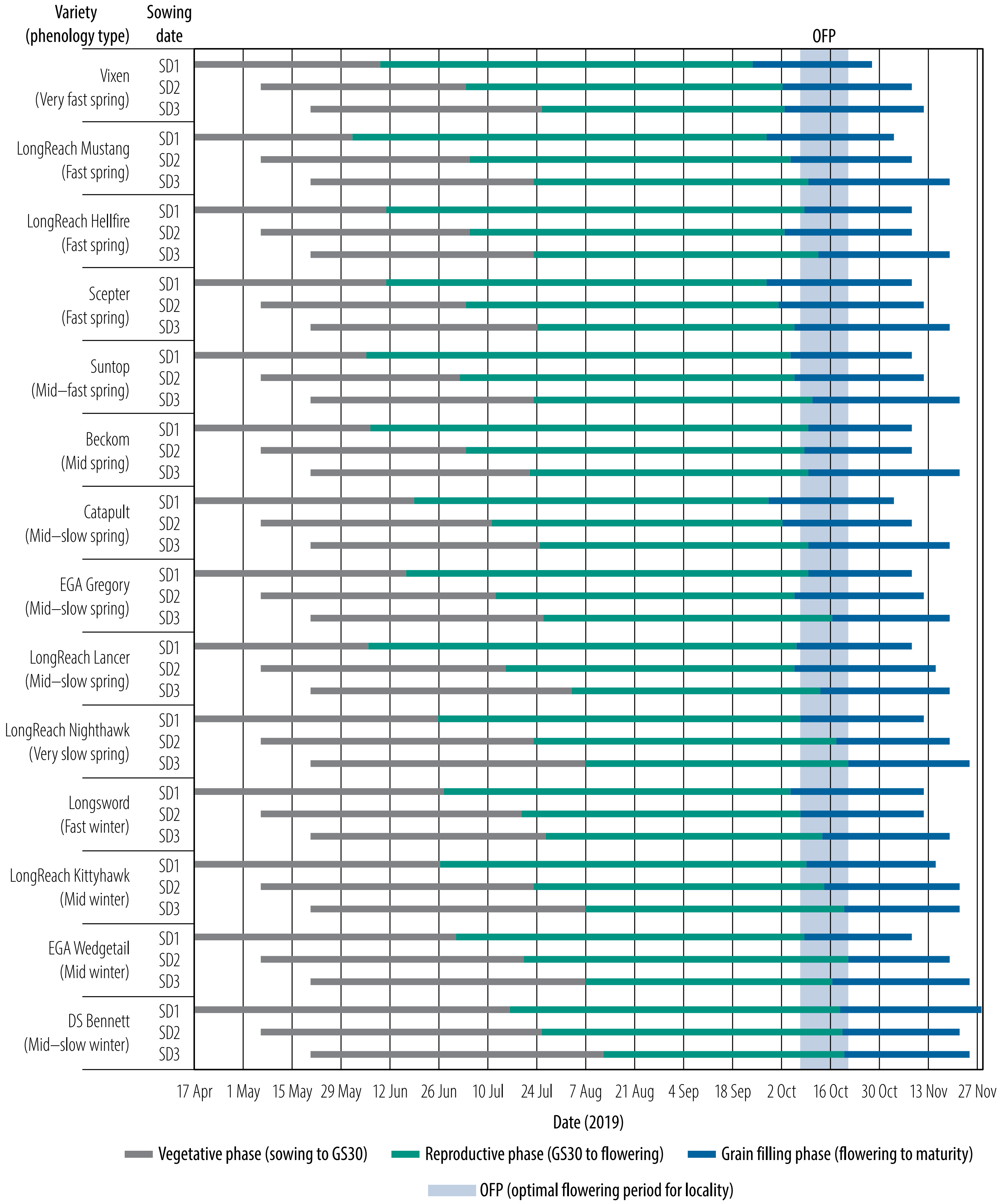


Figure 2 Influence of sowing date on phasic development of selected genotypes sown on three dates at Cudal, 2019.

Even with the drought conditions of the 2019 season, the vernalisation and photoperiod holds were demonstrated, with long season spring and winter types delaying stem elongation and flowering, avoiding the frost damage, and flowering in the OFP. Consistent with previous work by Harris et. al. 2018 and Harris et. al. 2019, genotypes with a strong photoperiod hold such as DS Bennett$^{\Phi}$ had a compact flowering period, flowering within a two day period across all three sowing dates in 2019, compared with Longsword$^{\Phi}$, another winter wheat but with a weak photoperiod hold that flowered over eight days. The hot, dry conditions in October coincided with the grain filling phase of later flowering genotypes that flowered through mid October, limiting yield potential and resulting in a significant yield decline in 2019.

Grain yield

Grain yield and genotype rankings varied significantly across sowing dates (late April to late May) supporting previous research in the region that genotypes are not broadly adapted across sowing dates (Table 2). In 2019, the highest yielding genotypes were the very fast spring wheats in SD2, with LongReach Dart⁽ᴾ⁾ achieving 2.23 t/ha. In SD1 the highest yielding genotype was the very slow spring genotype EGA Eaglehawk⁽ᴾ⁾ (1.43 t/ha), escaping the frost damage and still being able to fill grain despite the hot dry October–November period. Figure 3 shows the different yield response curves for a group of genotypes with the winter wheat LongReach Kittyhawk⁽ᴾ⁾ having a flatter response across sowing dates. The very slow spring wheat LongReach Nighthawk⁽ᴾ⁾ peaked in SD1 and Vixen⁽ᴾ⁾, a very fast spring wheat, maximised yield in SD2.

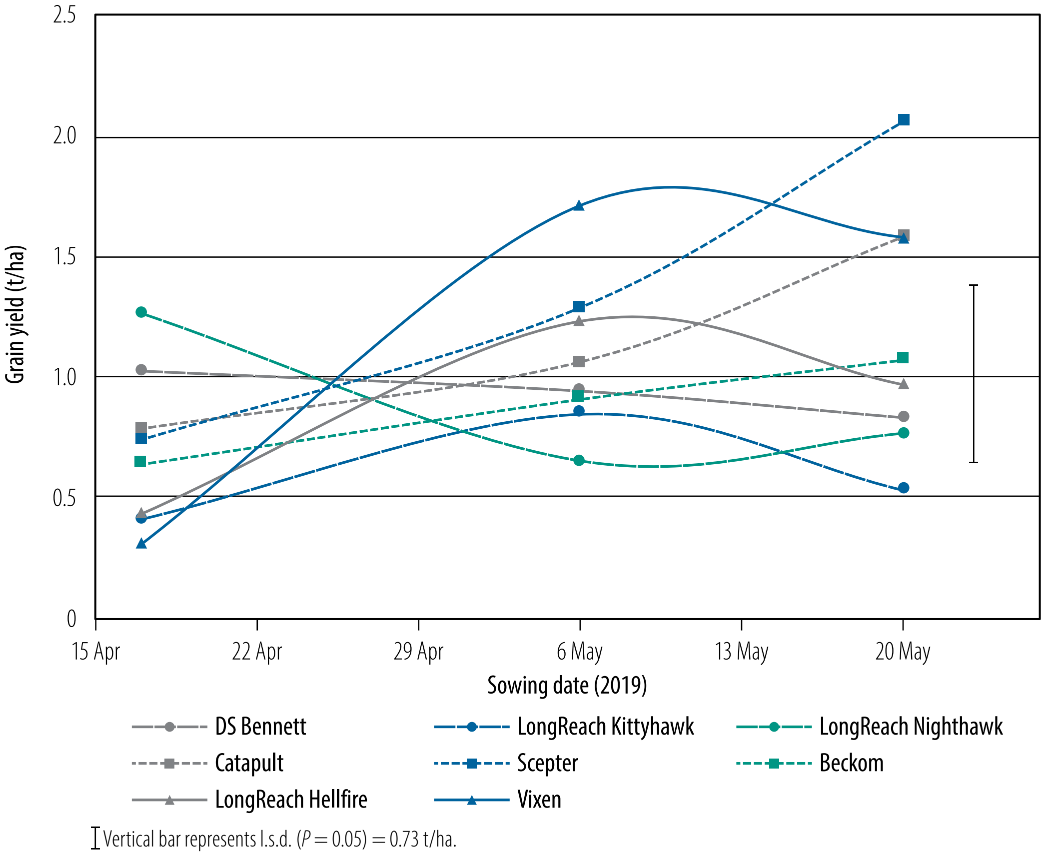


Figure 3 Grain yield of selected genotypes across three sowing dates 17 April, 6 May and 20 May at Cudal, 2019.

Table 2 Grain yield of genotypes across four sowing dates at Cudal, 2019.

Genotype	SD1: 17 April		SD2: 6 May		SD3: 20 May	
	Grain yield (t/ha)	Rank	Grain yield (t/ha)	Rank	Grain yield (t/ha)	Rank
Beckom	0.65	19	0.91	24	1.08	18
Catapult	0.79	11	1.07	19	1.59	4
Condo	0.90	9	1.74	2	1.25	13
Coolah	0.84	10	1.40	8	0.99	21
Corack	0.65	18	1.01	20	1.22	14
Cutlass	0.34	32	0.75	28	1.13	16
DS Bennett	1.03	5	0.95	23	0.84	26
DS Pascal	1.41	2	0.79	26	1.06	19
EGA Eaglehawk	1.43	1	0.62	32	0.89	25
EGA Gregory	0.45	24	1.44	7	0.97	22
EGA Wedgetail	0.68	14	0.70	29	0.36	35
H45	0.73	13	0.79	27	1.30	8
Janz	0.49	22	1.00	21	1.22	15
Longsword	0.22	34	1.24	12	1.05	20
LongReach Dart	0.44	25	2.23	1	1.26	11
LongReach Hellfire	0.44	26	1.23	13	0.97	23
LongReach Kittyhawk	0.42	27	0.86	25	0.54	32
LongReach Lancer	0.91	8	1.12	17	1.26	12
LongReach Mustang	0.39	29	1.23	14	0.76	29
LongReach Nighthawk	1.27	3	0.66	31	0.77	28
LongReach Reliant	0.56	20	1.33	10	1.32	7
LongReach Spitfire	0.47	23	1.09	18	0.83	27
LongReach Trojan	1.00	6	1.57	6	1.63	3
Mace	0.22	35	1.16	15	1.30	9
Manning	0.13	36	–	–	–	–
Mitch	0.65	17	0.69	30	0.36	34
RGT Accroc	0.54	21	0.54	34	–	–
RGT Zanzibar	0.35	30	1.12	16	0.68	31
Scepter	0.75	12	1.29	11	2.06	1
Sunlamb	0.35	31	0.26	36	0.37	33
Sunmax	0.68	16	0.97	22	1.27	10
Sunprime	0.96	7	1.70	4	1.51	6
Suntop	0.68	15	1.60	5	0.93	24
Sunvale	1.20	4	1.34	9	1.13	17
TenFour	0.40	28	0.62	33	1.99	2
Vixen	0.32	33	1.71	3	1.58	5
Mean	0.66		1.09		1.07	
l.s.d. ($P = 0.05$) Genotype	0.42					
l.s.d. ($P = 0.05$) SD	0.12					
l.s.d. ($P = 0.05$) Genotype × SD	0.73					

Grain quality

There were significant differences between genotypes, sowing dates and the interaction between genotype and sowing date for grain quality parameters (Table 3). The dry seasonal conditions affected grain protein accumulation, with low grain yield and the high paddock N levels resulting in high protein levels, ranging from 14.7%–18.4%. Even with the high protein levels, there were significant differences in genotype responses for protein accumulation, for example, LongReach Spitfire$^{\phi}$ and LongReach Hellfire$^{\phi}$ had higher grain protein concentrations than other genotypes at similar yield levels (Figure 4).

Grain screening percentages increased as sowing and flowering date was delayed. However, the early frost events that delayed flowering of the quicker genotypes and the ongoing moisture stress through the key grain setting and flowering period limited grain numbers and reduced the effects normally seen in a dry hot grain filling period.

Test weight (TWT) varied depending on maturity type, with the very fast and fast maturity genotypes showing an increase in TWT as sowing was delayed. Mid and mid–slow genotypes generally had peaks from SD2 and the winter types showed a decrease in TWT across sowing dates.

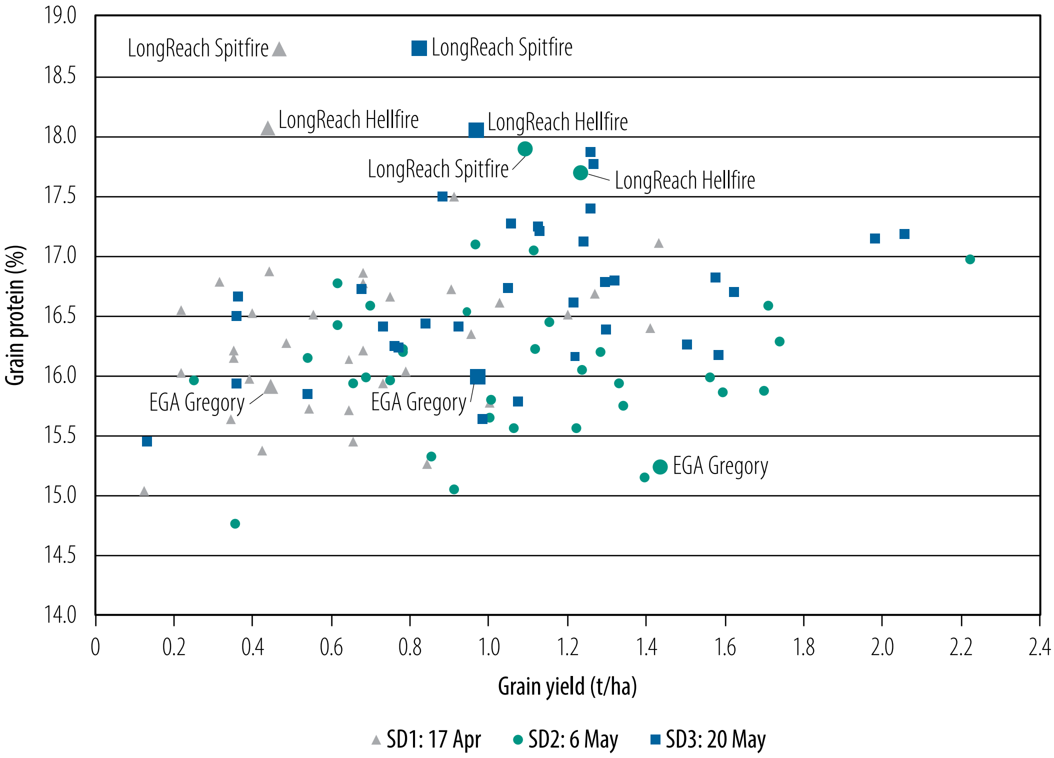


Figure 4 Relationship between grain yield and grain protein for 36 genotypes sown on three dates at Cudal, 2019.

Table 3 Grain protein, screenings and test weight of 36 genotypes across three sowing dates at Cudal, 2019.

Genotype	SD1: 17 April			SD2: 6 May			SD3: 20 May		
	Grain protein (%)	Screenings (%)	Test weight (kg/hL)	Grain protein (%)	Screenings (%)	Test weight (kg/hL)	Grain protein (%)	Screenings (%)	Test weight (kg/hL)
Beckom	15.7	1.6	81.2	15.0	2.1	81.4	15.8	3.2	82.7
Catapult	16.0	0.8	81.2	15.5	1.2	81.9	16.2	1.9	82.9
Condo	16.7	1.0	80.4	16.3	0.4	81.6	17.1	2.2	83.9
Coolah	15.3	0.4	81.3	15.1	2.6	83.4	15.6	4.0	82.7
Corack	16.1	0.1	81.7	15.8	0.4	82.5	16.1	0.7	82.6
Cutlass	15.6	0.6	81.1	15.9	0.9	82.1	17.2	1.2	81.6
DS Bennett	16.6	3.3	80.8	16.5	5.3	80.3	16.4	4.5	80.5
DS Pascal	16.4	1.1	81.2	16.2	2.3	83.0	17.3	3.7	82.5
EGA Eaglehawk	17.1	6.7	81.1	16.8	5.4	81.5	17.5	6.9	81.4
EGA Gregory	15.9	1.2	79.6	15.2	2.1	82.8	16.0	3.2	82.8
EGA Wedgetail	16.9	1.2	79.5	16.6	1.7	80.1	16.5	2.7	79.6
H45	15.9	3.6	80.1	16.2	3.7	80.4	16.4	7.0	82.2
Janz	16.3	0.2	80.7	15.6	1.4	82.6	16.6	1.6	83.4
Longsword	16.0	0.6	80.2	16.0	2.1	80.2	16.7	2.2	80.8
LongReach Dart	16.9	0.0	81.4	17.0	1.3	82.4	17.4	3.1	83.0
LongReach Hellfire	18.1	0.8	81.4	17.7	0.5	83.3	18.0	1.2	83.9
LongReach Kittyhawk	15.4	0.5	84.0	15.3	1.1	83.9	15.8	3.6	82.4
LongReach Lancer	17.5	1.0	81.3	17.0	2.6	82.6	17.9	4.1	82.6
LongReach Mustang	16.0	0.2	81.7	15.5	0.4	83.5	16.2	1.7	84.3
LongReach Nighthawk	16.7	3.7	81.6	15.9	5.7	81.3	16.2	5.4	81.3
LongReach Reliant	16.5	0.3	80.6	15.9	2.2	83.2	16.8	4.5	83.0
LongReach Spitfire	18.7	0.3	80.8	17.9	1.1	81.8	18.7	1.0	83.7
LongReach Trojan	15.8	0.5	83.0	16.0	1.2	83.9	16.7	2.4	83.6
Mace	16.5	–	80.2	16.4	1.0	80.8	16.8	1.1	81.9
Manning	15.0	3.3	76.8	–	–	–	–	–	–
Mitch	15.4	2.7	79.7	16.0	5.5	80.8	15.9	6.6	80.6
RGT Accroc	15.7	3.7	80.1	16.1	4.3	79.9	–	–	–
RGT Zanzibar	16.1	0.7	80.3	16.2	1.9	81.1	16.7	2.1	80.0
Scepter	16.7	0.2	80.8	16.2	0.7	82.0	17.2	1.7	83.2
Sunlamb	16.2	3.1	79.6	15.9	4.4	81.1	16.6	4.0	81.2
Sunmax	16.8	3.3	80.8	17.1	2.9	82.0	17.8	3.7	81.8
Sunprime	16.3	1.4	80.2	15.9	1.9	81.5	16.2	4.4	82.8
Suntop	16.2	2.4	81.4	15.8	4.3	83.5	16.4	4.4	82.2
Sunvale	16.5	0.6	82.2	15.7	2.1	82.6	17.2	3.9	83.2
TenFour	16.5	0.9	79.1	16.4	1.9	79.6	17.1	2.7	80.9
Vixen	16.8	0.3	79.6	16.6	0.1	80.9	16.8	0.4	82.6
Mean	16.4	1.4	80.7	16.1	2.3	81.8	16.7	3.3	82.1
l.s.d. ($P = 0.05$) Genotype	0.4	0.7	0.6						
l.s.d. ($P = 0.05$) SD	0.1	0.2	0.2						
l.s.d. ($P = 0.05$) Genotype × SD	0.6	1.3	1.0						

Summary

The 2019 season was one of the driest on record and included several frosts during the critical stem elongation phase through August and September, followed by periods of heat shock at flowering and grain fill for many of the genotypes included in the experiment. The season favoured the very fast–fast developing genotypes, sown mid–late May (SD2 and SD3), where flowering time avoided frost damage and grain filling occurred before the onset of severe moisture and heat stress. The relationship and development patterns of the genotypes, even in a 1:100 year event, were consistent with previous years' experimental findings with genotype performance driven by seasonal conditions. No one genotype maturity group was adapted to all three sowing dates in 2019, supporting previous work that growers can maximise grain yield by selecting varieties that target the OFP based on seasonal sowing opportunities.

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Acknowledgements

This experiment was part of the 'Optimising grain yield potential of winter cereals in the northern grains region' project, BLG104, 2017–20, a joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

We sincerely thank Rob Bowman and family, South Bowman Park, Cudal, for hosting the field experiment and acknowledge the technical support of Lorraine Thacker, David Cupitt and Gabriel Brown.

Contact

Peter Matthews
NSW DPI, Orange
peter.matthews@dpi.nsw.gov.au
0427 007 395

Frost damage identification in canola – symptoms and risk assessment

Dr Rajneet Uppal

NSW DPI, Wagga Wagga

Key findings

- Canola is susceptible to frost damage risk during its reproductive development phase.
- Late-season frosts can have negative economic implications.
- Accurate frost damage identification is important for making appropriate management decisions.

Introduction

Radiation frost can occur when air temperature drops below 2 °C. Frost can be detrimental to canola grain yield and quality depending upon the crop growth stage. Generally, late spring frosts at pod development and grain-filling are economically damaging and result in grain yield reduction and poor oil quality. Correctly identifying frost-affected crops is important for crop assessment early in the cropping season and to allow for appropriately timed management decisions.

Frost risk assessment

Frost risk factors

Damage to canola crops from frost can vary depending on a number of factors within a paddock including:

- temperature
- soil:
    - type
    - moisture
- cloud cover
- wind speed
- position in the landscape
- crop:
    - species
    - development stage
    - nutrition
    - density.

Generally, low-lying paddocks with light soils are more prone to frost risk. Frost damage can be random resulting in high yield variability within paddocks and individual plants.

Canola is most susceptible to frost risk during reproductive development from early flowering to the grain-filling stages. Canola can compensate for early flowering frost stress by producing more flowers if soil moisture is not limiting. However, the most economically damaging frosts for canola are spring frosts, which can occur during late-grain-fill. These frosts can kill developing seeds after flowering has finished and plants are unable to recover by producing more pods.

The risk of frost damage is also elevated when there are other abiotic or biotic stresses such as drought stress, heat stress, poor nutrition and disease pressure.

Frost identification

- Inspect the canola crop between late bud to grain-filling phase if night temperature falls below 2 °C. Revisit the paddock two to three days later to inspect for visible damage. Symptoms might not be obvious until five to seven days after the frost.
- Check low-lying areas first, followed by other areas at least 2 m into the paddock as plants on the outer edge can have less damage.
- Monitor pod development and seed-fill following a frost by tagging reference plants in a few spots and checking these a few days later for signs of senescence or continued development.

Frost symptoms

Bud stage

Bud discoloration occurs after frost stress in canola i.e. buds change colour from green to creamish white (Figure 1).

Figure 1 Bud discoloration in canola after a frost event.

Early flowering

Frosted plants lose flowers and abort young pods (Figure 2). Open flowers can be aborted after a frost whereas young buds and pods remain unaffected.

Figure 2 Frost damage symptoms in canola at early flowering stage.

Pod set

Frost at pod set results in abortion and death of developing seed (Figure 3). This can cause gaps in pod set and twisting of the inflorescence. The frosted pod surface can turn yellow/green and/or develop a pale blistered surface.

Figure 3 Pod abortion in two canola varieties evident at maturity.

Grain-filling

Damage during grain-fill is particularly evident after a severe late frost when developing grain turns into a mushy green mass that dries into a small black or brown speck (Figure 4). The extent of damage can be assessed by opening pods from tagged plants and checking for healthy and damaged seed.

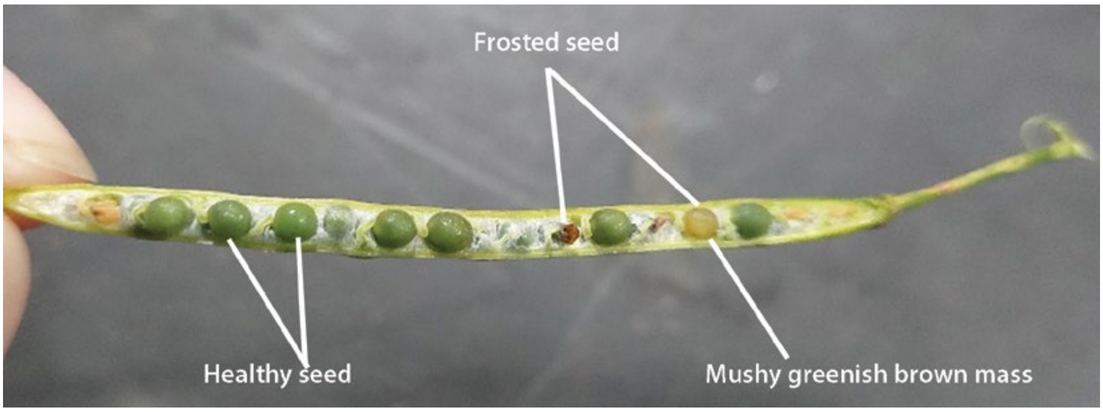


Figure 4 Frost damage symptoms on developing grain in a canola pod. Photo: Danielle Malcolm.

Frost management tips

Monitoring weather and temperature data

Frost risk occurs when air temperature falls below 2 °C (Bureau of Meteorology (BOM) prediction), however actual frost risk depends on the temperature at canopy height. BOM predictions measure temperature at 1.4 m height (standard) in a Stevenson screen and therefore it might or might not correlate well with crop height temperatures. Temperature at canopy height might be a few degrees lower than temperatures measured in a Stevenson screen. Therefore, it is important to monitor local temperatures (using iButtons, Tiny tags etc.) at paddock level and consider soil and topographic variability within each paddock.

Right phenology

No canola variety is tolerant to frost. Using more than one variety and targeting sowing windows to optimise flowering times will help to reduce frost risk in early-sown crops and heat risk in late-sown crops. As a frost avoidance strategy, a mix of sowing dates, crop types and maturity types are recommended.

Input management

Frost risk can also be managed by manipulating/avoiding in-season nitrogen application in frost prone areas, depending on the cropping season. High nitrogen application can exacerbate frost risk.

Seasonal conditions such as moisture availability play an important role in compensation from frost stress. Canola is indeterminate and flowers over 30- to 40-days. Canola can therefore recover from early flowering frost stress by producing more flowers if soil moisture availability is not limiting and other abiotic or biotic stresses are absent.

Useful resources

Frost damage identification in canola https://www.youtube.com/watch?v=6uruleESKk8

Frost damage identification in wheat https://www.youtube.com/watch?v=YeOlZNmwqxU

Acknowledgements

This experiment was part of the 'Assessing and quantifying frost damage in canola' project, BLG114, 2020–22, a joint investment by NSW DPI and GRDC under the Grains Agronomy and Pathology partnership (GAPP).

Thank you to Danielle Malcolm and Warren Bartlett for their technical support.

Contact

Dr Rajneet Uppal
Wagga Wagga Agricultural Institute, Wagga Wagga
rajneet.uppal@dpi.nsw.gov.au
0436 341 649

Phenology of commercial and new release canola varieties in 2020

Danielle Malcolm[1], Warren Bartlett[1] and Don McCaffery[2]

[1] NSW DPI, Wagga Wagga
[2] NSW DPI, Orange

Key findings

- Canola varieties varied markedly in the time it took from sowing/emergence to the start of flowering.
- Warmer than average temperatures throughout May and June resulted in early sown varieties meeting their thermal requirement and starting to flower earlier than usual.

Introduction

An important management strategy to maximise yield potential for canola is to sow varieties within the correct sowing window so they start flowering within the optimum flowering period for a particular location. Flowering too early increases the risk of frost damage, upper canopy blackleg and sclerotinia stem rot infection. Flowering too late increases the risk of damage from heat or moisture stress or both, potentially reducing yield.

The optimum start of flowering (determined as 50% of plants with one open flower) differs for each location. The optimum start of flowering for Wagga Wagga is between 31 July and 1 September, with the optimum date around 14 August. This means a variety's phenology needs to be understood so growers can sow varieties in the correct window for flowering to start during the optimum time and maximise yield potential.

An experiment at Wagga Wagga in 2020 examined the phenology of 34 commercial and newly released varieties sown on two dates.

Site details

Location	Wagga Wagga Agricultural Institute
Soil type	Red kandosol
Previous crop	Barley
Rainfall	Fallow (November 2019–March 2020): 143 mm In-crop (April 2020–October 2020): 305 mm In-crop long-term average: 330 mm
Soil nitrogen (N)	227 kg N/ha (0–180 cm, 27 March)

Treatments

Variety

Table 1 lists the details of varieties examined in this experiment.

Sowing date (SD)

SD1: 26 March 2020

SD2: 27 April 2020

Table 1 Characteristics of varieties examined in the Wagga Wagga experiment in 2020.

Variety	Phenology	Maturity	Herbicide tolerance *	Plant type
ATR Bonito⦹	Mid–fast	Early	TT	Open-pollinated
ATR Wahoo⦹	Mid–slow	Mid	TT	Open-pollinated
GT 53	Mid	Mid	RR	Hybrid
Hyola 350TT	Fast	Early	TT	Hybrid
Hyola 410XX	Mid–fast	Early–mid	Truflex RR	Hybrid
Hyola 540XC	Mid–fast	Early–mid	Truflex RR/CLF	Hybrid
Hyola 580CT	Fast	Mid	CLF/TT	Hybrid
Hyola Enforcer CT	Mid	Early–mid	CLF/TT	Hybrid
Hyola Garrison XC	Mid	Early–mid	Truflex RR/CLF	Hybrid
HyTTec Trident	Mid–fast	Early	TT	Hybrid
HyTTec Trifecta	Mid	Mid	TT	Hybrid
HyTTec Trophy	Mid	Mid	TT	Hybrid
InVigor R 4022P	Mid–fast	Early–mid	Truflex RR	Hybrid
InVigor R 4520P	Mid–fast	Mid	Truflex RR	Hybrid
InVigor R 5520P	Mid–slow	Mid	RR	Hybrid
InVigor T 3510	Mid–fast	Early	TT	Hybrid
InVigor T 4510	Mid–fast	Early–mid	TT	Hybrid
InVigor T 6010	Mid–late	Mid-late	TT	Hybrid
Nuseed Diamond	Fast	Early	Conventional	Hybrid
Nuseed Quartz	Mid	Early–mid	Conventional	Hybrid
Pioneer® 43Y29 (RR)	Mid–fast	Early	RR	Hybrid
Pioneer® 43Y92 (CL)	Mid–fast	Early	CLF	Hybrid
Pioneer® 44Y27 (RR)	Mid–fast	Early–mid	RR	Hybrid
Pioneer® 44Y90 (CL)	Mid–fast	Early–mid	CLF	Hybrid
Pioneer® 44Y94 (CL)	Mid	Early–mid	CLF	Hybrid
Pioneer® 45Y28 (RR)	Mid–slow	Mid	RR	Hybrid
Pioneer® 45Y91 (CL)	Mid–slow	Mid–late	CLF	Hybrid
Pioneer® 45Y93 (CL)	Mid–slow	Mid	CLF	Hybrid
Saintly CL	Mid–fast	Early	CLF	Hybrid
SF Ignite TT	Mid–slow	Mid–late	TT	Hybrid
SF Spark TT	Fast	Early	TT	Hybrid
Victory V75-03CL	Mid–slow	Mid	CLF	Hybrid
Xseed Condor	Mid–fast	Mid	Truflex RR	Hybrid
Xseed Raptor	Mid–fast	Early–mid	Truflex RR	Hybrid

*CLF = Clearfield, TT = Triazine tolerant, RR = Roundup Ready®.

Results

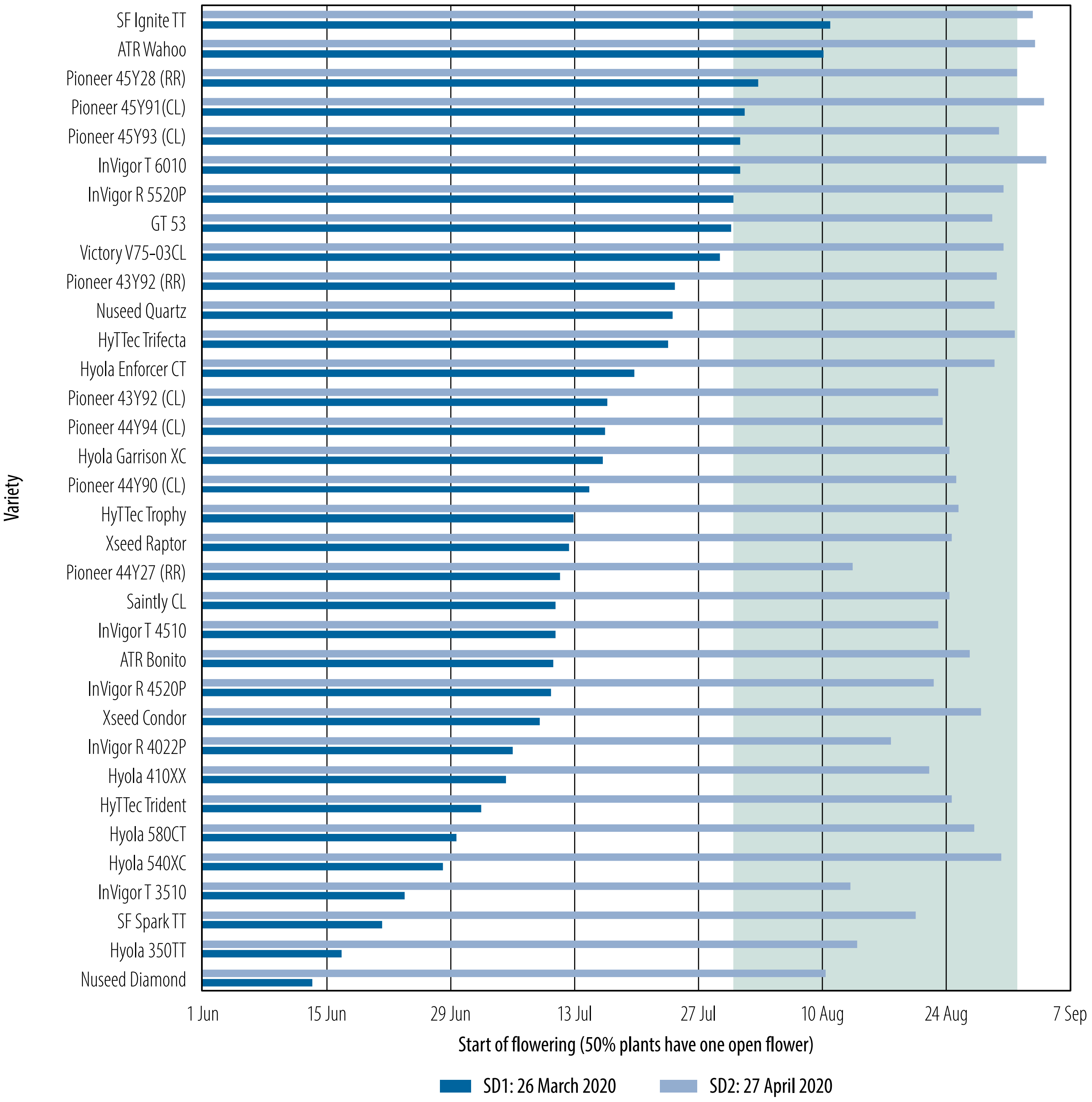
Seasonal conditions

Wagga Wagga recorded 305 mm growing season rainfall, 25 mm less than the long-term average.

Frost was not a major issue at Wagga Wagga in 2020, with only 11 days below 0 °C recorded between June and September at the experiment site. The lowest recorded temperature was –1.5 °C on 6 August. The long-term average number of days below 0 °C for Wagga Wagga is 18 (CliMate 2021).

Phenology

Nuseed Diamond was the first to flower from SD1. It flowered on 13 June, 48 days before its optimum start of flowering period of 31 July (shaded area, Figure 1). The varieties to flower after 31 July from SD1 were InVigor R 5520P, InVigor T 6010, Pioneer® 45Y93 (CL), Pioneer® 45Y91 (CL), Pioneer® 45Y28 (RR), ATR Wahoo$^{\Phi}$ and SF Ignite TT. ATR Wahoo$^{\Phi}$ and SF Ignite TT were the latest to start flowering, on 10 August. When the start of flowering begins through June and July, it increases the risk of the crop being damaged by frost, upper canopy blackleg infection and sclerotinia stem rot. Warmer than average early season temperatures meant that varieties had reached their thermal time requirement earlier than usual, with the plants switching from the vegetative to the reproductive stage earlier in the season, leading to earlier flowering dates for SD1.



▨ Shaded area shows the optimum start of flowering period (when 50% of plants have one open flower) for Wagga Wagga (31 July to 1 September).

Note: Some varieties are protected under the Plant Breeders Rights Act 1994. See Table 1.

Figure 1 Flowering dates of 34 canola varieties sown on two dates at Wagga Wagga in 2020.

Delaying the sowing date to late April (SD2) resulted in most varieties starting to flower within the optimum flowering period for Wagga Wagga (31 July–1 September), the earliest being Nuseed Diamond on 10 August. Pioneer® 45Y91 (CL) and InVigor T 6010 were the last varieties to reach the start of flowering on 4 September (Figure 1). Delaying the sowing of these varieties much later than SD2 would increase the risk of heat and/or moisture stress during their critical growth period (around 350 degree days following the start of flowering date) (Kirkegaard et al. 2018).

Thermal time in 2020 accumulated quicker than previous years, which has resulted in varieties flowering earlier than in previous seasons. Figure 2 shows the difference in thermal time and vernal time to flowering for Nuseed Diamond and Pioneer® 45Y91 (CL) for SD1 in 2018, 2019 and 2020 at Wagga Wagga. All varieties reached the start of flowering earlier than usual in 2020 where the vernal time requirement was met faster in SD1. In SD2, these differences were reduced.

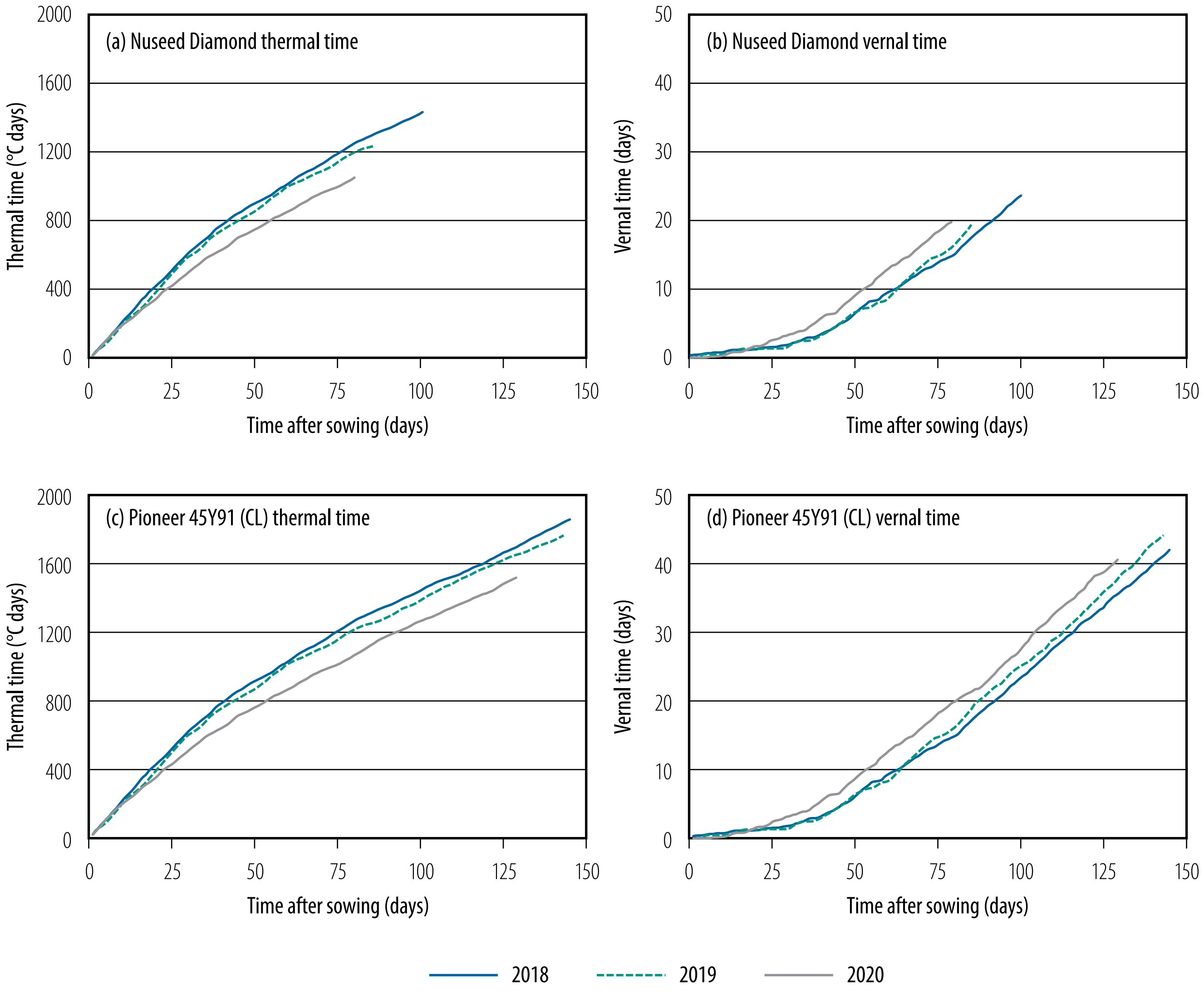


Figure 2 Thermal time accumulation and vernal time accumulation to flowering for Nuseed Diamond (a and b) and Pioneer 45Y91 (CL) (c and d) for SD1 in 2018, 2019 and 2020 at Wagga Wagga.

Yield and quality

The highest yielding variety in 2020 was Pioneer® 45Y28 (RR) (3.51 t/ha, SD2), closely followed by InVigor R 4520P (3.43 t/ha, SD1) (Table 2). The average site yield was 2.80 t/ha. Generally, the fast-developing varieties performed better when sown later (SD2), with the slower varieties being consistent in their yield across both sowing dates in the 2020 season.

Table 2 Yield and grain quality of 34 commercial and new release canola varieties at Wagga Wagga in 2020.

Variety	Grain yield$^{\#}$ (t/ha)		Oil content$^{\#}$ (%)		Protein content$^{\#}$ (%)		Seed weight (g/1000 seeds)	
	SD1	**SD2**	**SD1**	**SD2**	**SD1**	**SD2**	**SD1**	**SD2**
ATR Bonito$^{⌽}$	2.59	2.83	43.3	43.7	21.9	20.8	4.24	3.73
ATR Wahoo$^{⌽}$	2.10	3.05	41.4	41.2	22.4	24.5	4.22	4.26
GT 53	2.56	2.88	41.9	41.7	20.3	19.9	3.65	3.34
Hyola 350TT	2.42	2.62	41.2	42.3	23.0	21.9	5.15	4.40
Hyola 410XX	2.69	2.99	45.5	45.7	20.4	19.9	4.24	3.87
Hyola 540XC	2.29	2.71	41.4	41.3	22.4	22.1	4.45	3.87
Hyola 580CT	2.13	2.55	41.5	40.3	22.2	22.5	4.41	3.89
Hyola Enforcer CT	2.84	2.87	42.1	42.7	21.8	21.1	4.37	4.08
Hyola Garrison XC	2.10	3.11	42.7	44.1	21.8	20.0	4.39	3.98
HyTTec Trident	2.61	2.39	42.6	41.2	20.5	20.2	3.81	3.33
HyTTec Trifecta	3.01	3.21	43.1	42.3	20.9	22.4	4.05	3.89
HyTTec Trophy	2.63	2.93	41.8	42.1	21.8	20.8	3.52	3.20
InVigor R 4022P	3.16	3.08	43.3	43.1	20.5	20.5	4.45	3.77
InVigor R 4520P	3.43	3.28	42.2	41.9	20.8	20.0	3.74	3.29
InVigor R 5520P	2.71	2.66	43.0	42.3	20.3	20.6	3.43	3.09
InVigor T 3510	2.45	2.62	39.3	41.2	23.5	21.4	4.37	3.67
InVigor T 4510	2.62	2.80	41.1	41.4	21.3	20.8	4.19	3.57
InVigor T 6010	2.80	3.16	41.2	41.7	21.5	21.6	3.88	3.65
Nuseed Diamond	2.54	2.97	40.2	42.4	23.6	20.6	5.08	3.89
Nuseed Quartz	3.05	3.07	43.2	43.4	20.5	19.2	4.09	3.88
Pioneer 43Y29 (RR)	2.88	3.35	43.0	42.5	19.9	20.7	4.36	4.26
Pioneer 43Y92 (CL)	2.75	3.13	42.5	42.8	20.9	20.5	4.29	4.03
Pioneer 44Y27 (RR)	3.27	2.93	43.2	42.1	19.8	20.1	4.24	3.68
Pioneer 44Y90 (CL)	3.13	3.19	43.2	43.0	20.5	20.2	4.20	3.87
Pioneer 44Y94 (CL)	3.33	3.28	44.2	43.3	18.9	18.7	4.00	3.84
Pioneer 45Y28 (RR)	3.18	3.51	45.1	44.8	19.9	20.2	3.90	3.86
Pioneer 45Y91 (CL)	2.64	2.88	42.9	42.9	21.2	21.0	4.14	3.83
Pioneer 45Y93 (CL)	3.25	3.40	43.0	41.7	20.4	20.7	3.98	3.84
Saintly CL	3.12	3.12	43.4	44.0	20.5	19.4	4.35	3.76
SF Ignite TT	2.59	2.93	41.0	40.4	21.4	22.9	3.75	3.73
SF Spark TT	2.61	2.62	43.3	42.3	21.0	20.7	3.95	3.52
Victory V75-03CL	2.92	2.62	42.7	42.3	20.2	20.6	4.22	3.82
Xseed Condor	3.16	3.12	45.2	45.4	20.5	19.9	4.24	3.92
Xseed Raptor	2.97	3.20	42.8	42.5	20.9	20.2	3.64	3.16
l.s.d. ($P = 0.05$)								
Variety	0.29		0.8		0.8		0.10	
Sowing date	0.07		n.s.		0.2		0.02	
Variety × sowing date	0.41		1.14		1.1		0.14	

$^{\#}$ calculated at 6% moisture content.

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

There were differences in oil concentration between varieties with values ranging from 39% to 45%. Hyola 410XX and Xseed Condor achieved oil contents over 45%. The site average was 42%. Varieties did not differ noticeably in their oil concentration between the two sowing dates (Table 2).

Seed weight differed between both varieties and sowing dates, with SD1 typically having higher thousand seed weights (TSW). Hyola 350TT and Nuseed Diamond sown early had the highest seed weights.

Discussion

Flowering within a defined period for a given location is one of the most important drivers of grain yield potential and grain quality in canola. Understanding a variety's phenology and how that variety responds to temperature influences how the variety will perform in different environments and the correct window in which that variety should be sown.

During canola's leaf production stages, varieties can be influenced by thermal time or vernal time. While winter varieties have a requirement for vernalisation, the spring varieties do have a response to vernal time that influences the accumulated thermal time. Spring varieties differ in the amount of accumulated thermal and vernal time they need before they will switch from the vegetative stage (leaf production) to the reproductive growth stage (bud and flower production).

Thermal time also influences the time taken within the reproductive stage for buds to elongate and initiate flowers. There is no vernalisation requirement within the reproductive stage.

Differences observed in flowering times in 2020 and previous years of similar experiments show that the varieties still have different thermal requirements and respond differently to vernal time accumulated before they will begin flowering. Figure 2 shows that in 2020 at Wagga Wagga both fast and slow developing varieties responded to the cooler than normal autumn days with lower minimum temperatures releasing the 'handbrake' on their vernal time requirement, thereby reducing the amount of thermal time required to switch from the vegetative growth stage to the reproductive growth stage. As a result, from the early sowing date (SD1), these varieties flowered earlier than in previous seasons.

Varieties sown in different environments will change the length of time it takes to begin flowering. In warmer environments, accumulated thermal time will be quicker than for a cooler environment, therefore sowing varieties that have slow phenologies too late will cause them to run into possible moisture stress resulting in a lower yield potential.

While frost was not a major issue in 2020, yield penalties were measured in varieties such as Nuseed Diamond, Hyola 350TT and InVigor T 3510 when sown early (Table 2). Due to these varieties flowering earlier, the developing pods were exposed to a −1.5 °C frost (measured in canopy at −5 °C) in early August. The season in 2020 at Wagga Wagga had a mild finish, with good moisture and no heat stress, which contributed to higher yields from the later sowing date (SD2), even in the slow maturing varieties.

Conclusion

Canola varieties differ in their flowering times depending on where and when they are sown. Understanding how a variety responds to thermal time and photoperiod and therefore knowing a variety's phenology will influence the decision on when to sow a variety to avoid flowering when there is an increased risk of frost, disease or moisture stress.

Matching a variety's phenology to its sowing time is critical for flowering to start during the optimum flowering period for each region, which is when environmental and disease risks are minimised for the highest yield potential. More information on sowing windows to suit variety phenology can be found in NSW DPI's Winter crop variety sowing guide.

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Acknowledgements

This experiment was part of the 'Optimised canola profitability' project, CSP00187, 2014–19. The project was a collaborative partnership between GRDC, NSW DPI, CSIRO and SARDI.

Thank you to Dr Hongtao Xing (NSW DPI, Wagga Wagga) for assistance with data presentation.

Contact

Danielle Malcolm
Wagga Wagga Agricultural Institute, Wagga Wagga
danielle.malcolm@dpi.nsw.gov.au
0429 171 337

Faba bean, narrow-leaf lupin and vetch variety experiments – Rankins Springs 2020

Dr Aaron Preston, Mark Richards and Nelson West
NSW DPI, Wagga Wagga

Key findings

Faba bean

- No establishment or grain yield differences were found between varieties.
- Flowering time differed with PBA Marne$^{\phi}$, PBA Nanu$^{\phi}$ and PBA Nasma$^{\phi}$ flowering first, followed by PBA Samira$^{\phi}$ and PBA Bendoc$^{\phi}$, with PBA Zahra$^{\phi}$ flowering last.

Narrow-leaf lupin

- No establishment differences were found between varieties.
- PBA Bateman$^{\phi}$ was the highest yielding variety.
- PBA Bateman$^{\phi}$ and Mandelup$^{\phi}$ were earliest flowering, followed by PBA Gunyidi$^{\phi}$, PBA Jurien$^{\phi}$ and Wonga$^{\phi}$, with PBA Barlock$^{\phi}$ flowering last.

Vetch

- Timok$^{\phi}$ and Volga$^{\phi}$ were the highest yielding common vetch varieties at Rankins Springs, outperforming Studenica$^{\phi}$ and Morava$^{\phi}$ respectively.
- There were significant flowering time differences between all varieties with Studenica$^{\phi}$ flowering first, followed by Volga$^{\phi}$, Timok$^{\phi}$, and Morava$^{\phi}$ respectively.
- Studenica$^{\phi}$ and Timok$^{\phi}$ were the earliest maturing varieties, followed by Volga$^{\phi}$, and Morava$^{\phi}$ respectively.
- No differences were found in peak dry matter production between varieties.

Introduction

A variety experiment was conducted at Rankins Springs in 2020 to evaluate the phenology and grain yield responses of six faba bean, six narrow-leaf lupin and four vetch varieties. This paper reports the findings of these experiments.

Site details

Location	Rankins Springs
Soil type	Red sandy loam
Previous crop	Wheat
Rainfall	• Fallow (November–March): 181 mm; long-term average (LTA): 168 mm • In-crop (April–October): 285 mm; LTA: 245 mm
Starter fertiliser	80 kg (nitrogen [N]: 0; phosphorus [P]: 15.7; potassium [K]: 0; sulfur [S]: 4.6; calcium [Ca]: 14)
Sowing date	8 May: faba bean, narrow-leaf lupin, vetch

Treatments

Variety

Faba bean

PBA Samira$^{\phi}$, PBA Marne$^{\phi}$, PBA Nanu$^{\phi}$, PBA Bendoc$^{\phi}$, PBA Nasma $^{\phi}$ and PBA Zahra$^{\phi}$

Narrow-leaf lupin

PBA Bateman$^{\phi}$, PBA Jurien$^{\phi}$, PBA Gunyidi$^{\phi}$, PBA Barlock$^{\phi}$, Wonga$^{\phi}$, and Mandelup$^{\phi}$

Vetch

Timok$^{\phi}$, Volga$^{\phi}$, Studenica$^{\phi}$ and Morava$^{\phi}$

Results

Seasonal conditions

In 2020, at Rankins Springs an early break allowed sowing into a good water profile on 8 May. Although rain throughout the growing season was generally below the LTA, it was buoyed by timely and significant rain pre-sowing in April and later in August.

Faba bean

Varietal differences were only significant for the number of days to flowering; all varieties had similar establishment and yield (Table 1). PBA Zahra$^{\phi}$ flowered very late, while PBA Marne$^{\phi}$, PBA Nanu$^{\phi}$ and PBA Nasma$^{\phi}$ flowered very early.

Table 1 Results of faba bean yield evaluation experiment at Rankins Springs, 2020.

Variety	Grain yield (t/ha)	Establishment count (plants/m^2)	Days to flower (days after sowing)
PBA Bendoc	2.77	30.3	98.0
PBA Marne	2.71	33.6	86.7
PBA Nanu	2.58	39.7	86.0
PBA Nasma	2.54	27.2	85.7
PBA Samira	2.54	29.7	98.7
PBA Zahra	2.68	28.9	100.7
Site mean	2.64	31.6	92.6
l.s.d. ($P = 0.05$)	n.s.	n.s.	1.7

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

Narrow-leaf lupin

Significant differences were observed in time to flowering and grain yield in lupin (Table 2). PBA Barlock$^{\phi}$ was the last to flower at 107 days after sowing; PBA Bateman$^{\phi}$ and Mandelup$^{\phi}$ were the earliest to flower at 99 and 100 days after sowing respectively. The early flowering PBA Bateman$^{\phi}$ was the highest yielding variety (2.70 t/ha), while all other varieties were not significantly different.

Vetch

A combination of mild temperatures, few frosts and adequate soil water during the crop's reproductive period were conducive to above average grain yields.

Grain yield was significantly higher for Timok$^{\phi}$ (2.35 t/ha), Volga$^{\phi}$ (2.30 t/ha), and Studenica$^{\phi}$ (2.08 t/ha) compared with Morava$^{\phi}$ (1.72 t/ha) (Table 3). Differences in grain yield between Volga$^{\phi}$ and Studenica$^{\phi}$ were not significant. While dry matter yield for the site was above average (5.80 t/ha), there were no significant differences between commercial varieties.

There were significant differences in days to flower between all commercial varieties. Studenica$^{\phi}$ was first to flower after 102 days, followed by Volga$^{\phi}$, Timok$^{\phi}$, and Morava$^{\phi}$ flowering after 112, 119, and 125 days respectively. Significant differences were also observed in maturity. Studenica$^{\phi}$ and Timok$^{\phi}$

were the earliest to mature, followed by Volga$^{\phi}$. Differences between Timok$^{\phi}$ and Volga$^{\phi}$ were not significant. Morava$^{\phi}$ matured significantly later than all other common vetch varieties.

Table 2 Results of narrow-leaf lupin yield evaluation experiment at Rankins Springs, 2020.

Variety	Grain yield (t/ha)	Establishment count (plants/m^2)	Days to flower (days after sowing)
PBA Bateman	2.70	36.9	99
PBA Jurien	2.45	48.3	103
PBA Barlock	2.38	46.9	107
Mandelup	2.37	47.5	100
PBA Gunyidi	2.35	53.9	103
Wonga	2.34	44.7	104
Site mean	2.43	46.4	103
l.s.d. ($P = 0.05$)	0.24	n.s.	2.9

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

Table 3 Results of vetch yield evaluation experiment at Rankins Springs, 2020.

Variety	Days to flower (days after sowing)	Dry matter (t/ha), 7 Sep 2020	Grain yield (t/ha)	Maturity score*
Timok	119	5.99	2.35	4.0
Volga	112	5.84	2.30	5.7
Studenica	102	5.46	2.08	3.3
Morava	125	5.65	1.72	9.0
Site mean	117	5.80	2.24	6.0
l.s.d. ($P = 0.05$)	3.3	n.s.	0.31	2.0

*Maturity score: 1 = very early, 9 = late.
l.s.d. = least significant difference; n.s. = not significant.

Summary

In 2020, a combination of mild temperatures, few frosts and adequate soil water during the crop's reproductive period were conducive to above average grain yields for all species. Faba bean was harvested on 10 December with a site average grain yield of 2.64 t/ha with no significant difference between faba bean varieties. Lupin was harvested on 11 November with a site average grain yield of 2.43 t/ha; the highest yielding lupin was PBA Bateman$^{\phi}$. Vetch was harvested on 9 November with a site average grain yield of 2.24 t/ha.

Acknowledgements

Thanks to Ollie Owen and Scott Clark for technical assistance.

Contact

Dr Aaron Preston
Wagga Wagga Agricultural Institute, Wagga Wagga
aaron.preston@dpi.nsw.gov.au
0422 135 703

Field pea, narrow-leaf lupin and vetch variety experiments – Wagga Wagga 2020

Dr Aaron Preston, Mark Richards and Nelson West

NSW DPI, Wagga Wagga

Key findings

Field pea

- Grain yields from PBA Butlerᶲ, PBA Wharton, and PBA Ouraᶲ field pea varieties were significantly higher than PBA Percyᶲ and Sturtᶲ.
- PBA Butlerᶲ, PBA Ouraᶲ, and PBA Whartonᶲ ended flowering significantly earlier than PBA Percyᶲ, and Sturtᶲ.
- There were significant differences in flowering duration; PBA Percyᶲ had the longest flowering period, followed by Sturtᶲ, PBA Ouraᶲ, PBA Whartonᶲ, and PBA Butlerᶲ respectively.

Narrow-leaf lupin

- Although lupin grain yields were above average across all varieties, there were no significant differences between varieties.
- Plant establishment rates between varieties were not significant.
- There were significant differences in days to flower with PBA Batemanᶲ, PBA Jurienᶲ, and Mandelupᶲ beginning flowering significantly earlier than PBA Gunyidiᶲ, Wongaᶲ and PBA Barlockᶲ.

Vetch

- Moravaᶲ was the highest yielding common vetch variety, outperforming Volgaᶲ and Timokᶲ. Studenicaᶲ was the lowest yielding variety.
- There were significant flowering time differences between all varieties with Studenicaᶲ flowering first, followed by Volgaᶲ, Timokᶲ, and Moravaᶲ respectively.
- Moravaᶲ ended flowering significantly later than Studenicaᶲ, Volgaᶲ, and Timokᶲ.
- Volga'sᶲ peak dry matter production was significantly higher than Timokᶲ and Studenicaᶲ.

Introduction

A variety experiment was conducted at Wagga Wagga in 2020 at the Wagga Wagga Agricultural Institute to evaluate the phenology and grain yield responses of five field pea, six narrow-leaf lupin and four vetch varieties. This paper reports the findings of these experiments.

Site details

Location	Wagga Wagga Agricultural Institute
Soil type	Clay loam
Previous crop	Wheat
Rainfall	• Fallow (November–March): 192 mm; long-term average (LTA): 198 mm • In-crop (April–October): 345 mm; LTA: 330 mm

Starter fertiliser	80 kg (nitrogen [N]: 0; phosphorus [P]: 15.7; potassium [K]: 0; sulfur [S]: 4.6; calcium [Ca]: 14)
Sowing date	• 11 May: narrow-leaf lupin • 26 May: vetch • 5 June: field pea

Treatments

Variety

Field pea

PBA Butlerᶲ, PBA Whartonᶲ, PBA Ouraᶲ, PBA Percyᶲ and Sturtᶲ

Narrow-leaf lupin

PBA Batemanᶲ, PBA Jurienᶲ, PBA Gunyidiᶲ, PBA Barlockᶲ, Wongaᶲ and Mandelupᶲ

Vetch

Timokᶲ, Volgaᶲ, Studenicaᶲ and Moravaᶲ

Results

Seasonal conditions

Above average rainfall in March and April provided good soil moisture conditions for sowing on 11 May for lupins, 26 May for vetch and 5 June for field peas.

Field pea

Grain yield was significantly higher for PBA Butlerᶲ (3.07 t/ha), PBA Whartonᶲ (3.03 t/ha), and PBA Ouraᶲ (3.01 t/ha) compared with PBA Percyᶲ (2.51 t/ha) and Sturtᶲ (2.31 t/ha) (Table 1).

There were significant differences in days to flower, days to flower end, and flower duration between varieties. PBA Percyᶲ and Sturtᶲ began flowering significantly earlier than the site average of 131 days, flowering after 125 and 128 days respectively. PBA Whartonᶲ (135 days) and PBA Butlerᶲ (137 days) began flowering significantly later than the site average.

PBA Percyᶲ, and Sturtᶲ ended flowering after 170 days, significantly later than PBA Ouraᶲ (168 days), PBA Butlerᶲ and Whartonᶲ (167 days). Varietal differences in days to flower and days to flower end resulted in significant differences in flowering duration between all varieties. PBA Percyᶲ, Sturtᶲ, and PBA Ouraᶲ flowering durations were above the site 37.5 days average.

Table 1 Results of field pea yield evaluation experiment at Wagga Wagga, 2020.

Variety	Establishment (plants/m^2)	Flowering (days from sowing)		Flowering duration (days)	Grain yield (t/ha)
		Start	End		
PBA Butler	50.5	137.0	166.7	29.7	3.07
PBA Oura	46.7	130.0	168.0	38.0	3.01
PBA Percy	53.9	125.0	170.0	45.0	2.51
Sturt	42.4	128.3	170.0	41.7	2.31
PBA Wharton	51.1	135.0	166.7	31.7	3.03
Site mean	46.3	131.1	168.6	37.5	2.85
l.s.d. ($P = 0.05$)	n.s.	0.4	1.19	1.26	0.33

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

Narrow-leaf lupin

Although lupin grain yields were above average across all varieties with a site average of 3.47 t/ha, there were no significant differences between varieties (Table 2). There was uniform plant establishment with a 47.8/plants m^2 site average; no varietal differences were observed.

PBA Bateman$^{\Phi}$, PBA Jurien$^{\Phi}$, and Mandelup$^{\Phi}$ ended flowering significantly earlier than PBA Gunyidi$^{\Phi}$, PBA Barlock$^{\Phi}$ and Wonga$^{\Phi}$. Significant differences in flowering period were observed; Wonga$^{\Phi}$ had the longest followed by PBA Barlock$^{\Phi}$, PBA Bateman$^{\Phi}$, and PBA Gunyidi$^{\Phi}$. PBA Jurien$^{\Phi}$ and Mandelup$^{\Phi}$ had a significantly shorter flowering period than all other varieties.

Table 2 Results of narrow-leaf lupin yield evaluation experiment at Wagga Wagga, 2020.

Variety	Establishment (plants/m^2)	Flowering (days from sowing)		Flowering duration (days)	Grain yield (t/ha)
		Start	End		
PBA Barlock	43.0	119.0	157.0	38.0	3.64
PBA Bateman	45.7	115.3	149.7	34.3	3.35
PBA Gunyidi	51.1	118.0	152.0	34.0	3.53
PBA Jurien	49.3	116.0	149.0	33.0	3.66
Mandelup	49.1	116.3	149.0	32.7	3.24
Wonga	48.7	118.0	158.7	40.7	3.41
Site mean	47.8	117.1	152.6	35.4	3.47
l.s.d. ($P = 0.05$)	n.s.	1.7	0.6	1.6	n.s.

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

Vetch

A combination of mild temperatures, few frosts and adequate soil water during the crop's reproductive period were conducive to above average peak dry matter yields. Late season storms caused lodging in all varieties and pod shattering in the moderately susceptible varieties (Studenica$^{\Phi}$, Volga$^{\Phi}$, and Timok$^{\Phi}$). This led to below average grain yields from the machine harvest on 15 December.

Grain yield was significantly higher for Morava$^{\Phi}$ (1.77 t/ha) than other cultivars (Table 3). This might be due to harvest timing and the cultivar's late maturity and pod shatter resistance. Grain yields were significantly higher for Timok$^{\Phi}$ (1.30 t/ha) and Volga$^{\Phi}$ (1.38 t/ha) when compared with Studenica$^{\Phi}$ (1.09 t/ha).

Peak dry matter yield for Volga$^{\Phi}$ (6.23 t/ha) was significantly higher than Studenica$^{\Phi}$ and Timok$^{\Phi}$, with dry matter yields of 4.85 and 4.87 t/ha respectively. Although the dry matter yield for Morava$^{\Phi}$ (5.89 t/ha) was above the site average of 5.50 t/ha, the differences between Morava$^{\Phi}$, Timok$^{\Phi}$, and Studenica$^{\Phi}$ were not significant.

There were significant differences in days to flower between all varieties. Studenica$^{\Phi}$ was first to flower after 105 days, followed by Volga$^{\Phi}$, Timok$^{\Phi}$, and Morava$^{\Phi}$ (108, 113, and 118 days respectively).

Differences in days to end of flowering were also observed. Volga$^{\Phi}$ and Studenica$^{\Phi}$ ended flowering after 139 days, significantly earlier than other varieties. Timok$^{\Phi}$ ended flowering significantly earlier than Morava$^{\Phi}$ (142 and 149 days respectively). Although the Studenica$^{\Phi}$ flowering period (34 days) was above the 31.7 day site average, varietal differences were not significant.

Plot maturity was assessed on 16 November with Timok$^{\Phi}$ and Studenica$^{\Phi}$ both maturing significantly earlier than Volga$^{\Phi}$. Morava$^{\Phi}$ matured significantly later than all other common vetch varieties.

Table 3 Results of vetch yield evaluation experiment at Wagga Wagga, 2020.

Variety	Flowering (days from sowing)		Flowering duration (days)	Dry matter (t/ha), 29 Sep 2020	Maturity score*	Grain yield (t/ha)
	Start	End				
Timok	113	142	29	4.87	2.0	1.30
Volga	108	139	31	6.23	5.3	1.38
Studenica	105	139	34	4.85	2.3	1.09
Morava	118	149	31	5.89	8.7	1.77
Site mean	110.7	142	31.69	5.50	4.3	1.54
l.s.d. (*P* = 0.05)	2.2	4.0	n.s.	1.22	1.6	0.25

* Maturity score: 1 = very early, 9 = late; l.s.d. = least significant difference; n.s. = not significant.

Summary

In 2020, a combination of mild temperatures, few frosts and adequate soil water during the crops' reproductive period were conducive to above average grain yields for all species. Field pea was harvested on 30 November with a site average grain yield of 2.85 t/ha, lupin was harvested on 11 December with a site average grain yield of 3.47 t/ha and vetch was harvested on 15 December with a site average grain yield of 1.54 t/ha.

Acknowledgements

Thanks to Karl Moore, Nelson West, Ollie Owen and Scott Clark for technical assistance.

Contact

Dr Aaron Preston
Wagga Wagga Agricultural Institute, Wagga Wagga
aaron.preston@dpi.nsw.gov.au
0422 135 703

Chickpea response to sowing date and water treatment – Wagga Wagga, Leeton and Condobolin 2020

Mark Richards[1], Dr Aaron Preston[1], Dr Lance Maphosa[1], Karl Moore[1], Scott Clark[1], Nelson West[1], Tony Napier[2], Daniel Johnston[2], Reuben Burrough[3] and Richard Maccallum[3]

[1] NSW DPI, Wagga Wagga
[2] NSW DPI, Leeton
[3] NSW DPI, Condobolin

Key findings

- Environmental and management conditions such as water availability and sowing date (SD) significantly affected phenological development, grain yield, disease levels and biomass accumulation.
- The highest yields at both Wagga Wagga and Leeton were associated with mid to late sowing (SD2 and SD3), and early sowing (SD1) at Condobolin.
- The highest yields at both Wagga Wagga and Leeton were associated with the dryland treatment; there was a significant yield penalty associated with irrigation due to increased disease incidence (Wagga Wagga) and lodging (Leeton).

Introduction

In central western and southern NSW, frost damage during the vegetative and reproductive phases, in combination with heat and moisture stress later in the season, limits chickpea yield potential. Therefore, to maximise yield, it is important to optimise sowing date and irrigation to ensure that critical growth phases coincide with a period of low abiotic stress risk. This paper reports the findings of field experiments conducted at Wagga Wagga and Leeton (southern NSW), and Condobolin (central western NSW) in 2020, where the phenology and biomass accumulation and yield responses of diverse chickpea varieties were evaluated across three sowing dates from late April to early June (Wagga Wagga and Leeton) and two sowing dates, early May and early June (Condobolin, Figure 1), under dryland conditions, with additional irrigated treatments at Wagga Wagga and Leeton. Site details are summarised in Table 1 and the varieties and sowing dates tested at each site are summarised in Table 2.

Figure 1 Chickpea plots at Condobolin, 5 August 2020.

Table 1 Summary of site conditions and experiment management at Wagga Wagga, Leeton and Condobolin, 2020.

Site	**Wagga Wagga**	**Leeton**	**Condobolin**
Location	Wagga Wagga Agricultural Institute	Leeton Field Station	Condobolin Agricultural Research and Advisory Station
Soil type	Red kandosol	Grey vertosol	Red chromosol
Previous crop	Wheat	Barley	2019 fallow
Rainfall	• Fallow (November–March): 192 mm • Fallow long-term average (LTA): 198 mm • In-crop (April–October): 345 mm • In-crop LTA: 330 mm An additional 56 mm was applied periodically during the season for the irrigated treatment as follows: • 8.1 mm on 21 September • 9.9 mm on 14 October • 13.9 mm on 16 November • 14.1 mm on 22 November.	• Fallow (November–March): 188 mm • Fallow (LTA): 155mm • In-crop (April–October): 260 mm • In-crop LTA: 262 mm An additional 50 mm was applied before sowing on 9 April in order to start the experiment with a full moisture profile. The irrigated treatment further received: • 80 mm on 10 September • 80 mm on 8 October.	• Fallow (November–March): 275 mm • Fallow (LTA): 192 mm • In-crop (April–October): 396 mm • In-crop LTA: 240 mm
Soil nitrogen	• 0–10 cm: 48.9 kg/ha • 10–60 cm: 20.2 kg/ha • 60–120 cm: 8.4 kg/ha	• 0–10 cm: 15.7 kg/ha • 10–60 cm: 31.8 kg/ha • 60–110 cm: 20.2 kg/ha	• 0–10 cm: 44.2 kg/ha • 10–60 cm: 69.0 kg/ha • 60–110 cm: 120.0 kg/ha
Starter fertiliser	Granulock®Z Soygran 100 kg/ha (nitrogen [N]: 5.5; phosphorus [P]: 15.3; potassium [K]: 0.0; sulfur [S]: 7.5)	Utiliser pulse mix 120.0 kg/ha (nitrogen [N]: 7.48; phosphorus [P]: 17.64; potassium [K]: 6.24; calcium [Ca]: 6.4; Zinc [Z]: 0.32; manganese [Mn]: 3.2)	Pasture King (0% nitrogen [N]; 15.7% phosphorus [P]; 0 % potassium [K]; 4.6% sulfur [S]) at 120 kg/ha
Target plant density	45 plants/m^2	45 plants/m^2	45 plants/m^2
Weed management			
Fallow management and pre-sowing knockdown	• Gladiator® CT (450 g/L glyphosate) 2 L/ha + Striker® (240 g/L oxyfluorfen) 100 mL/ha on 24 February • Gladiator® CT (450 g/L glyphosate) 2 L/ha + Triclopyr 600 (600 g/L triclopyr) 80 mL/ha on 11 March • Panzer 450 (450 g/L glyphosate) 2 L/ha + Triclopyr 600 (600 g/L Triclopyr) 80 mL/ha on 14 May • Spray.Seed® 250 (135 g/L paraquat and 115 g/L diquat) 2 L/ha on 27 April • Paraquat 360 (paraquat 360 g/L) 2 L/ha + Genfarm Genwet 1000 250 mL/ha	• Roundup Ultra® Max (570 g/L glyphosate) 3.0 L/ha + Hammer® 400 EC (400 g/L carfentrazone-ethyl) 50 mL/ha on 21 April	• Roundup Ultra® Max (570 g/L glyphosate) 1.5 L/ha + TriflurX (480g/L trifluralin) 1.2 L/ha, cultivator incorporated on 24 April
Pre-emergence (at sowing)	• Treflan™ (480 g/L trifluralin) 1.2 L/ha + Terbyne® Xtreme® (875 g/L terbuthylazine) 900 g/ha	• Rifle® 440 (440 g/L pendimethalin) 2.0 L/ha + Terbyne® Xtreme® (875 g/L terbuthylazine) 1.2 kg/ha + Avadex® Xtra (500 g/L tri-allate) 1.6 L/ha	• Roundup Ultra® Max (570 g/L glyphosate) 1.5 L/ha + Terbyne® Xtreme® (875 g/L terbuthylazine) 1.2 kg/ha

Site	Wagga Wagga	Leeton	Condobolin
Post-emergence	• Verdict® 520 (520 g/L haloxyfop) 75 mL/ha + Platinum® XTRA 360 (360 g/L clethodim) 330 mL/ha + Uptake™ 500 mL/ha on 29 June • Verdict® 520 (520 g/L haloxyfop) 75 mL/ha + Factor® WG (250 g/kg butroxydim) 180 g/ha + Supercharge® 1 L/ha on 3 August	• Verdict® 520 (520 g/L haloxyfop) 100 mL/ha on 25 May for sowing date (SD) one (SD1) • Status® (240 g/L clethodim) 400 mL/ha on 11 June for all sowing dates • Leopard® 200 (200 g/L quizalofop-p-ethyl) 190 mL/ha on 28 June for SD2 and SD3	Nil
Disease management	• Dithane® (750 g/kg mancozeb) 2.2 kg/ha on 30 June • Aviator® Xpro® (150 g/L prothioconazole and 75 g/L bixafen) 650 mL/ha on 4 August • Veritas® (200 g/L tebuconazole and 120 g/L azoxystrobin) 1 L/ha on 15 September • Echo® 900WDG (900 g/kg chlorothalonil) 1.2 kg/ha on 29 September, 9 October, 22 October, 10 November	• Aviator® Xpro® (150 g/L prothioconazole and 75 g/L bixafen) 600 mL/ha on 11 June • Dithane® (750 g/kg mancozeb) 2.2 kg/ha on 3 July and 23 July • Veritas® (200 g/L tebuconazole and 120 g/L azoxystrobin) 1.0 L/ha on 3 August • Cheers® 720 (720 g/L chlorothalonil) 1.8 L/ha on 3 August, 17 August, 4 September, 20 October, 29 October	• Penncozeb® 750DF (750 g/kg mancozeb) 1 kg/ha + 0.1% Bond on 8 July • Aviator® Xpro® (150 g/L prothioconazole and 75 g/L bixafen) 600 mL/ha on 6 August • Dithane® (750 g/kg mancozeb) 2.2 kg/ha on 23 July • Veritas® (200 g/L tebuconazole and 120 g/L azoxystrobin) 1.0 L/ha on 29 September
Pest management	• Lemat® (290 g/L omethoate) 200 mL/ha on 29 May • Chlorpyrifos 500EC (500 g/L chlorpyrifos) 300 mL/ha on 30 June • Astound® (100 g/L alpha-cypermethrin) 200 mL/ha on 17 September • Astound® (100 g/L alpha-cypermethrin) 200 mL/ha on 15 October • Trojan® (150 g/L gamma-cyhalothrin) 35 mL/ha on 19 November	• Decis® options (27.5 g/L deltamethrin) 500 mL/ha on 20 October and 29 October	• Karate Zeon® (250 g/L lambda-cyhalothrin) 36 mL/ha + Aphidex WG (500g/L pirimicarb) 250 g on 14 October
Desiccation	Gramoxone® 250 (250 g/L paraquat) 800 mL/ha on 2 December and 8 December	Nil	Nil

Table 2 Summary of the experiment treatments: variety, sowing date, and water treatment, at Wagga Wagga, Leeton and Condobolin, 2020.

Site	Wagga Wagga	Leeton	Condobolin
Variety	CBA Captain(D) PBA HatTrick(D) PBA Striker(D) PBA Drummond(D)	CBA Captain(D) PBA HatTrick(D) PBA Striker(D) PBA Drummond(D)	CBA Captain(D) PBA HatTrick(D) PBA Striker(D) PBA Drummond(D) PBA Slasher(D) PBA Royal(D) Genesis079 Genesis090
Sowing date (SD)	SD1: 24 April SD2: 15 May SD3: 5 June	SD1: 24 April SD2: 15 May SD3: 5 June	SD1: 8 May SD2: 5 June
Water treatment	Dryland and irrigated	Dryland and irrigated	Dryland only

Results

Seasonal conditions

In 2020, southern and central western NSW growing season rainfall was close to the long-term average. Rainfall, though appearing average across the growing season, was atypical for Wagga Wagga, Leeton and Condobolin with above average rainfall during the pre-sowing period (April) and again in spring (October). This rain pattern prevented significant decline in soil moisture throughout much of the growing season.

Wagga Wagga

Grain yield, biomass and plant phenology

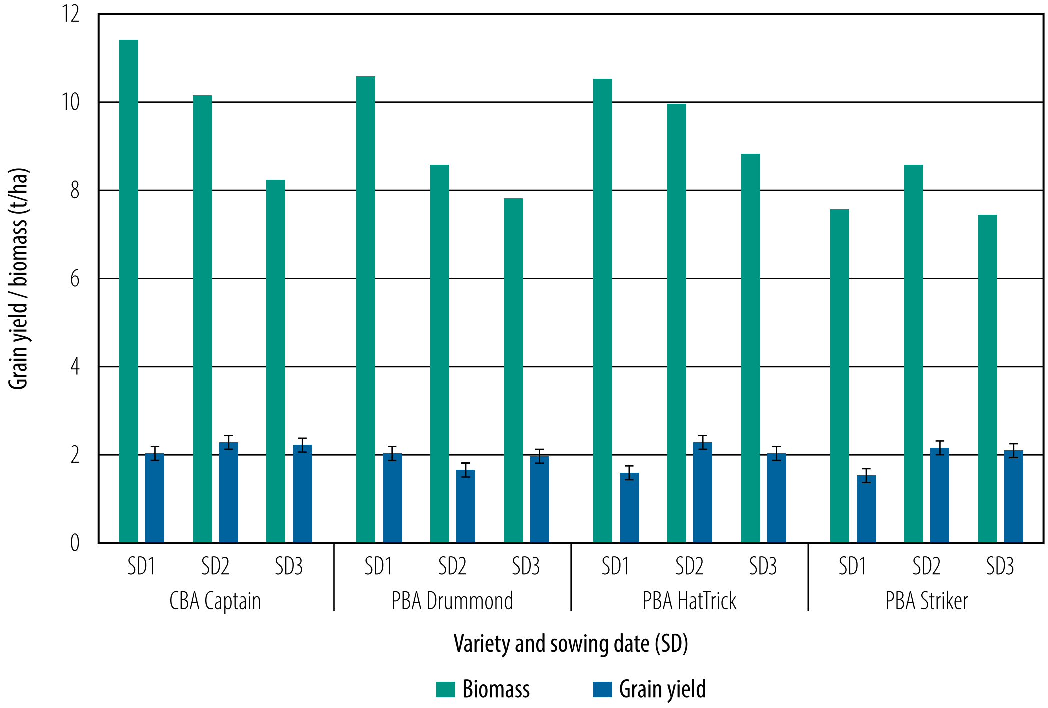
Sowing date, variety and water treatment were the major drivers of phenology, grain yield, biomass accumulation and physiological responses at Wagga Wagga (Table 3; Figure 2). Sowing date influenced all traits, although there were no varietal differences or effect of water treatment on bottom pod height. Grain yield did not differ amongst the four varieties, and water treatment did not affect the total biomass accumulated at harvest. Early sowing resulted in large biomass accumulation but lower grain yield (Figure 2). The dryland experiment yielded higher (2.24 t/ha) than the irrigated experiment (1.72 t/ha). This is likely due to poorer overall plot health in the irrigated plots (results not shown). The high levels of basal sclerotinia, especially in PBA Striker$^{\Phi}$ in SD1 and overall poor health under irrigation decreased the plant density at maturity accounting for reduced grain yield. Early sowing and irrigation resulted in a longer time to the start of flowering. CBA Captain$^{\Phi}$ and PBA Striker$^{\Phi}$ were early flowering, PBA Drummond$^{\Phi}$ was mid flowering, and PBA HatTrick$^{\Phi}$ was late flowering.

Table 3 Performance of four chickpea varieties across three sowing dates and two water treatments at Wagga Wagga, 2020.

	Harvest index cut			Header yield	Plant phenology			
	Biomass (t/ha)	Grain yield (t/ha)	Harvest index (HI)	Grain yield (t/ha)	Days to start of flowering	Plant height (mm)	Bottom pod height (mm)	Top pod height (mm)
Sowing date								
SD 1: 24 April	10.01	1.78	0.18	1.78	142.5	1085.0	688.4	1032.7
SD 2: 15 May	9.32	2.09	0.22	2.02	124.5	994.5	597.4	949.2
SD 3: 5 June	8.08	2.07	0.26	2.27	111.0	908.2	529.3	866.1
P value	<0.001	0.009	<0.001	<0.001	<0.001	<0.001	0.001	<0.001
l.s.d. (*P*<0.05)	0.63	0.21	0.02	0.19	1.8	47.4	77.8	45.6
Variety								
CBA Captain	9.92	2.18	0.22	2.28	124.2	1020.0	588.6	969.7
PBA Drummond	8.98	1.88	0.21	1.98	126.4	–	–	–
PBA HatTrick	9.77	1.95	0.20	1.83	128.5	971.7	621.4	929.0
PBA Striker	7.87	1.92	0.25	2.00	124.9	–	–	–
P value	<0.001	0.117	<0.001	0.001	<0.001	0.015	0.33	0.029
l.s.d. (*P*<0.05)	0.72	n.s.	0.02	0.22	2.1	38.7	n.s.	37.3
Water treatment								
Dryland	9.08	2.24	0.25	2.30	125.1	951.7	582.9	901.0
Irrigated	9.19	1.72	0.19	1.75	126.9	1040.1	627.1	997.7
P value	0.67	<0.001	<0.001	<0.001	0.02	<0.001	0.159	<0.001
l.s.d. (*P*<0.05)	n.s.	0.17	0.01	0.15	1.4	38.8	n.s.	37.0

– = not measured

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



SD1: 24 April SD2: 15 May SD3: 5 June

I Vertical bars represent l.s.d. ($P = 0.05$).

Figure 2 Grain yield and biomass (t/ha) from harvest cuts of four chickpea varieties sown on three dates at Wagga Wagga, 2020.

Leeton

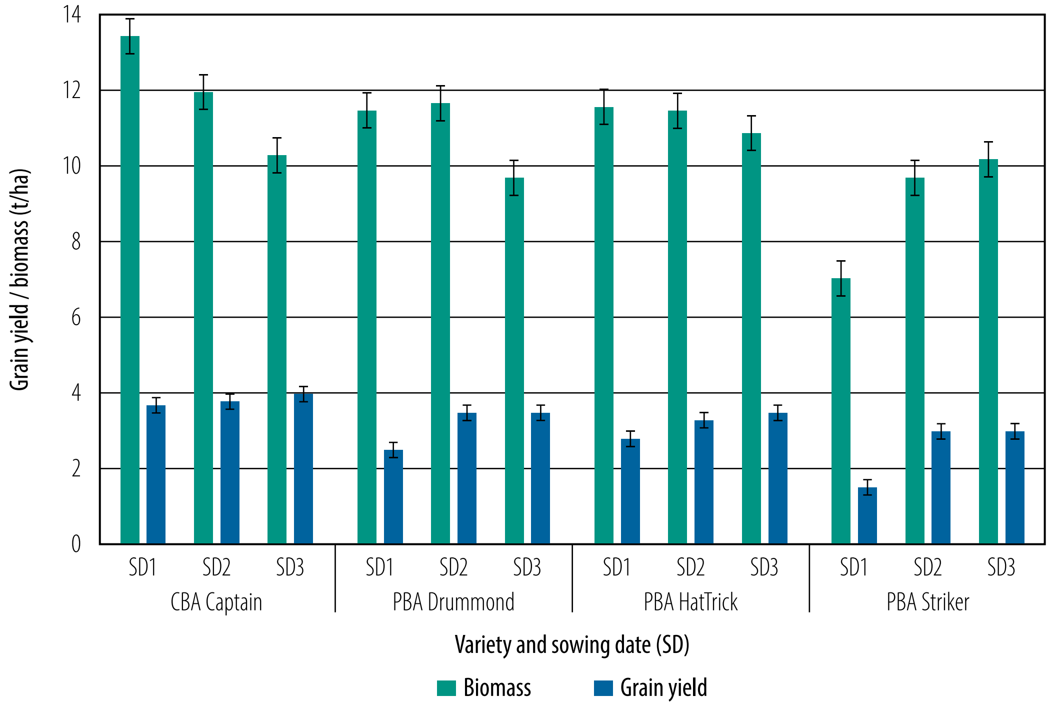
Grain yield, biomass and plant phenology

At Leeton, sowing date, variety and water treatment all affected grain yield, biomass accumulation and physiological responses to varying extents (Table 4; Figure 3). Varietal differences were observed for all the traits except the start of flowering. Early sowing (SD1) resulted in a lower yield (2.68 t/ha) compared with the later sowing dates (SD2 and SD3) under both water treatments (Figure 3). CBA Captain$^{\phi}$ was the highest yielding variety at 3.85 t/ha when averaged across sowing dates. It also had the highest accumulated biomass (11.96 t/ha). A decrease in yield was evident in the header yield between dryland and irrigated treatments, with irrigation reducing yield from 4.10 t/ha to 2.22 t/ha, probably due to increased lodging and disease levels (results not shown).

Table 4 Performance of four chickpea varieties across three sowing dates and two water treatments at Leeton, 2020.

	Harvest index cut			Header yield	Plant phenology
	Biomass (t/ha)	**Grain yield (t/ha)**	**Harvest index (HI)**	**Grain yield (t/ha)**	**Days to flower – from sowing**
Sowing date					
SD 1: 24 April	10.95	2.68	0.24	2.89	141.1
SD 2: 15 May	11.22	3.42	0.31	3.21	127.7
SD 3: 5 June	10.31	3.52	0.36	3.39	109
P value	0.393	0.05	<0.001	0.17	<0.001
l.s.d. (*P*<0.05)	n.s	0.71	0.02	n.s	4.284
Variety					
CBA Captain	11.96	3.85	0.33	3.86	126.1
PBA Drummond	10.98	3.18	0.30	3.35	125.3
PBA HatTrick	11.35	3.24	0.30	3.05	127.1
PBA Striker	9.02	2.56	0.29	2.38	125.2
P value	<0.001	<0.001	<0.001	<0.001	0.771
l.s.d. (*P*<0.05)	0.597	0.268	0.02	0.25	n.s
Water treatment					
Dryland	9.75	3.55	0.37	4.10	125.3
Irrigated	11.90	2.86	0.23	2.22	126.5
P value	<0.001	<0.001	<0.001	<0.001	0.458
l.s.d. (*P*<0.05)	0.47	0.21	0.013	0.20	n.s.

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



SD1: 24 April SD2: 15 May SD3: 5 June

I Vertical bars represent l.s.d. ($P = 0.05$).

Figure 3 Grain yield and biomass (t/ha) from harvest cuts of four chickpea varieties sown on three dates at Leeton, 2020.

Condobolin

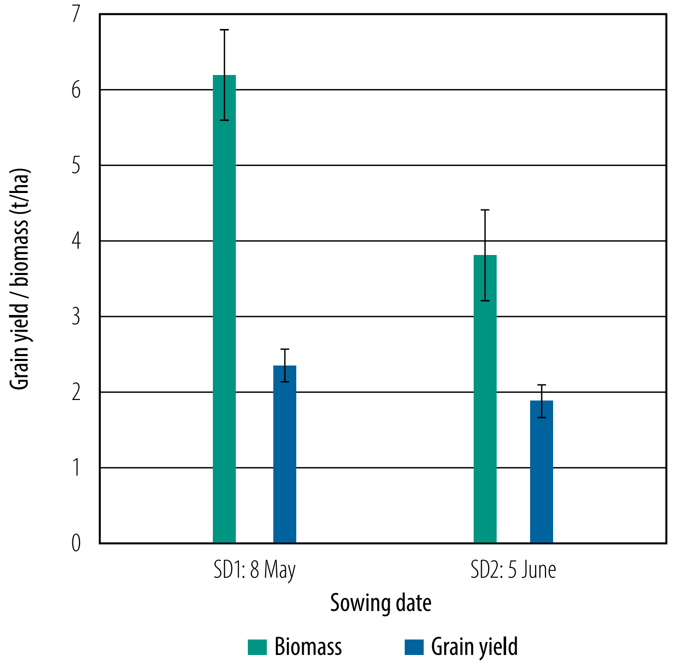
Grain yield and biomass

At Condobolin, sowing date affected all traits (Table 5). There was a decrease in grain yield and biomass accumulation as sowing was delayed (Figure 4). Early sowing (SD1) increased grain yield from 1.90 t/ha to 2.34 t/ha, while biomass increased from 3.81 t/ha to 6.18 t/ha (Table 5). However, harvest index was higher at the later sowing date (SD2), increasing from 0.37 to 0.46 (Table 5). There were no varietal differences in the measured traits.

Table 5 Performance of eight chickpea varieties across two sowing dates at Condobolin, 2020.

	Grain yield (t/ha)	Harvest index	Biomass (t/ha)
Sowing date			
SD 1: 8 May	2.34	0.37	6.18
SD 2: 5 June	1.90	0.46	3.81
P value	<0.001	<0.001	<0.001
l.s.d. (*P*<0.05)	0.21	0.03	0.59
Variety			
CBA Captain	2.40	0.39	5.60
Genesis079	2.13	0.47	4.68
Genesis090	1.80	0.43	4.10
PBA Drummond	2.10	0.42	5.44
PBA HatTrick	2.21	0.40	5.50
PBA Royal	2.00	0.42	4.59
PBA Slasher	2.25	0.40	4.89
PBA Striker	2.09	0.42	5.17
P value	0.296	0.10	0.148
l.s.d. (*P*<0.05)	n.s.	n.s.	n.s.

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



Ⳁ Vertical bars represent l.s.d. ($P = 0.05$).

Figure 4 Grain yield and biomass (t/ha) from harvest cuts from chickpea sown on two dates at Condobolin, 2020.

Summary

In 2020, seasonal conditions significantly influenced grain yield responses to sowing date and water treatment at Wagga Wagga and Leeton, and Condobolin (dryland only). Sowing date significantly affected grain yield responses with the lowest yields at Wagga Wagga and Leeton associated with the April sowing (SD1) and with the June sowing (SD2) at Condobolin.

High levels of sclerotinia infection were observed in the late April sowing (SD1) at Wagga Wagga with lower incidence as sowing was delayed. At both Wagga Wagga and Leeton, which had an irrigation treatment, the highest yields were in the dryland treatment; there was a significant yield penalty associated with irrigation due to increased disease incidence (lodging at Leeton). Irrigation, in a wet year (2020) with close to average rainfall did not offer any production advantage and in fact decreased grain yield. Therefore, the rainfall received was enough to maximise yield without the need for additional irrigation water. Atypical rainfall, low heat and minimal frost stress lengthened the growing season, allowing later sowing dates to produce higher yields and minimise yield penalties.

Acknowledgements

This experiment was part of the 'Matching adapted pulse genotypes with soil and climate to maximise yield and profit, with manageable risk in Australian cropping systems' project, BLG118, 2020–22, a joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

Thanks to Daryl Reardon, NSW DPI Condobolin for technical assistance.

Contact

Mark Richards
Wagga Wagga Agricultural Institute, Wagga Wagga
mark.richards@dpi.nsw.gov.au
0428 630 429

Lentil response to sowing date and water treatment – Wagga Wagga, Leeton and Condobolin 2020

Mark Richards[1], Dr Aaron Preston[1], Dr Lance Maphosa[1], Karl Moore[1], Scott Clark[1], Nelson West[1], Tony Napier[2], Daniel Johnston[2], Reuben Burrough[3] and Richard Maccallum[3]

[1] NSW DPI, Wagga Wagga
[2] NSW DPI, Leeton
[3] NSW DPI, Condobolin

Key findings

- Sowing date and water availability significantly affected grain yield responses.
- The highest yields at Wagga Wagga were associated with the early June sowing date; there was no significant difference in yield between sowing dates at Leeton or Condobolin.
- The highest yields at Wagga Wagga were obtained in the dryland treatment; there was a significant yield penalty associated with irrigation due to increased disease.
- Atypical rainfall, low heat and no frost stress lengthened the growing season, allowing later sowing dates to yield higher (or remove the yield penalty).

Introduction

In central western and southern NSW, abiotic stresses such as heat and moisture stress late in the season and frost damage during the vegetative and reproductive phases limit lentil yield potential. To maximise yield, it is important to optimise sowing date to ensure that critical growth phases coincide with a period of low abiotic stress risk. This paper reports the findings of field experiments conducted at Wagga Wagga and Leeton (both southern NSW), and Condobolin (central western NSW) in 2020, where lentil variety yield responses were evaluated across three sowing dates from late April to early June (Wagga Wagga, Figure 1, and Leeton) and two sowing dates, early May and early June (Condobolin), under dryland conditions, with an additional irrigated treatment at Wagga Wagga. Table 1 summarises site details and Table 2 summarises the varieties and sowing dates tested at each location.

Figure 1 Lentil plots at Wagga Wagga, 21 July 2020.

Table 1 Summary of site conditions and experiment management at Wagga Wagga, Leeton and Condobolin, 2020.

Site	**Wagga Wagga**	**Leeton**	**Condobolin**
Location	Wagga Wagga Agricultural Institute	Leeton Field Station	Condobolin Agricultural Research and Advisory Station
Soil type	Red kandosol	Grey vertosol	Red chromosol
Previous crop	Wheat	Barley	2019 fallow
Rainfall	• Fallow (November–March): 192 mm • Fallow long-term average (LTA): 198 mm • In-crop (April–October): 345 mm • In-crop LTA: 330 mm An additional 56 mm was applied periodically during the season for the irrigated treatment as follows: • 8.1 mm on 21 September • 9.9 mm on 14 October • 13.9 mm on 16 November • 14.1 mm on 22 November.	• Fallow (November–March): 188 mm • Fallow long-term average (LTA): 155 mm • In-crop (April–October): 260 mm • In-crop LTA: 262 mm Approximately 200 mm was applied before sowing in order to start the experiment with a full moisture profile.	• Fallow (November–March): 275 mm • Fallow long-term average (LTA): 192 mm • In-crop (April–October): 396 mm • In-crop LTA: 240 mm
Soil nitrogen	• 0–10 cm: 48.9 kg/ha • 10–60 cm: 20.2 kg/ha • 60–120 cm: 8.4 kg/ha	• 0–10 cm: 14.7 kg/ha • 10–60 cm: 112.0 kg/ha • 60–120 cm: 57.1 kg/ha	• 0–10 cm: 44.2 kg/ha • 10–60 cm: 69.0 kg/ha • 60–110 cm: 120.0 kg/ha
Starter fertiliser	Granulock®Z Soygran 100 kg/ha (nitrogen [N]: 5.5; phosphorus [P]: 15.3; potassium [K]: 0.0; sulfur [S]: 7.5)	Utiliser pulse mix 120.0 kg/ha (nitrogen [N]: 7.48; phosphorus [P]: 17.64; potassium [K]: 6.24; calcium [Ca]: 6.4; zinc [Z]: 0.32; manganese [Mn]: 3.2)	70 kg/ha mono-ammonium phosphate (MAP)
Target plant density	120 plants/m^2	120 plants/m^2	120 plants/m^2
Weed management			
Fallow management and pre-sowing knockdown	• Gladiator® CT (450 g/L glyphosate) 2 L/ha + Striker® (240 g/L oxyfluorfen) 100 mL/ha on 24 February • Gladiator® CT (450 g/L glyphosate) 2 L/ha + Triclopyr 600 (600 g/L triclopyr) 80 mL/ha on 11 March • Panzer 450 (450 g/L glyphosate) 2 L/ha + Triclopyr 600 (600 g/L triclopyr) 80 mL/ha on 14 May • Spray.Seed® 250 (135 g/L paraquat and 115 g/L diquat) 2 L/ha on 27 April • Paraquat 360 (360 g/L paraquat) 2 L/ha + Genfarm Genwet 1000 250 mL/ha	• Roundup Ultra® Max (570 g/L glyphosate) 3.0 L/ha + Hammer® 400 EC (400 g/L carfentrazone-ethyl) 50 mL/ha on 21 April	Nil
Pre-emergence (at sowing)	• Treflan™ (480 g/L trifluralin) 1.2 L/ha + Terbyne® Xtreme® (875 g/L terbuthylazine) 900 g/ha	• Rifle® 440 (440 g/L pendimethalin) 2.0 L/ha + Terbyne® Xtreme® (875 g/L terbuthylazine) 1.2 kg/ha + Avadex® Xtra (500 g/L tri-allate) 1.6 L/ha	• Triflur X (480 g/L trifluralin) 1.2 L/ha on 24 April (pre-sowing) • Roundup Ultra Max (570 g/L glyphosate) 1.5 L/ha + Terbyne® Xtreme® (875 g/kg) 1.2 kg/ha

Site	Wagga Wagga	Leeton	Condobolin
Post-emergence	• Verdict® 520 (520 g/L haloxyfop) 75 mL/ha + Platinum® XTRA 360 (360 g/L clethodim) 330 mL/ha + Uptake™ 500 mL/ha on 29 June • Verdict® 520 (520 g/L haloxyfop) 75 mL/ha + Factor® WG (250 g/kg butroxydim) 180 g/ha + Supercharge® 1 L/ha on 3 August	• Rifle® 440 (440 g/L pendimethalin) 2.0 L/ha + Terbyne® Xtreme® (875 g/L terbuthylazine) 1.2 kg/ha +Avadex® Xtra (500 g/L tri-allate) 1.6 L/ha	Nil
Disease management	• Dithane® (750 g/kg mancozeb) 2.2 kg/ha on 30 June • Aviator® Xpro® (150 g/L prothioconazole and 75 g/L bixafen) 650 mL/ha on 4 August • Veritas® (200 g/L tebuconazole and 120 g/L azoxystrobin) 1 L/ha on 15 September • Echo® 900WDG (900 g/kg chlorothalonil) 1.2 kg/ha on 29 September, 9 October, 22 October, 10 November	• Aviator® Xpro® (150 g/L prothioconazole and 75 g/L bixafen) 600 mL/ha on 11 June • Dithane® (750 g/kg mancozeb) 2.2 kg/ha on 3 July and 23 July • Veritas® (200 g/L tebuconazole and 120 g/L azoxystrobin) 1.0 L/ha on 3 August • Cheers® 720 (720 g/L chlorothalonil) 1.8 L/ha on 3 August, 17 August, 4 September, 20 October, 29 October	• Penncozeb® 750DF (750 g/kg mancozeb) 1 kg/ha + 0.1% Bond on 8 July • Aviator® Xpro® (150 g/L prothioconazole and 75 g/L bixafen) 600 mL/ha on 6 August • Veritas® (200 g/L tebuconazole and 120 g/L azoxystrobin) 1.0 L/ha on 29 September
Pest management	• Lemat® (290 g/L omethoate) 200 mL/ha on 29 May • Chlorpyrifos 500EC (500 g/L chlorpyrifos) 300 mL/ha on 30 June • Astound® (100 g/L alpha-cypermethrin) 200 mL/ha on 17 September • Astound® (100 g/L alpha-cypermethrin) 200 mL/ha on 15 October • Trojan® (150 g/L gamma-cyhalothrin) 35 mL/ha on 19 November	• Decis® options (27.5 g/L deltamethrin) 500 mL/ha on 20 October and 29 October	• Karate Zeon® (250 g/L lambda-cyhalothrin) 36 mL/ha + Aphidex® WG (500 g/L pirimicarb) 250 g on 14 October
Desiccation	• Gramoxone® (250 g/L paraquat) 800mL/ha on 2 December and 8 December	Nil	Nil

Table 2 Summary of the experiment treatments: variety, sowing date, and water treatment at Wagga Wagga, Leeton and Condobolin, 2020.

Site	Wagga Wagga – WWAI	Leeton – LFS	Condobolin – CARAS
Variety	PBA Hallmark XTᶲ PBA Jumbo2ᶲ PBA Boltᶲ PBA Kelpie XTᶲ	PBA Hallmark XTᶲ PBA Jumbo2ᶲ PBA Boltᶲ PBA Kelpie XTᶲ	PBA Highland XTᶲ PBA Hallmark XTᶲ PBA Jumbo2ᶲ PBA Blitzᶲ PBA Aceᶲ PBA Greenfieldᶲ PBA Boltᶲ PBA Kelpie XTᶲ
Sowing date (SD)	SD1: 24 April SD2: 15 May SD3: 5 June	SD1: 24 April SD2: 15 May SD3: 5 June	SD1: 8 May SD2: 5 June
Water treatment	Dryland and irrigated	Dryland only	Dryland only

Note: PBA Kelpie XTᶲ previously known as CIPAL1721.

Results

Seasonal conditions

In 2020, southern and central western NSW growing season rainfall was close to the long-term average. Rainfall, though appearing average across the growing season, was atypical for Wagga Wagga, Leeton and Condobolin with above average rainfall during the pre-sowing period (April) and again in spring (October), and less than average rainfall between these periods. This rain pattern prevented significant decline in soil moisture throughout much of the growing season.

Wagga Wagga

Grain yield, biomass and plant phenology

Sowing date, variety and water treatment all influenced grain yield and harvest index at Wagga Wagga (Table 3). Generally, earlier sowing reduced grain yield and harvest index as did irrigation.

Lentils sown on SD3 (5 June) had the highest grain yield in the experiment, although this is uncharacteristic for this environment, which generally favours mid May sowing (Richards et al. 2020). PBA Kelpie XT$^{\phi}$ was the highest yielding variety (2.84 t/ha) across all sowing dates, with no significant difference between PBA Bolt$^{\phi}$, PBA Hallmark XT$^{\phi}$, PBA Jumbo2$^{\phi}$.

Maximum biomass (9.06 t/ha) occurred with lentil sown on SD2 (15 May), with SD1 and SD3 producing significantly less biomass (7.57 and 7.89 t/ha respectively). No differences in the amount of biomass produced was detected between varieties and adding the water treatment only served to reduce the biomass produced across all sowing dates. Irrigation increased the severity of disease (botrytis grey mould), which ultimately reduced the biomass and yield produced. Additionally, early sowing facilitated virus infection and spread by aphids.

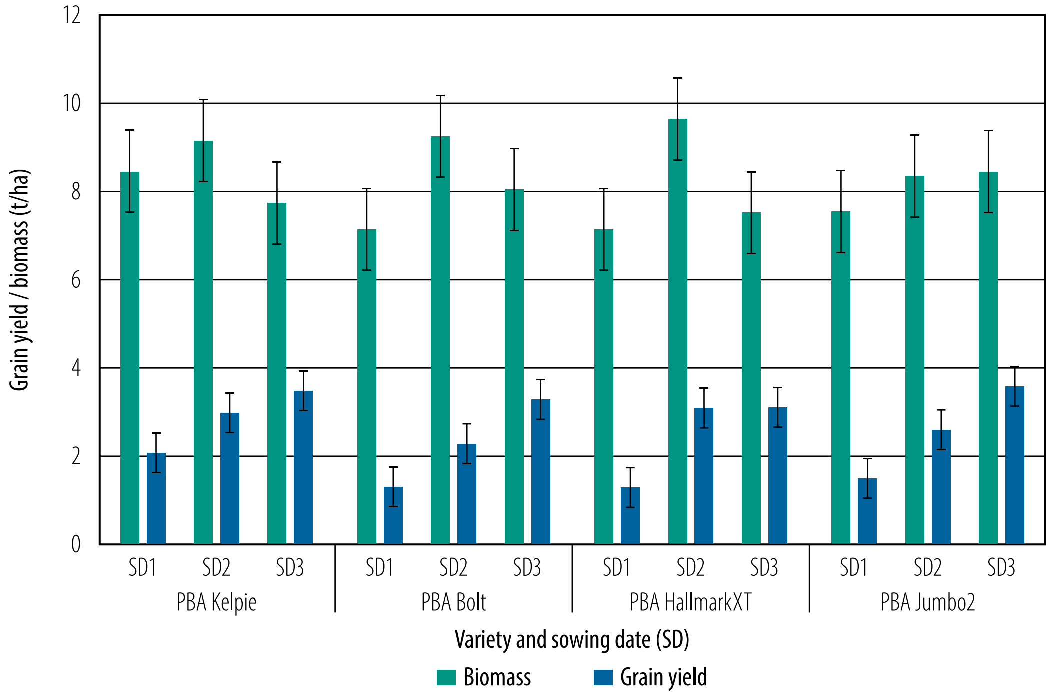
Table 3 Summary of means of each treatment for yield from biomass cuts taken at harvest, header yield, start of flowering, plant height, top and bottom pod height at Wagga Wagga, 2020.

	Harvest index cut			Header yield	Plant phenology			
	Biomass (t/ha)	**Grain yield (t/ha)**	**Harvest index (HI)**	**Grain yield (t/ha)**	**Start of flowering**	**Plant height (mm)**	**Bottom pod height (mm)**	**Top pod height (mm)**
Sowing date								
SD 1: 24 April	7.57	1.51	0.19	1.02	3 Sept	640.00	27.90	64.31
SD 2: 15 May	9.06	2.72	0.30	1.94	16 Sept	522.65	25.15	53.88
SD 3: 5 June	7.89	3.34	0.42	2.91	21 Sept	464.03	20.62	47.21
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	<0.001
l.s.d. (*P*<0.05)	0.430	0.220	0.020	0.150	2.740	44.194	4.013	3.965
Variety								
PBA Kelpie XT	8.42	2.84	0.34	2.02	9 Sept	n.c.	n.c.	n.c.
PBA Bolt	8.13	2.26	0.27	1.63	12 Sept	566.25	22.40	55.04
PBA Hallmark XT	8.07	2.47	0.30	1.93	16 Sept	n.c.	n.c.	n.c.
PBA Jumbo2	8.08	2.52	0.30	2.25	16 Sept	518.20	26.71	55.23
P value	0.628	0.002	<0.001	<0.001	<0.001	0.015	0.023	0.978
l.s.d. (*P*<0.05)	n.s.	0.263	0.024	0.169	3.167	35.42	3.24	n.s.
Water treatment								
Dryland	8.63	2.87	0.33	2.22	14 Sept	555.65	25.33	55.39
Irrigated	7.72	2.17	0.28	1.70	13 Sept	528.80	23.78	54.88
P value	<0.001	<0.001	<0.001	<0.001	0.292	0.12	0.32	0.79
l.s.d. (*P*<0.05)	0.35	0.18	0.02	0.12	n.s.	n.s.	n.s.	n.s.

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

Variety × sowing date interactions were observed for biomass and grain yield with delayed sowing increasing yield for all varieties (Figure 2). As with the sowing date mean trend, biomass generally peaked for all varieties at SD2.

Delayed sowing also delayed the start of flowering (Table 3), with varieties performing as expected; PBA Kelpie XT$^{\phi}$ and PBA Bolt$^{\phi}$ flowered earlier than PBA Hallmark XT$^{\phi}$ and PBA Jumbo2$^{\phi}$. Given bottom pod height is an important factor affecting harvest efficiency, SD 3 (5 June) had a significantly lower bottom pod height of 20.62 cm compared to SD1 and SD2 (27.9 and 25.15 respectively). Only PBA Bolt$^{\phi}$ and PBA Jumbo2$^{\phi}$ were measured at maturity for height, and although PBA Bolt$^{\phi}$ was significantly taller than PBA Jumbo2$^{\phi}$, PBA Jumbo2$^{\phi}$ had a higher bottom pod height (22.4 mm and 26.7 mm respectively).



SD1: 24 April SD2: 15 May SD3: 5 June

Vertical bars represent l.s.d. ($P = 0.05$).

Figure 2 Grain yield and biomass (t/ha) from harvest cuts of four lentil varieties sown on three dates at Wagga Wagga, 2020.

Leeton

Grain yield and biomass

At Leeton, greater biomass was associated with earlier sowing (SD1 and SD2) with no differences between varieties (Table 4). Sowing date did not affect grain yield however, although varietal differences were detected with PBA Hallmark XT$^{\phi}$ yielding lower than all other varieties. No interaction was found between sowing date × variety for biomass, however, interactions were evident for yield (Figure 3). SD1 and PBA Jumbo2$^{\phi}$ was the highest yielding combination (4.42 t/ha), with SD3 and PBA Hallmark XT$^{\phi}$ the lowest (3.04 t/ha).

Table 4 Summary of means of each treatment for yield from biomass cuts taken at harvest and header yield at Leeton, 2020.

	Harvest index cut			Header yield
	Biomass (t/ha)	**Grain yield (t/ha)**	**Harvest index (HI)**	**Grain yield (t/ha)**
Sowing date				
SD 1: 24 April	9.59	3.82	0.40	2.80
SD 2: 15 May	9.14	3.50	0.39	2.73
SD 3: 5 June	8.79	3.73	0.43	3.10
P value	<0.001	n.s.	<0.001	0.002
l.s.d. (*P*<0.05)	0.645		0.02	0.204
Variety				
PBA Bolt	9.53	3.70	0.39	3.10
PBA Hallmark XT	9.09	3.34	0.37	2.84
PBA Kelpie XT	8.73	3.73	0.43	2.67
PBA Jumbo2	9.33	3.96	0.43	2.90
P value	n.s.	0.009	0.002	0.019
l.s.d. (*P*<0.05)		0.47	0.03	0.47

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

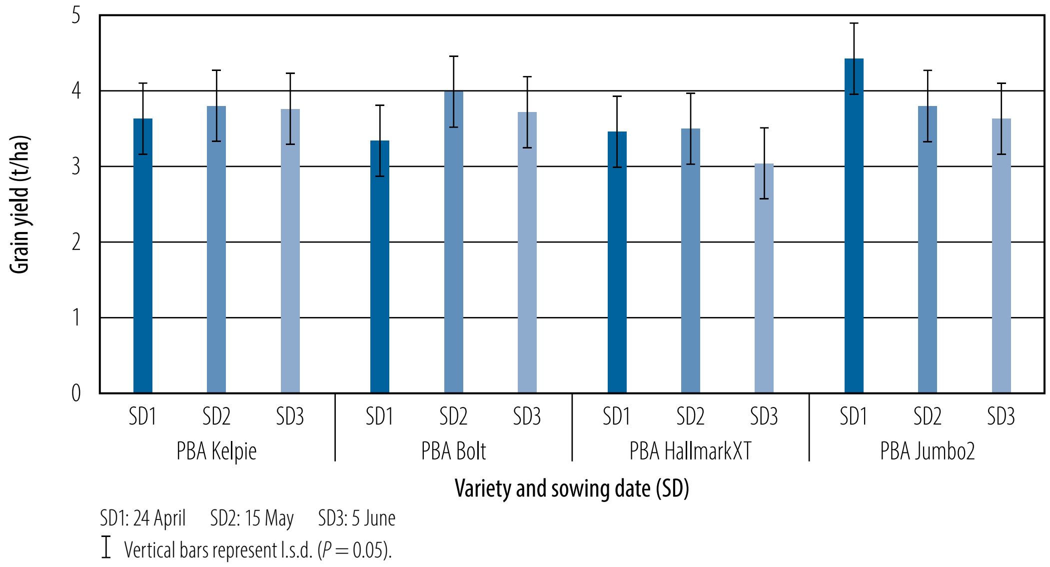


Figure 3 Grain yield from harvest cuts of four lentil varieties sown on three dates at Leeton, 2020.

Condobolin

Grain yield and biomass

At Condobolin, greater biomass was associated with the earlier sowing date (SD1) with significant differences between the varieties, mostly due to low biomass in PBA Blitz$^{\Phi}$ (Table 5). However, sowing date did not affect grain yield, nor were any varietal differences detected. No interaction was found between sowing date × variety for biomass or yield.

Table 5 Performance of four lentil varieties across two sowing dates at Condobolin, 2020.

	Harvest index cut			Header yield
	Biomass (t/ha)	Grain yield (t/ha)	Harvest index (HI)	Grain yield (t/ha)
Sowing date				
SD 1: 8 May	3.03	1.36	0.45	0.54
SD 2: 5 June	2.43	1.22	0.50	0.57
P value	<0.001	n.s.	<0.001	n.s.
l.s.d. (P<0.05)	0.034		0.029	
Variety				
PBA Kelpie XT	2.89	1.48	0.51	0.61
PBA Bolt	2.60	1.19	0.47	0.60
PBA Hallmark XT	3.02	1.50	0.50	0.68
PBA Jumbo2	2.89	1.35	0.47	0.63
PBA Blitz	2.10	1.08	0.51	0.28
PBA Greenfield	2.42	1.10	0.44	0.35
PBA Highland XT	2.90	1.24	0.46	0.71
PBA Ace	3.05	1.41	0.46	0.61
P value	0.027	n.s.	n.s.	<0.001
l.s.d. (*P*<0.05)	0.579			0.141

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

Summary

In 2020, seasonal conditions significantly influenced grain yield responses to sowing date at Wagga Wagga, Leeton and Condobolin. Irrigation at Wagga Wagga in a wet year (2020) with above average rainfall increased viral disease incidence and decreased overall plant health, ultimately decreasing grain yield. The decrease was more pronounced for the early sowing date (SD1). Rainfall in 2020 was sufficient to maximise yield without additional irrigation water and associated complications in the form of increased disease severity.

Reference

Richards M, Preston A, Maphosa L, Maheswaran R, Moore K, Clark S, Johnston D, Burrough R and Napier T 2020. Lentil phenology and grain yield response to sowing date – Wagga Wagga and Leeton 2019; D Slinger, T Moore and C Martin (eds), *Southern NSW research results 2020*, pp. 51–58, NSW Department of Primary Industries.

Acknowledgements

This experiment was part of the 'Matching adapted pulse genotypes with soil and climate to maximise yield and profit, with manageable risk in Australian cropping systems' project, BLG118, 2020–22, a joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

Thanks to Daryl Reardon, NSW DPI Condobolin for technical assistance.

Contact

Mark Richards
Wagga Wagga Agricultural Institute, Wagga Wagga
mark.richards@dpi.nsw.gov.au
0428 630 429

The effect of sowing date and irrigation management on faba bean – Leeton 2020

Tony Napier[1], Daniel Johnston[1], Mark Richards[2], Dr Aaron Preston[2] and Dr Lance Maphosa[2]

[1] NSW DPI, Yanco

[2] NSW DPI, Wagga Wagga

Key findings

- Irrigating faba bean on a border check layout significantly increased grain yield for all sowing dates (24 April, 15 May and 5 June).
- Sowing date affected grain yield under both irrigated and non-irrigated treatments. Delayed sowing after 24 April resulted in reduced grain yields for both dryland and irrigated treatments.
- An irrigation efficiency of 1.51 t/ML was achieved with faba bean when sown on 24 April. Any delay in sowing after 24 April resulted in reduced irrigation efficiency.
- Sowing on 24 April resulted in a header yield of 6.86 t/ha averaged across all varieties when irrigated.
- In the irrigated treatment, PBA Nasma$^{\phi}$ achieved the highest grain yield of 5.73 t/ha when averaged across sowing dates.

Introduction

To maximise faba bean productivity and yield, it is important to optimise sowing time and amount of irrigation water applied. Faba bean is affected by a range of abiotic stresses such as moisture stress and extreme temperatures (low and high). An irrigated faba bean experiment was established at Leeton Field Station in 2020 to determine the effect of sowing time and irrigation on four varieties of faba bean in southern NSW. This paper reports the findings from this experiment.

Site details

Location	Leeton Field Station
Soil type	Grey vertosol
Previous crop	2019 Barley
Rainfall	• Non-irrigated (1 May to 15 October): 115 mm • Irrigated (1 May to 30 October): 144 mm
Starter fertiliser	120 kg/ha Utiliser pulse mix (nitrogen [N]: 7.48, phosphorus [P]: 17.64, potassium [K]: 6.24, calcium [Ca]: 6 4, zinc [Z]: 0.32)
Herbicides	• 2.0 L/ha Rifle® 440 (440 g/L pendimethalin) • 1.2 kg/ha Terbyne® Xtreme (875 g/L terbuthylazine) • 1.6 L/ha Avadex® Xtra (500 g/L tri-allate) • 0.1 L/ha Verdict® 520 (520 g/L haloxyfop), first sowing date only • 0.4 L/ha Status® (240 g/L clethodim), all sowing dates

	• 0.19 mL/ha Leopard® (200 g/L quizalofop-p-ethyl), second and third sowing date only
Fungicide	• 600 mL/ha Aviator® Xpro® (150 g/L prothioconazole and 75 g/L bixafen) • 1.0 L/ha Veritas® (200 g/L tebuconazole and 120 g/L azoxystrobin) • 2.2 kg/ha Dithane® (750 g/kg mancozeb), 3 July and 23 July • 1.8 L/ha Cheers® 720 (720 g/L chlorothalonil), 17 August, 4 September, 20 October and 29 October
Harvest dates	• Hand harvest, 23 October to 17 November 2020 • All plots were machine harvested on 7 December 2020

Treatments

The experiment included four varieties (Table 1) replicated three times, on three sowing dates (Table 2) and with two irrigation treatments (Table 3).

Table 1 Varieties evaluated in the Leeton Field Station faba bean experiment, 2020.

Variety	Comment
PBA Bendoc$^{(D)}$	Released in 2018 and is the first faba bean variety with tolerance to imidazolinone herbicides
PBA Marne$^{(D)}$	Shorter season variety released in 2018 and recommended for lower rainfall areas
PBA Nasma$^{(D)}$	Large seed variety released in 2015 and recommended for northern NSW
PBA Samira$^{(D)}$	Mid-season variety released in 2014 and recommended for southern NSW

Table 2 Sowing dates evaluated in the Leeton Field Station faba bean experiment, 2020.

Sowing date (SD)	Comment
SD1: 24 April 2020	Earlier than recommended sowing window (irrigated)
SD2: 15 May 2020	Late in recommended sowing window (irrigated)
SD3: 5 June 2020	Later than recommended sowing window

Table 3 Irrigation treatments evaluated in the Leeton Field Station faba bean experiment, 2020.

Irrigation treatment	Irrigation applications
Irrigated	Two spring irrigations applied 10 September and 8 October
Non-irrigated	No spring irrigations applied

Experiment details

The experiment was a split-split plot design with water treatment as main plots, sowing date as subplots and varieties randomised within the subplots.

The whole paddock was pre-irrigated 15 days before the first sowing date to provide a full moisture profile across all plots. The irrigated treatments received a total of 355 mm (including rainfall and irrigation) while the non-irrigated treatments received a total of 165 mm (Table 4). All trial plots were 1.5 m wide (six rows at 250 mm row spacing) and 10 m long with a 500 mm wide empty buffer between rows.

Table 4 Rainfall and irrigation totals for the Leeton Field Station faba bean experiment, 2020.

	Irrigated treatments	Non-irrigated treatments
Pre-irrigation	50 mm (0.50 ML)	50 mm (0.50 ML)
In-season rainfall	144 mm (1.44 ML)	115 mm (1.15 ML)
10 September irrigation	80 mm (0.80 ML)	0 mm
8 October irrigation	80 mm (0.80 ML)	0 mm
Total	354 mm (3.54 ML)	165 mm (1.65 ML)

The in-season rainfall was higher in the irrigated treatments due to the growing season being approximately two weeks longer.

Assessments

At physiological maturity, 2 m^2 biomass cuts were collected to determine hand yield. Total biomass, harvest index and 1000 grain weights were measured and calculated from the 2 m^2 biomass samples. The header yield was collected from the remainder of the plots at harvest maturity.

Results

Grain yield

The header grain yield averaged 4.44 t/ha across all variety, sowing date and irrigation treatments. PBA Nasma$^{\Phi}$ was the highest yielding variety (4.82 t/ha) and PBA Bendoc$^{\Phi}$ had the lowest header yield (4.04 t/ha) (Table 5). A consistent trend was observed in the hand yields with PBA Nasma$^{\Phi}$ as the highest yielding variety (6.25 t/ha) and PBA Bendoc$^{\Phi}$ as the lowest yielding variety (5.45 t/ha). Hand cuts, although not representative of likely achievable yields in a header, demonstrated the maximum potential yield.

Table 5 Variety results averaged across all sowing dates and irrigation treatments in the Leeton Field Station faba bean experiment, 2020.

Variety	Machine yield (t/ha)	Hand yield (t/ha)	Total biomass (t/ha)	Harvest index	Grain weight (g/1000 grains)
PBA Nasma	4.82	6.25	12.82	0.49	744.3
PBA Marne	4.50	5.78	11.35	0.51	693.4
PBA Samira	4.40	5.76	12.42	0.47	732.5
PBA Bendoc	4.04	5.45	11.51	0.48	604.6
Average	4.44	5.81	12.03	0.49	693.7
l.s.d. (P<0.05)	0.14	0.38	0.79	0.01	10.4

l.s.d. = least significant difference.

Early sowing (SD1) achieved the highest header yield (5.66 t/ha) and SD3 recorded the lowest header yield (3.39 t/ha) (Table 6). A similar trend was observed when measuring the hand harvested yield with the highest yield achieved in SD1 (6.35 t/ha) while SD3 recorded the lowest yield (5.30 t/ha).

Table 6 Sowing date results averaged across all variety and irrigation treatments in the Leeton Field Station faba bean experiment, 2020.

Sowing date	Machine yield (t/ha)	Hand yield (t/ha)	Total biomass (t/ha)	Harvest index	Grain weight (g/1000 grains)
SD1	5.66	6.35	13.77	0.46	691.1
SD2	4.27	5.78	11.96	0.49	697.0
SD3	3.39	5.30	10.34	0.52	693.0
Average	4.44	5.81	12.02	0.49	693.7
l.s.d. (P<0.05)	0.12	0.38	0.76	0.01	n.s.

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

The irrigated treatments achieved a significantly higher header yield than the non-irrigated treatments when averaged across all varieties and sowing dates. The irrigated treatments averaged 5.09 t/ha while the non-irrigated treatments averaged 3.78 t/ha (Table 7). A similar trend was observed when measuring the hand yield with the irrigated treatments averaging 6.93 t/ha while the non-irrigated treatments recorded a significantly lower hand yield of 4.69 t/ha.

Table 7 Irrigation treatment results averaged across all variety and sowing date treatments in the Leeton Field Station faba bean experiment, 2020.

Irrigation treatment	Header yield (t/ha)	Hand yield (t/ha)	Total biomass (t/ha)	Harvest index	Grain weight (g/1000 grains)
Irrigated	5.09	6.93	14.35	0.48	739.7
Non-irrigated	3.78	4.69	9.70	0.49	647.7
Average	4.44	5.81	12.02	0.49	693.7
l.s.d. (*P*<0.05)	0.09	0.24	0.48	n.s.	9.1

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

A significant interaction between the irrigation treatments and varieties was observed in header yields. PBA Nasma$^{\phi}$ achieved a significantly higher header yield than all other varieties in the irrigated treatments (5.73 t/ha) while PBA Bendoc$^{\phi}$ recorded a significantly lower header yield than all other varieties in the irrigated treatments (4.40 t/ha) (Table 8). There were no statistical differences observed in header yields in the non-irrigated treatments across all varieties.

Table 8 Header yield results for irrigation treatment × varieties (averaged across all sowing dates) in the Leeton Field Station faba bean experiment, 2020.

Treatment	Grain yield (t/ha)			
	PBA Nasma	PBA Marne	PBA Samira	PBA Bendoc
Irrigated	5.73	5.24	4.90	4.40
Non-irrigated	3.80	3.75	3.90	3.68
l.s.d. (*P*<0.05)	0.20			

l.s.d. = least significant difference.

There was a significant interaction between the sowing dates and irrigation treatments for header yields. The irrigation treatments in SD1 achieved the highest header yields when averaged across all varieties (6.86 t/ha) and was significantly higher than all other treatments (Table 9). The non-irrigated treatments in SD3 recorded the lowest header yields when averaged across all varieties (3.07 t/ha).

Table 9 Header yield results for irrigation treatment × sowing date treatment (averaged across varieties) in the Leeton Field Station faba bean experiment, 2020.

Irrigation treatment	Grain yield (t/ha)		
	SD1	SD2	SD3
Irrigated	6.86	4.71	3.71
Non-irrigated	4.46	3.83	3.07
l.s.d. (*P*<0.05)	0.17		

l.s.d. = least significant difference.

Total biomass

Total biomass averaged 12.03 t/ha across all variety, sowing date and irrigation treatments. PBA Nasma$^{\phi}$ achieved the highest average total biomass (12.82 t/ha) and PBA Marne$^{\phi}$ recorded the lowest average total biomass (11.35 t/ha) and was statistically similar in total biomass with PBA Bendoc$^{\phi}$ (Table 5).

SD1 achieved the highest total biomass (13.77 t/ha) and SD3 recorded the lowest total biomass (10.34 t/ha) (Table 6).

The irrigated treatments (14.35 t/ha) produced significantly more total biomass than the non-irrigated treatments (9.70 t/ha) when averaged across all varieties and sowing dates (Table 7).

Harvest index

Harvest index (HI) averaged 0.49 across all variety, sowing date and irrigation treatments. PBA Marne$^{\phi}$ achieved the highest average HI (0.51) and PBA Samira$^{\phi}$ recorded the lowest average HI (0.47) (Table 5).

SD3 achieved the highest average HI (0.52) and SD1 recorded the lowest average HI (0.46) (Table 6).

The irrigated treatment achieved a HI of 0.48, which was statistically similar to the non-irrigated treatment of 0.49 (Table 7) indicating that irrigation did not affect HI.

Grain weight

Grain weight averaged 693.7 g/1000 grains across all variety, sowing date and irrigation treatments. PBA Nasma$^{\phi}$ achieved the highest average thousand grain weight (744.3 g) while PBA Bendoc$^{\phi}$ recorded the lowest average thousand grain weight (604.6 g) (Table 5).

Sowing date did not affect grain weight.

The irrigated treatment achieved a significantly higher grain weight than the non-irrigated treatment when averaged across all varieties and sowing dates. The irrigated treatment averaged 739.7 g/1000 grains while the non-irrigated treatment averaged 647.7 g/1000 grains (Table 7).

Water use and irrigation efficiency

SD1 in the non-irrigated treatments achieved the highest average water use efficiency (2.70 t/ML) and SD3 in the irrigated treatments recorded the lowest average water use efficiency (1.05 t/ML) (Table 10).

Table 10 Water use efficiency for the three sowing dates (averaged across all varieties) in the Leeton Field Station faba bean experiment, 2020.

Treatments	**Water use efficiency (t/ML)**		
	SD1	**SD2**	**SD3**
Irrigated	1.94	1.33	1.05
Non-irrigated	2.70	2.32	1.86

SD1 achieved the highest irrigation efficiency of 1.51 t/ML with an average header yield increase of 2.41 t/ha, while SD3 recorded the lowest irrigation efficiency of 0.41 t/ML with an average header yield increase of 0.65 t/ha (Table 11).

Table 11 Irrigation efficiency for the three sowing dates (averaged across all varieties) in the Leeton Field Station faba bean experiment, 2020.

Treatments	**SD1**	**SD2**	**SD3**
Header yield increase from irrigation	2.41 t/ha	0.89 t/ha	0.65 t/ha
Irrigation quantity	1.60 ML/ha	1.60 ML/ha	1.60 ML/ha
Irrigation efficiency	1.51 t/ML	0.56 t/ML	0.41 t/ML

Summary

With the application of two spring irrigations, the irrigated treatments achieved a significantly higher header yield than the non-irrigated treatments for all three sowing dates. SD1 had the highest yield increase due to irrigation with a gain of 2.41 t/ha compared with the non-irrigated treatments. With 2.41 t/ha grain yield increase from the application of 1.6 ML of irrigation water, SD1 achieved an irrigation efficiency of 1.51 t/ML.

Sowing date had a significant effect on grain yield with average header yields significantly decreasing as the sowing date was delayed. In the irrigated treatments, header yields decreased from 6.86 t/ha to 3.71 t/ha when sowing was delayed by six weeks from 24 April to 5 June. In the non-irrigated treatments, header yields decreased from 4.64 t/ha to 3.07 t/ha when sowing was delayed by the same time period. Even though this experiment demonstrated that sowing faba bean on 24 April achieved the highest yield in the 2020 Leeton Field Station faba bean experiment, the sowing date is earlier than recommended for the Murrumbidgee Irrigation Area (MIA). This experiment will be repeated in 2021 to confirm any yield increase to the earlier sowing date for faba bean.

PBA Nasma$^{\Phi}$ was the best performing variety, achieving the highest grain yield when averaged across sowing dates and irrigation treatments. PBA Nasma$^{\Phi}$ achieved an average header grain yield of 5.73 t/ha in the irrigation treatments, which was more than any other variety. While there were significant yield differences between varieties in the irrigated treatments, there was no varietal differences observed for grain yield in the non-irrigated treatments.

Acknowledgements

This research is part of the 'Matching adapted pulse genotypes with soil and climate to maximise yield and profit, with manageable risk in Australian cropping systems' project, BLG118, 2020–22, a joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

We would like to gratefully acknowledge the support of Michael Hately and Phil Armstrong for assistance with experiment management, field assessments and data collection.

Contact

Tony Napier
Yanco Agricultural Institute, Yanco
tony.napier@dpi.nsw.gov.au
0427 201 839

Southern NSW soybean breeding experiments – Leeton 2020

Tony Napier and John Dando

NSW DPI, Yanco

Key findings

- Burrinjuck$^{\phi}$ achieved both a higher grain yield and protein content than Snowy$^{\phi}$ when sown in mid November compared with a mid December sowing.
- One advanced new cross was identified with superior qualities to Burrinjuck$^{\phi}$ and warrants further evaluation as a late sown clear hilum option.
- Sixty-five new Burrinjuck$^{\phi}$ backcrosses were identified as suitable for further evaluation towards releasing an enhanced Burrinjuck$^{\phi}$ line.

Introduction

The Yanco Agricultural Institute soybean project evaluates new lines from the Australian National Soybean Breeding Program aiming to release new varieties for southern NSW. The program is looking for new varieties that possess desirable combinations of yield, protein, improved agronomic traits, broad adaptation, disease resistance and high weathering tolerance.

The focus of the Riverina industry has been to breed suitable varieties for the human consumption market. Djakal is the current standard in the Riverina for the crushing market. It is high yielding but has a dark hilum making it undesirable for human consumption. The current standard for the soymilk market is Snowy$^{\phi}$ with a clear hilum, but it is much lower yielding than Djakal.

Burrinjuck$^{\phi}$, a clear hilum variety, was recently released for the human consumption market. Soymilk processors are yet to approve Burrinjuck$^{\phi}$ as a preferred variety for their use, but approval is anticipated within 12 months. Burrinjuck$^{\phi}$ has a significantly higher grain yield and protein content than Snowy$^{\phi}$ when sown in mid November but has not always demonstrated an advantage when sown in late December. The breeding program is continuing to evaluate new crosses and aims to enhance Burrinjuck$^{\phi}$ with powdery mildew and Phytophthora Root Rot resistance combined with resistance to sulfonylurea herbicides.

Site details

Location	Leeton Field Station
Soil type	Grey vertosol
Previous crop	2019 barley
Starter fertiliser	100 kg/ha Rustica Plus pulse mix (12:5:14)
Sowing dates	• S4 early experiment on 18 November 2019 • S4 late experiment on 17 December 2019 • S1 experiment (hill plots) on 20 January 2020
Harvest dates	• S4 early experiment on 15 April 2020 • S4 late experiment on 21 April 2020 • S1 experiment (hill plots) from 4 to 25 May 2020

Treatments and establishment

Two S4 (F8 equivalent) experiments were established to evaluate new crosses, looking for new superior genotypes that are either suitable for human consumption or the crushing market.

One S1 (early generation) experiment was established to screen new enhanced Burrinjuckᶲ backcrosses with similar or improved grain yield and protein content as Burrinjuckᶲ. S2 and S3 experiments are also conducted annually but are not reported in this paper.

S4 experiments (early and late)

The S4 experiments had 36 entries: 31 breeding lines and five commercial varieties (Burrinjuckᶲ, Djakal, Snowyᶲ, Bidgeeᶲ and Bowyer). Both S4 experiments had four replicates in a randomised block design and were sown on raised beds at 1.83 m centres. There were two plant rows per bed with a plant row spacing of 0.915 m. Plots were two beds wide by 10 m long giving a total 36.6 m^2 plot area.

S1 experiment

Ninety new enhanced Burrinjuckᶲ backcrosses were evaluated in the S1 experiment, along with multiple plots of Burrinjuckᶲ as a control. The S1 experiment was sown on raised beds in single plots with no replication (due to limited seed).

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 colour to yellow (expressed as P95). Yield was calculated from 10 m of the centre two rows from each plot. Subsamples of grain were collected to calculate grain protein, 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). Grain size was measured from a subsample of 200 grains.

Results

S4 early experiment

Grain yield averaged 3.81 t/ha across all cultivars. Burrinjuckᶲ achieved a grain yield of 4.14 t/ha, which was higher than Snowyᶲ (3.02 t/ha) (Table 1). No new cultivars achieved a significantly higher grain yield than Burrinjuckᶲ.

Grain protein content averaged 40.15% across all cultivars. Burrinjuckᶲ achieved a protein content of 40.5%, which was significantly higher than Snowyᶲ (38.65%) (Table 1). Only the three new cultivars, 2B25-1230, 2B25-1238 and 2C17B-932-769 had a significantly higher grain protein content than Burrinjuckᶲ in the S4 early experiment.

Burrinjuckᶲ had a maturity time of 128.97 days which was similar to Snowyᶲ (128.66 days). Bidgeeᶲ and eight new crosses were significantly quicker to mature than Burrinjuckᶲ.

Burrinjuckᶲ achieved a grain size of 41.55 g/200 seeds and was similar to Snowyᶲ (40.52 g/200 seeds). Only the two new cultivars, 2C17B-933-803 and 2C17B-933-802 achieved a significantly larger grain size than Burrinjuckᶲ.

S4 late experiment

Grain yield averaged 3.36 t/ha across all cultivars. Burrinjuckᶲ achieved a grain yield of 3.35 t/ha, which was statistically similar to Snowyᶲ (3.17 t/ha) (Table 2). Five new clear hilum cultivars achieved a significantly higher grain yield than Burrinjuckᶲ.

Table 1 Hilum colour, grain yield, protein, time to maturity and seed size of each cultivar, presented in order of decreasing yield, in the Leeton Field Station early S4 variety evaluation experiment, 2019–20.

Cultivar	Hilum colour	Grain yield (t/ha)	Protein (%)	Maturity (days to P95)	Seed size (g/200 seeds)
2C15-573	Clear	4.19[a]	41.16	132.42	42.50[a]
2C17B-933-801	Clear	4.16[a]	40.76	130.02	41.59
2C15-566	Clear	4.14[a]	41.08	129.66	40.07
Burrinjuck	Clear	4.14[a]	40.50	128.97	41.55
2C17B-934-795	Clear	4.14[a]	40.41	132.21	39.93
P176-1-1	Clear	4.14[a]	39.62	123.01[a]	40.74
P176-2br	Dark brown	4.13[a]	39.01	131.94	35.58
P176-2-1	Dark brown	4.11[a]	39.38	121.91[a]	37.63
Djakal	Dark brown	4.09[a]	38.49	126.04	37.64
P176-37	Clear	4.08[a]	38.42	128.65	38.01
P176-2-2	Dark brown	4.07[a]	37.84	124.32[a]	36.25
2C17B-935-822	Clear	4.06[a]	40.63	135.18	40.72
2C17B-932-1A	Clear	4.02[a]	41.11	133.17	40.16
2C17B-933-803	Clear	4.00[a]	39.84	130.64	43.93[a]
2C17B-932-769	Clear	3.95[a]	41.62	128.71	40.32
P176-1-2	Clear	3.94[a]	39.49	123.10[a]	38.72
2C17B-932-2	Clear	3.88[a]	41.05	127.83	40.12
2C17B-933-802	Clear	3.88[a]	39.87	132.82	43.66[a]
P176-14-1	Clear	3.88[a]	38.59	128.65	38.57
2C17B-934-793	Clear	3.87[a]	39.96	132.97	39.80
2C15-550	Clear	3.86[a]	40.85	128.39	41.97
P176-14-2	Clear	3.85[a]	38.78	124.65	39.25
2C17B-931-1	Clear	3.83[a]	40.87	133.79	40.27
Q015A-6	Clear	3.80	40.51	124.38[a]	36.47
2C17B-928-800	Clear	3.79	40.50	130.57	40.90
2C15-593	Clear	3.73	40.76	130.16	38.74
P168-11	Clear	3.64	40.81	125.13	39.08
2C17B-928-797	Clear	3.56	39.84	127.99	40.36
P213-41	Clear	3.50	39.39	128.43	38.47
2B25-1238	Clear	3.49	42.04	124.70	40.88
2B25-1230	Clear	3.44	43.68[a]	129.26	39.77
P176-23	Clear	3.42	39.12	128.91	36.66
Bidgee	Clear	3.34	39.77	121.73[a]	32.83
Z009-627	Clear	3.26	41.24	130.07	37.79
Snowy	Clear	3.02	38.65	128.66	40.52
Bowyer	Light brown	2.88	39.88	132.34	39.59
Average		3.81	40.15	128.60	39.47
l.s.d.		0.36	1.02	2.53	1.63

[a] Numbers in the same column sharing the letter 'a' are in the top grouping and are not significantly different by l.s.d. test at $P = 0.05$.

Table 2 Hilum colour, grain yield, protein, time to maturity and seed size of each cultivar, presented in order of decreasing yield, in the Leeton Field Station late S4 variety evaluation experiment, 2019–20.

Cultivar	Hilum colour	Grain yield (t/ha)	Protein (%)	Maturity (days to P95)	Seed size (g/200 seeds)
P176-2-1	Dark brown	3.83[a]	39.15	108.73	38.00
P176-2br	Dark brown	3.83[a]	39.49	112.48	36.92
2C15-566	Clear	3.82[a]	42.18[a]	118.98	43.13
P176-14	Clear	3.76[a]	39.15	110.70	39.02
Z007K-2	Clear	3.74[a]	40.39	118.45	41.01
P176-14-2	Clear	3.73[a]	39.52	109.53	40.25
P176-1-2	Clear	3.66[a]	39.14	112.50	39.10
Djakal	Dark brown	3.63[a]	38.93	111.28	36.79
2C15-593	Clear	3.57	42.18[a]	120.47	40.95
P176-1-1	Clear	3.52	39.81	112.47	42.30
2C15-573	Clear	3.49	42.52	117.03	43.98
Q015A-6	Clear	3.47	40.71	108.52	37.89
M095-66-2	Clear	3.44	39.83	107.28	35.11
2C17B-928-800	Clear	3.39	41.53	119.03	45.03
M095-68-2	Clear	3.37	39.87	107.53	33.41
Burrinjuck	Clear	3.35	41.31	117.52	43.40
Bidgee	Clear	3.34	41.13	104.97[a]	33.27
2C17B-932-1A	Clear	3.33	41.91[a]	119.03	43.34
2C17B-931-1	Clear	3.31	41.91[a]	121.23	44.94
2C17B-932-769	Clear	3.31	42.20[a]	119.03	44.56
2C17B-933-801	Clear	3.29	41.99[a]	119.72	45.87[a]
2B25-1230	Clear	3.27	42.15[a]	112.98	41.42
2C17B-934-793	Clear	3.26	41.48	121.23	42.64
2C17B-933-803	Clear	3.24	41.99[a]	120.03	46.77[a]
2C17B-932-2	Clear	3.23	42.73[a]	117.98	43.38
2B22-851	Clear	3.22	41.54	117.97	39.18
2C15-550	Clear	3.20	42.10[a]	118.00	45.59
2C17B-935-822	Clear	3.20	42.40[a]	122.05	45.15
2C17B-933-802	Clear	3.17	41.37	120.50	46.59[a]
2C17B-934-795	Clear	3.17	41.23	119.25	42.26
Snowy	Clear	3.17	41.32	112.73	41.40
2B22-850	Clear	3.13	39.57	119.48	38.33
2B22-846	Light brown	3.08	39.56	118.47	41.20
2B22-847	Clear	3.03	40.64	115.52	43.01
2C17B-928-797	Clear	2.92	41.93[a]	117.02	44.68
Bowyer	Light brown	2.53	41.17	118.53	42.96
Average		3.36	41.00	115.78	41.47
l.s.d.		0.25	0.84	1.97	0.97

[a] Numbers in the same column sharing the letter 'a' are in the top grouping and are not significantly different by l.s.d. test at $P = 0.05$.

Grain protein content averaged 41% across all cultivars. Burrinjuck$^{\Phi}$ achieved a protein content of 41.31%. which was similar to Snowy$^{\Phi}$ (41.32%) (Table 2). Six new cultivars achieved a significantly higher grain protein content than Burrinjuck$^{\Phi}$.

Burrinjuck$^{\Phi}$ had a maturity time of 117.52 days, which was significantly longer than Snowy$^{\Phi}$ (112.73 days). Bidgee$^{\Phi}$ and eight new crosses achieved a significantly quicker maturity time than Burrinjuck$^{\Phi}$.

Burrinjuck$^{\Phi}$ achieved a grain size of 43.40 g/200 seeds and was significantly larger than Snowy (41.40 g/200 seeds). Nine new cultivars achieved a significantly larger grain size than Burrinjuck$^{\Phi}$.

S1 experiment

Burrinjuck$^{\Phi}$ plots in the S1 experiment ranged in maturity time from 112 to 114 days; the new lines ranged from 112 to 129 days. Four new lines had a maturity time longer than 120 days and were not considered suitable for further evaluation. In total, 90 new crosses were evaluated in the S1 experiment (results not shown).

The Burrinjuck$^{\Phi}$ plots achieved an average protein content of 43%; the new crosses ranged from 40.3% to 46.5%.

The Burrinjuck$^{\Phi}$ plots had an average seed size of 41 g/200 seeds; the new crosses ranged from 38.5 g/200 seeds to 45.9 g/200 seeds.

Discussion

Burrinjuck$^{\Phi}$ demonstrated superiority over Snowy$^{\Phi}$ in the S4 early experiment with higher grain yield and protein content. Burrinjuck$^{\Phi}$ did not demonstrate an advantage over Snowy$^{\Phi}$ in the S4 late experiment (similar grain yield and protein content). No new cultivars in the S4 early experiment had a higher grain yield than Burrinjuck$^{\Phi}$, while five new clear hilum cultivars in the S4 late experiment achieved a higher grain yield than Burrinjuck$^{\Phi}$.

In the S4 late experiment, three of the five new cultivars that had a higher yield than Burrinjuck$^{\Phi}$ also had a lower protein content. The other two higher yielding crosses in the S4 late experiment included Z007K-2, which had a similar protein content to Burrinjuck$^{\Phi}$ and 2C15-566, which had a higher protein content than Burrinjuck$^{\Phi}$.

Burrinjuck$^{\Phi}$ had a similar maturity time to Snowy in the S4 early experiment, but took nearly five more days to mature in the S4 late experiment. The two new crosses (Z007K-2 and 2C15-566) in the S4 late experiment, with superior yield and high protein content, both had a similar maturity time to Burrinjuck$^{\Phi}$.

In the S4 late experiment, Z007K-2 had a smaller grain size than Burrinjuck$^{\Phi}$, while 2C15-566 had a similar grain size to Burrinjuck$^{\Phi}$.

The only identified new breeding line with superior qualities to Burrinjuck$^{\Phi}$ in the S4 experiments was 2C15-566 at the later sowing date.

In the S1 experiment, 65 new Burrinjuck$^{\Phi}$ backcrosses were identified as suitable for further evaluation.

Acknowledgements

These experiments were part of the 'Australian National Soybean Breeding Program', which is a joint investment by the GRDC, CSIRO and NSW DPI.

We would like to gratefully acknowledge the support of Yanco Agricultural Institute farm staff for their assistance with paddock preparation and irrigation management.

Contact

Tony Napier
Yanco Agricultural Institute, Yanco
tony.napier@dpi.nsw.gov.au
0427 201 839

Influence of sowing date and variety selection on growth and development of cotton – Yanco 2019–20

Hayden Petty, Gabby Panazzolo and David Troldahl

NSW DPI, Yanco

Key findings

- Sowing cotton in the southern regions of New South Wales should aim to increase the season length as much as possible.
- Pushing the sowing date past the last week in October resulted in 64% yield loss compared with a late September sowing date.
- Varietal difference within sowing dates was minimal, having no real effect on yield.
- In 2019–20, low quality cotton was avoided by sowing a variety with a more determinate growth habit in late September such as Sicot 707B3F and Sicot 714B3F.

Introduction

In southern NSW, cotton growers often face sub-optimal temperature at sowing and again during boll maturity and harvest. To maximise yields and achieve high quality cotton, growers must alter management practices to ensure season length is adequate to successfully mature the crop. Two of the main management practices that can be easily altered are sowing date and variety selection.

This paper reports findings from a field experiment conducted during the 2019–20 season, where all current commercially available cotton varieties were tested for yield and quality characteristics across four sowing dates from late September to early November.

Site details

Location	Yanco Agricultural Institute – Leeton Field Station
Soil type	Grey vertisol – irrigated
Previous crop	Pasture rotation (virgin country)
Sowing configuration	1 m hills with John Deere Max Emerge 2 seeder
Mineral nitrogen (N)	117 kg N/ha (0–90 cm) at sowing
Fertiliser applied	• **Pre-sowing**: 200 kg/ha urea, 100 kg/ha Granulock Z (centre-busted below the plant line) • **In-crop**: 110 kg/ha urea (side dressed)

Treatments

Sowing date (SD)

SD1: 26 September 2019

SD2: 10 October 2019

SD3: 23 October 2019

SD4: 8 November 2019

Variety

Sicot 707B3F, Sicot 714B3F, Sicot 746B3F, Sicot 748B3F, Sicot 754B3F.

Results

Seasonal conditions

The 2019–20 season was drawn out and many growers experienced a late pick due to mild conditions during boll opening. Fluctuations in temperature, especially during early season growth, resulted in crops putting on extra vegetative growth in response to cooler temperatures. Accumulation of day degrees (DD) between each sowing date reinforces research by Bange, Caton, and Milroy (2008) that sowing later exposes the crop to warmer conditions thereby accumulating DD quicker than sowing early. For example, SD1 had accumulated 613 DD 69 days after sowing whereas SD4 had accumulated 842 DD by this time (Figure 1). As the crop reached February and temperatures cooled, this difference between accumulated DD declined and SD4 did not fulfil the 2000 day degree requirement to finish the crop.

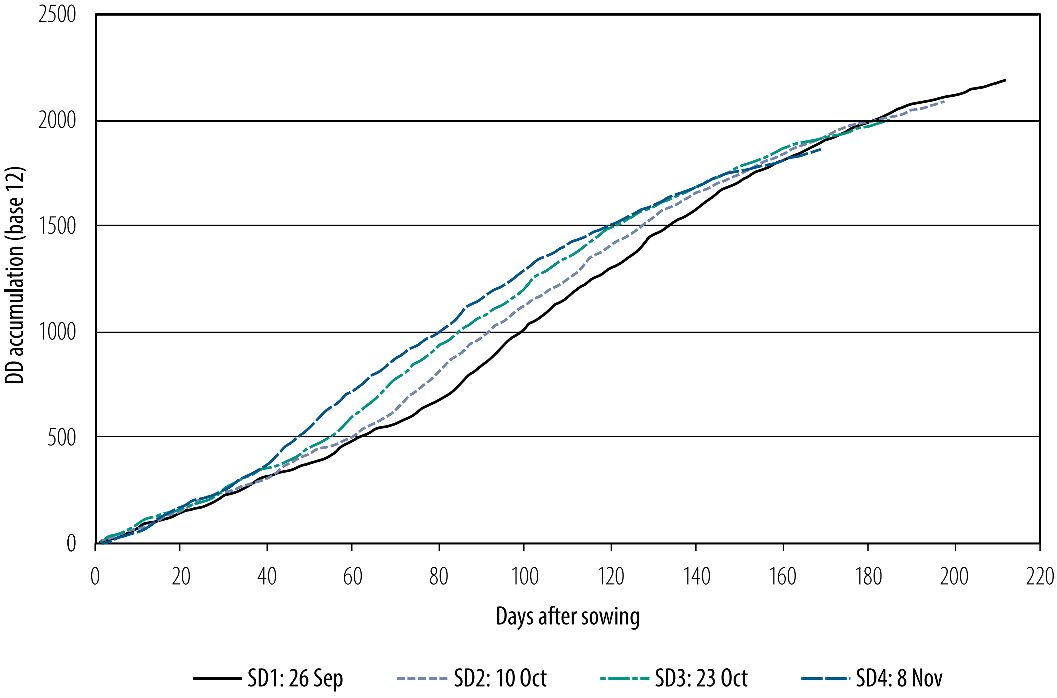


Figure 1 Day degree accumulation (base 12) plotted against days after sowing for each sowing date.

Establishment

Cotton seed was sown dry at 17 seeds/m and watered up. Across all treatments the average number of plants/m was 14.8 and exceeded the 10–12 plants/m optimum. Interestingly, significance between treatments was only identified at the variety level and was not significantly different between sowing dates. Across all sowing dates, Sicot 714B3F consistently had the highest germination rate of 15.1 plants/m. However, it was only significantly higher than Sicot 754B3F, all other varieties were statistically the same.

Phenology

The target DD accumulation (base 12) to reach first square is 505, plus 5.2 DD for each cold shock that occurs. In Table 1, the target DD accumulation to reach squaring is adjusted to reflect the number of cold shock days leading up to the date recorded for first square. Interestingly, SD1 and SD2, on average, reached squaring 33 DD and 46 DD earlier than the adjusted DD targets, whereas SD3 and SD4 exceeded the adjusted DD target by 75 DD and 127 DD respectively. Within SD3 and SD4, the variety response was limited, and all reached squaring within one day of each other. These findings suggest that the interaction between DD accumulation at base 12 and the number of cold shocks still requires further research to understand the plants' response on phasic development. The high–low temperature fluctuations during early reproductive development is influencing the time it takes for the crop to start setting fruit. The number of days after sowing to reach first square shows a similar relationship to expectations and declines with delayed sowing, but the crop perceives time based on day degree accumulation. Sowing later exposes the crop to environmental conditions that favour quick accumulation of day degrees, however, the response time to first square is not hastened under these conditions but was rather delayed.

Table 1 Day degree accumulation for each treatment to reach first square. Days after sowing recorded in brackets.

Variety	**Time to reach first square (accumulated day degrees)**			
	SD1: 26 September	**SD2: 10 October**	**SD3: 23 October**	**SD4: 8 November**
Sicot 707B3F	655.0 (77)	596.2 (67)	656.4 (63)	692.3 (57)
Sicot 714B3F	652.4 (77)	593.8 (67)	655.8 (63)	684.6 (57)
Sicot 746B3F	661.9 (78)	593.9 (67)	660.1 (63)	694.8 (57)
Sicot 748B3F	659.7 (78)	590.4 (67)	671.6 (64)	700.6 (57)
Sicot 754B3F	669.1 (79)	596.2 (67)	671.6 (64)	697.7 (58)
Mean	659.6 (78)	594.1 (67)	663.1 (63)	694.0 (57)
l.s.d. Variety	13.56 (0.5)			
l.s.d. Sowing date	7.73 (0.8)			
l.s.d. Variety × sowing date	n.s.			
Number cold shocks	36	26	16	12
Adjusted DD accumulation (base 12) target	692.2	640.2	588.2	567.4

Least significant difference (l.s.d.) presented is significant at $P<0.05$.
n.s. = not significant.

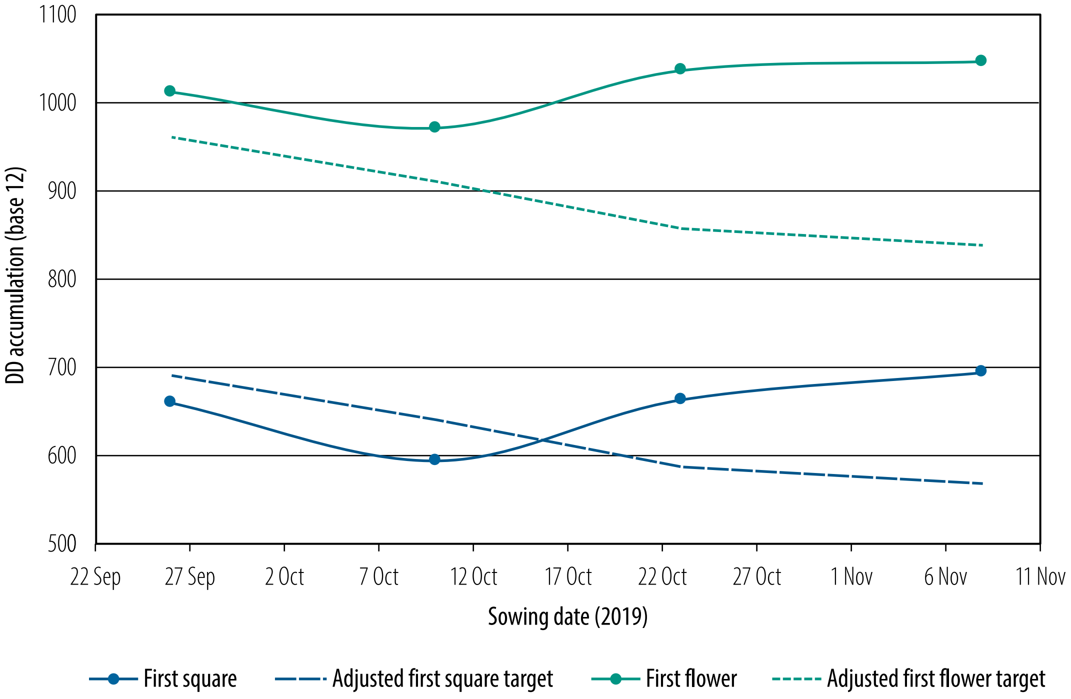
Similarly, first flower was delayed by the same number of cold shock days as by the time to first square. The relationship across sowing dates differed from first square with all actual flowering dates exceeding the adjusted DD target. The difference between target and actual increased after SD2 (Figure 2). SD1 and SD2 flowered just 50 DD and 60 DD above the target respectively, whereas SD3 and SD4 flowered 180 DD and 210 DD above the target respectively (Table 2). This delay in flowering reduced the crop's capacity to achieve high yields with the season length capped by cold temperatures typically experienced in autumn in the southern regions of NSW.

The actual recorded day degree accumulations across all sowing dates for both squaring and flowering follow the same trend, and on average flowering occurred 366 DD after squaring in this season.

Table 2 Day degree accumulation for each treatment to reach first flower. Days after sowing recorded in brackets.

Variety	**Time to reach first flower (accumulated day degrees)**			
	SD1: 26 September	**SD2: 10 October**	**SD3: 23 October**	**SD4: 8 November**
Sicot 707B3F	1009.2 (99)	959.6 (89)	1020.2 (85)	1034.5 (82)
Sicot 714B3F	994.5 (98)	968.1 (89)	1033.2 (86)	1038.3 (82)
Sicot 746B3F	1019.5 (100)	976.2 (90)	1043.2 (87)	1043.4 (82)
Sicot 748B3F	1030.4 (100)	968.1 (89)	1061.1 (88)	1083.1 (84)
Sicot 754B3F	1019.5 (100)	991.8 (90)	1041.0 (87)	1051.6 (83)
Mean	1014.6 (99)	972.7 (89)	1039.7 (87)	1050.2 (82)
l.s.d. Variety	16.28 (1)			
l.s.d. Sowing date	27.49 (1.7)			
l.s.d. Variety × sowing date	n.s.			
Number cold shocks	36	26	16	12
Adjusted DD accumulation (base 12) target	964.2	912.2	860.2	839.4

Least significant difference (l.s.d.) presented is significant at $P<0.05$.
n.s. = not significant.



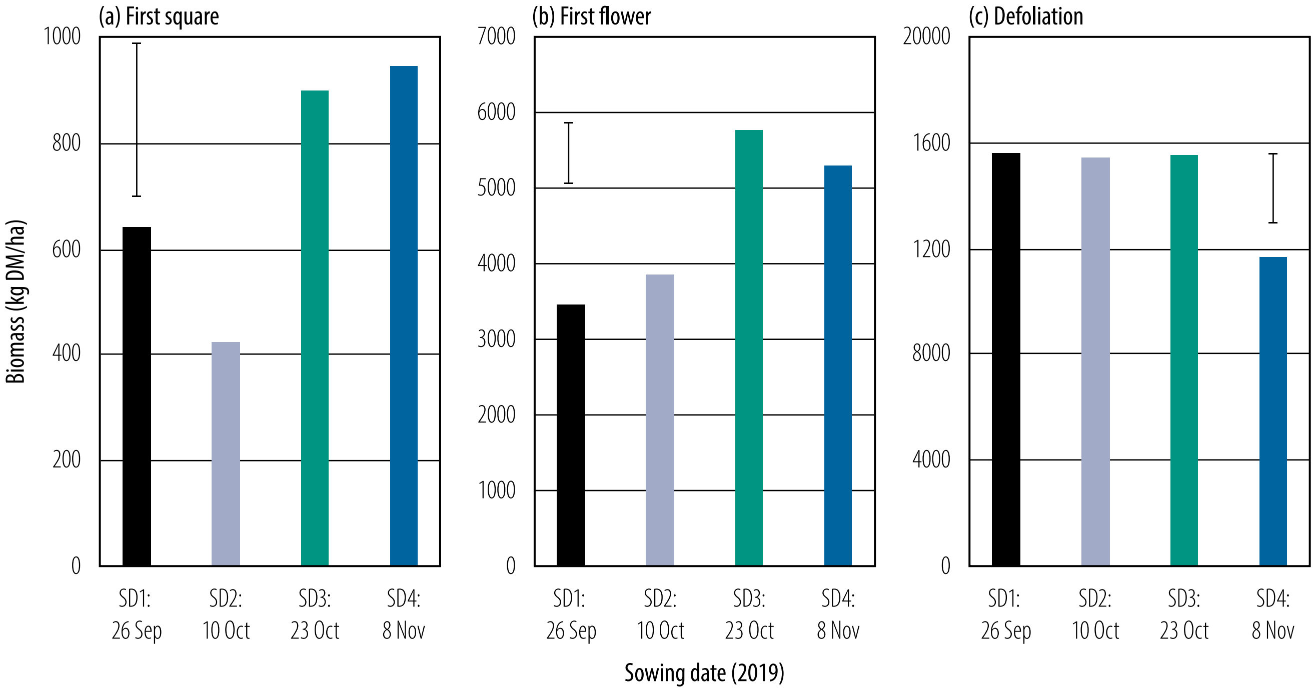
Dashed lines indicates the target threshold for each developmental stage adjusted for the number of cold shocks the crop experienced.

Figure 2 Average day degree accumulation plotted against sowing date for first square and first flower.

Biomass

Biomass measured at the key phasic development stages (first square, first flower and defoliation) was significantly different between the sowing date treatments, but there was no variation between variety. Dry matter (DM) measured at first square shows a relationship similar to that previously mentioned where the later-sown crops (SD3 and SD4) experienced climatic conditions that favoured day degree accumulation and therefore, increased biomass production (Figure 3a). This was also observed in the first flower data where the late-sown treatments (SD3 and SD4) had significantly more biomass (Figure 3b).

This relationship changed at the end of the season where the last sowing date (SD4) yielded less biomass than the three earlier sowing dates (Figure 3c). From the phenology data presented (Table 2), SD4 initiated fruit set much later than the other sowing dates and as such did not bare the same fruit load leading to less above ground biomass.



Ι Error bar: least significant difference (l.s.d.) at *P*<0.05.

Figure 3 Biomass (kg DM/ha) produced for each sowing date averaged across all varieties at (a) first square, (b) first flower and (c) defoliation.

Yield components

The number of vegetative branches is highly dependent on variety and early season climatic conditions. With the cool start to the season, the number of vegetative branches was high and a significant treatment effect for variety was evident. Sicot 748B3F had the most vegetative branches, averaging 10.7 across all sowing dates and Sicot 707B3F had the least, averaging 8.9 across all sowing dates (Table 3).

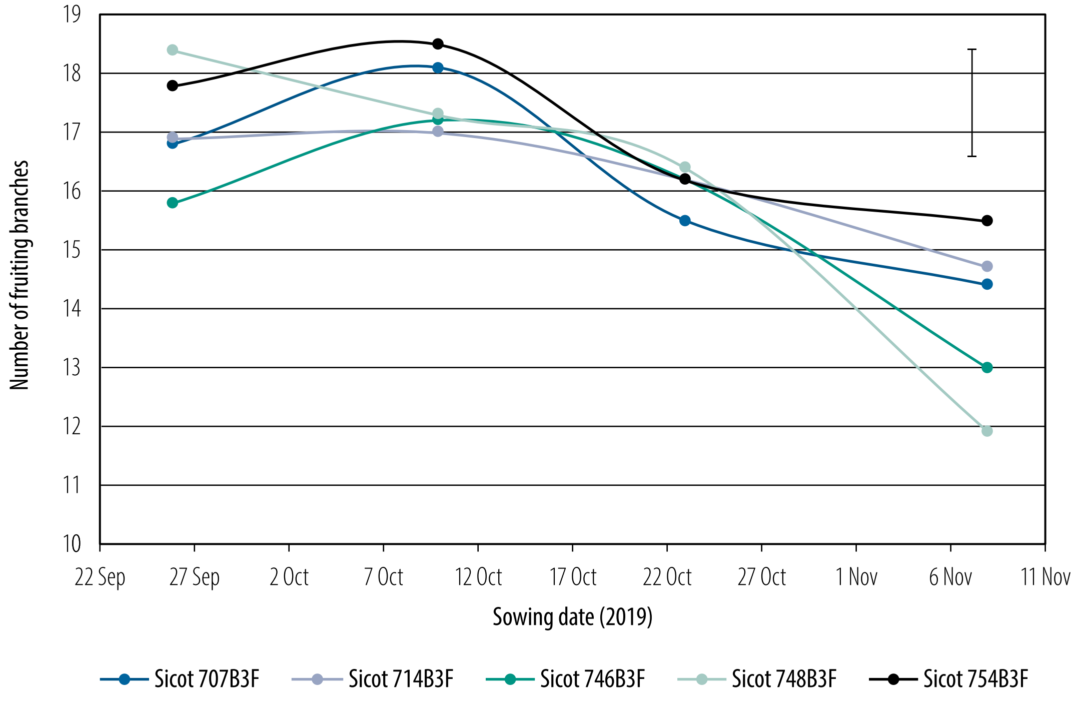
Sicot 714B3F was the first variety to initiate fruit set with the first fruiting branch occurring on average at node 9.5. Sicot 748B3F started setting fruit on node 11. Sicot 754B3F had the highest number of bolls per plant at 16.2 and Sicot 746B3F and Sicot 748B3F the lowest at 14 and 13.3 respectively.

Table 3 Summary of variety averages for number of vegetative branches, first fruiting branch and number of bolls per plant.

Variety	Number of vegetative branches	First fruiting branch	Boll number (bolls/plant)
Sicot 707B3F	8.9	9.7	15.6
Sicot 714B3F	9.3	9.5	15.4
Sicot 746B3F	9.8	10.5	14.0
Sicot 748B3F	10.7	11.0	13.3
Sicot 754B3F	10.0	10.6	16.2
Mean	9.7	10.3	14.9
l.s.d. Variety	0.8	0.71	1.65

Least significant difference (l.s.d.) presented is significant at $P<0.05$.

The number of fruiting branches on a plant influences the crop's ability to achieve high yields. The overall trend is that the number of fruiting branches declines with later sowing dates due to the crop being limited by season length (Figure 4). Within sowing dates, varieties only marginally differed from each other with Sicot 748B3F outperforming Sicot 746B3F in SD1 by 2.6 fruiting branches. Across SD2 and SD3 there were no variety differences. Sicot 746B3F and Sicot 748B3F produced fewer fruiting branches than Sicot 754B3F in SD4.



Error bar: least significant difference (l.s.d.) at $P<0.05$.

Figure 4 Number of fruiting branches plotted against sowing date for each variety.

Yield

Given the seasonal conditions of 2019–20, early-sown crops had more time to set fruit and yielded higher than a late-sown crop. Sicot 707B3F was the highest yielding variety across all sowing dates averaging 11.48 bales/ha (Figure 5). Sicot 714B3F was the highest yielding variety from SD1 at 14.47 bales/ha, but was not statistically different from the other varieties in SD1 averaging 14 bales/ha. SD1 established well from the hot temperatures over the October long weekend and was able to develop more fruit as a result of having a longer season compared with the other sowing dates.

The average yield for SD2 was 12.61 bales/ha – 90% of SD1 yields. Sicot 707B3F and Sicot 714B3F were the highest yielding varieties from SD2, significantly out yielding the other three varieties, at 13.7 bales/ha and 13.84 bales/ha respectively.

Sowing in late October (SD3) resulted in a 22% yield reduction from the late September sowing date (SD1), averaging across all varieties to 10.87 bales/ha. Sicot 707B3F was the highest yielding variety from SD3 producing 12.48 bales/ha, almost yielding the same as the average across SD2.

Pushing sowing into early November (SD4) resulted in a 64% yield reduction from the late September sowing (SD1) averaging just 5.1 bales/ha. Sicot 748B3F performed poorly in SD4 compared with the other varieties dropping down to 3.8 bales/ha. A field of cotton sown at this time with any variety would not have grown to maturity due to its late sowing leading to an inability to set and mature fruit. This sowing date was implemented as a treatment to answer the question surrounding a replant scenario and how late a grower could make the decision to replant. Sowing past the 23 October (SD3) in this experiment proved that lint yields received were less than half that of the district average and therefore unviable.

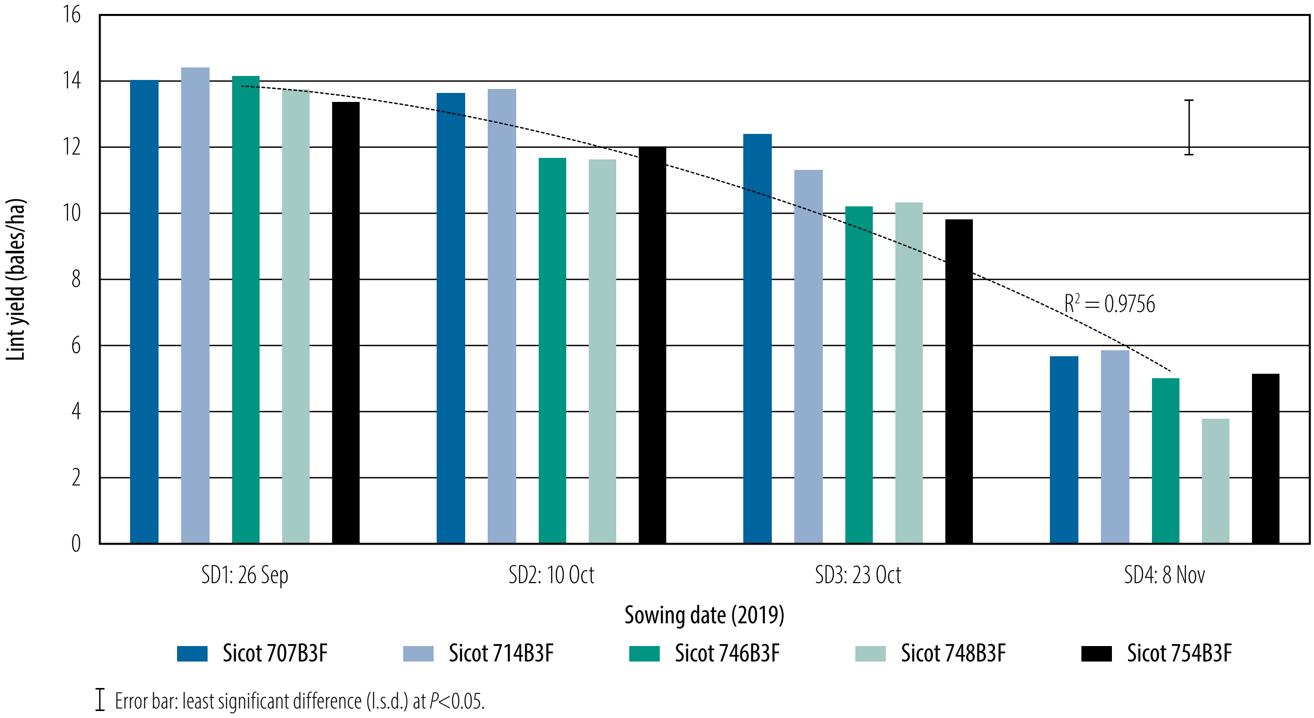


Figure 5 Average lint yields of each variety across all sowing dates.

Quality

The 2019–20 season had a mild finish, resulting in a large number of bolls being unable to mature due to the cold. Reports from across the valley indicated that up to 60% of cotton was classed with low micronaire. Analysed lint samples hand ginned from this experiment indicate that Sicot 707B3F and Sicot 714B3F from SD1 were the only treatments to achieve micronaire greater than the discount threshold of 3.5 (Table 4). All other varieties from SD1 received a quality downgrade on micronaire. Beyond this sowing date all other treatments returned a micronaire less than 3.5 and received a severe discount.

Table 4 Lint micronaire data across sowing date and variety.

Variety	Lint micronaire			
	SD1: 26 September	SD2: 10 October	SD3: 23 October	SD4: 8 November
Sicot 707B3F	3.51	3.09	2.91	2.23
Sicot 714B3F	3.56	3.07	2.77	2.31
Sicot 746B3F	3.16	2.74	2.54	2.48
Sicot 748B3F	3.17	2.71	2.55	2.2
Sicot 754B3F	2.92	2.8	2.52	2.16
Mean	3.26	2.88	2.66	2.28
l.s.d. Variety	0.13			
l.s.d. Sowing date	0.12			
l.s.d. Variety × sowing date	0.25			

Least significant difference (l.s.d.) presented is significant at $P<0.05$.

Summary

Yield and quality interactions were largely driven by sowing date rather than variety selection. Variety attributes such as time to first square and first flower, boll number, first fruiting branch, number of vegetative branches and node number was not reflected in the yields. Having the crop in the ground for the longest amount of time equalled more yield in 2019–20, a season with a mild and delayed finish, proving late September to be the optimum sowing date. Sicot 707B3F and Sicot 714B3F with more determinate growth habits, when sown on the 26 September (SD1), were the only two varieties to achieve base grade micronaire and not incur a discount.

These inferences are made from a season where starting temperatures and moisture interactions were not limiting. The number of plants established averaged 14.8 plants/m across all sowing dates. When sowing early always consider the soil temperature and forecast for the next week to ensure the highest establishment rate and refer to the *Australian cotton production manual for these guidelines*.

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Acknowledgements

This experiment was part of the 'Supporting southern cotton production' project, DAN2001, 2019–22, a joint investment by the Cotton Research and Development Corporation (CRDC) and NSW DPI.

Thanks to the technical assistance of Dionne Wornes, Peter Davidson and Sam Hopper. A special thankyou to Cotton Seed Distributers (CSD) Ltd for supplying the seed and to ProClass Griffith for undertaking quality analysis on the lint samples.

Contact

David Troldahl
Yanco Agricultural Institute, Yanco
david.trodahl@dpi.nsw.gov.au
0447 276 997

Applying plant growth hormones during early season developmental stages to increase cotton yield potential in southern NSW – Yanco 2019–20

Hayden Petty, Gabby Panazzolo and David Troldahl
NSW DPI, Yanco

Key findings

- A positive yield response was identified when the gibberellic acid treatment was applied at squaring.
- All other measurements returned nil significant difference between hormone treatments and the control.
- This experiment will be completed again next season with more specific measurements taken to identify the plant interactions with plant hormones.

Introduction

The growing regions of southern NSW typically experience cool, unfavourable (to cotton) starts to the growing season. These environmental conditions hinder early season growth and development, which the grower cannot control. Linkages between applying gibberellic acid (GA) and floral development initiation have been identified. Cotton switches to reproductive development as early as the two-leaf stage and adverse conditions around this growth stage can cause delayed onset of flowering. While GA applications during early season growth largely promote leaf area growth, this connection with floral initiation could be beneficial in the south to initiate flowering earlier and potentially lead to an increased yield potential. Another plant hormone widely used in horticulture, aviglycine (AVG), is applied to reduce fruit shedding. With a potential increase in fruit load from GA application, AVG could be used to help capture and retain this potential yield increase. This field experiment applied GA and AVG plant hormones at key developmental stages to identify any potential yield gain.

Site details

Location	Yanco Agricultural Institute – Leeton Field Station
Soil type	Grey vertisol – irrigated
Previous crop	Pasture rotation (virgin country)
Sowing configuration	1 m hills with John Deere Max Emerge 2 seeder
Mineral nitrogen (N)	117 kg N/ha (0–90 cm) at sowing
Fertiliser applied	• **Pre-sowing**: 200 kg/ha urea, 100 kg/ha Granulock Z (centre-busted below the plant line) • **In-crop:** 110 kg/ha urea (side dressed)
Variety	Sicot 746B3F – treated with Vibrance® Complete and Cruiser®

Treatments

The experiment was conducted in a split-plot randomised complete block design with four replicates.

Main treatment

Gibberellic acid (400 g/kg) at 20 g/ha applied at:

- nil control
- two-leaf
- first square.

Sub treatment

Aviglycine (150 g/kg) at 100 g/ha applied at:

- nil control
- first square
- first flower
- first square and first flower.

Results

Establishment

As all treatments were implemented after planting, no significant difference between plots was identified. There were, on average, 15.4 plants per metre row established across all plots. Plants emerged on 16 October 2020, just six days after irrigation.

Phenology

No significant differences were identified for the number of nodes over time (Figure 1). The crop grew a total of 24.7 nodes on average and required mepiquat chloride application to keep excess vegetative growth in check. A low rate of 250 mL was applied just before flowering and a cut out rate of 2 L/ha was applied at four nodes above the white flower to cease vegetative growth.

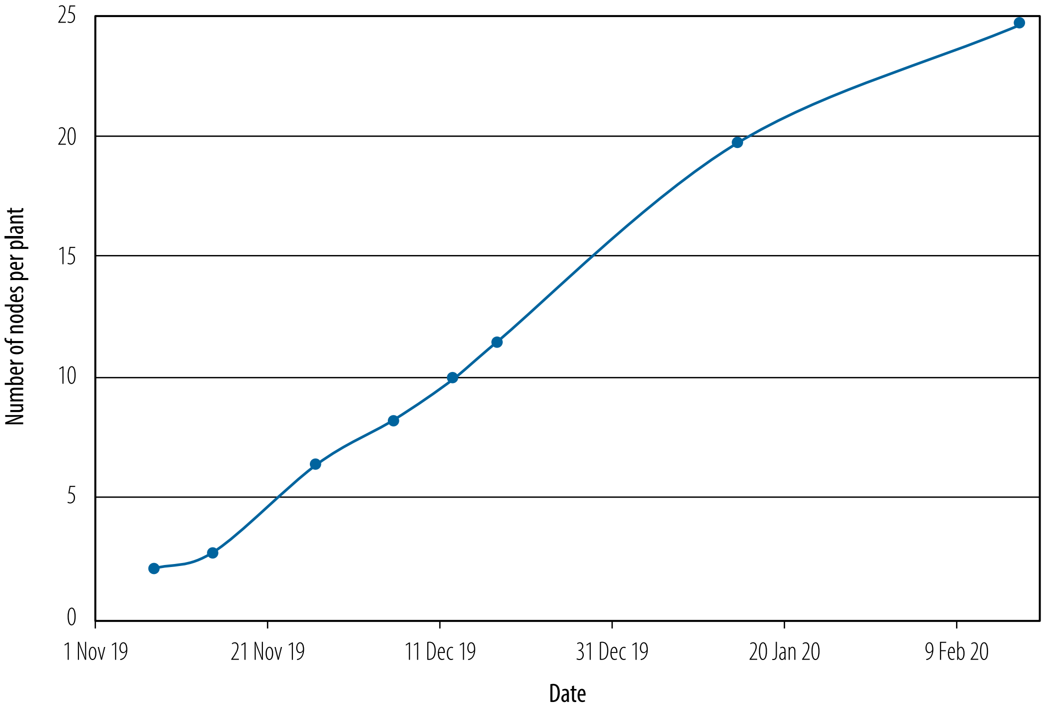


Figure 1 Number of nodes per plant average across all treatments over time.

Biomass

Biomass samples were taken at first square, first flower and defoliation. No significant difference was identified at the time of first square or first flower with an average of 398 kg DM/ha and 3,815 kg DM/ha respectively. Defoliation biomass returned on average 17,113 kg DM/ha and was not significant at *P*-value <0.05.

Leaf area

To further quantify the effect of plant hormones on growth, leaf area index was measured at flowering. Like biomass, there was no significant difference identified and averaged across all treatments to 2.63 m^2/m^2.

Yield

Machine-picked yields returned a significant yield response across the GA spray application treatments (Figure 2). There was no yield increase from applying GA at two nodes above the control, averaging 11.96 bales/ha. Applying GA at squaring increased yield by 0.73 bales/ha above the control, yielding 12.48 bales/ha.

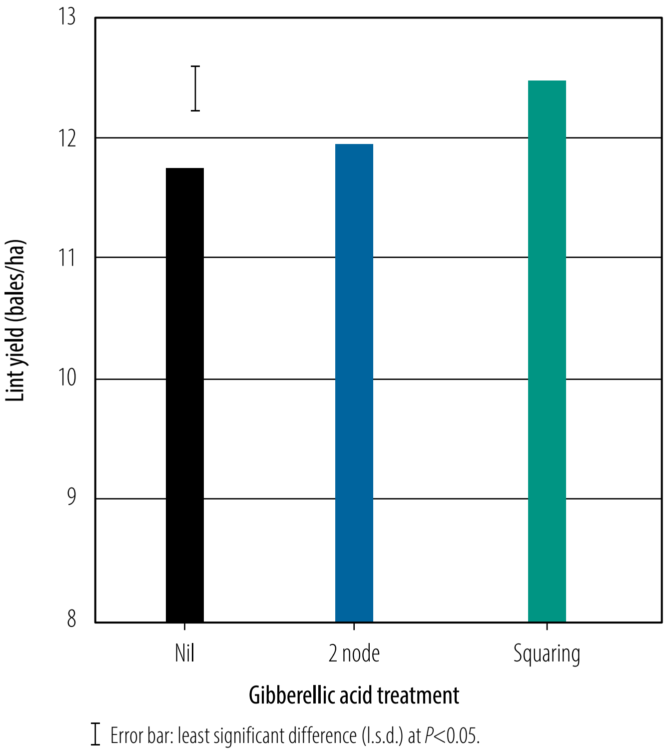


Figure 2 Yield (bales/ha) measured across the gibberellic acid treatments.

Yield components

The number of bolls counted per metre at defoliation was quite variable across treatments, but returned a significant interaction between GA and AVG. Applying GA hormone at the two-leaf stage significantly increased the number of bolls above the control, but application at squaring did not increase boll numbers (Table 1). This result varies from the yield data, which suggests applying GA at squaring improved yields.

Table 1 Boll count per metre at time of defoliation across all treatments.

GA\AVG	Boll count (bolls/m)				
	Nil	Squaring	Flowering	Squaring/ flowering	Mean
Nil	172.2	187.0	199.4	233.9	198.1
2 node	237.5	223.3	173.8	193.4	207.0
Squaring	198.1	166.0	213.1	204.6	195.4
Mean	202.6	192.1	195.4	210.7	200.2
l.s.d. GA	n.s.				
l.s.d. AVG	n.s.				
l.s.d. GA × AVG	41.98				

l.s.d. = least significant difference; n.s. = no significance.

Summary

From these findings there was no significant difference identified across the treatments for the measures conducted throughout the growing season. The yield response identified from applying GA at squaring suggests that a developmental response has been triggered in the plant and as a result yield improved over the control. Due to the measurements returning nil significance to support this yield increase, the experiment will be conducted again next season with more detailed measurements to help identify the plants' response to these hormone applications.

Acknowledgements

This experiment was part of the 'Supporting southern cotton production' project, DAN2001, 2019–22, a joint investment by the Cotton Research and Development Corporation (CRDC) and NSW DPI.

Thanks to the technical assistance of Dionne Wornes, Peter Davidson and Sam Hopper.

Contact

David Troldahl
Yanco Agricultural Institute, Yanco
david.troldahl@dpi.nsw.gov.au
0447 276 997

Cover cropping in the cotton system to improve infiltration and water holding capacity in red–brown earth soils – Yanco 2019–20

Hayden Petty, Gabby Panazzolo and David Troldahl

NSW DPI, Yanco

Key findings

- Cover cropping did not improve cotton yields in this experiment.
- High stubble loads from spraying out the cover crop after the cereals reached growth stage Z39 negatively affected established cotton plant numbers and consequently lint yield.
- Cover crops terminated at growth stage Z39 had no yield penalty, but stored more soil water than the fallow treatment.

Introduction

The aim of growing a cover crop during the winter fallow between summer crops is ultimately to improve soil structure. Cover crops can increase organic matter in the soil, providing increased aeration, aggregate stability, soil water holding capacity, nutrient cycling and erosion control.

This experiment aimed to improve the infiltration and water holding capacity of red–brown earth irrigated by furrow. Previous experiments on this soil type showed the type of cover crop grown has minimal influence on crop yields, however, the amount of biomass produced has an effect.

Establishing a desirable plant stand of cotton hinges on soil temperature, moisture and physical parameters. To ensure a field is suitable to plant cotton, there is great emphasis placed on having a uniform seed bed with the capacity to hold water once irrigated. If cover cropping is to have a place in the cotton system, the land must be prepared before the cover crop is planted. It is essential the field undergoes a no-till system to retain the cover crop and influence the subsequent cotton crop. The cover crop should then be terminated with enough time to establish cotton. The research question now posed is how much biomass needs to be produced to have a positive influence on the above soil parameters that can contribute to an increase in lint yield. In other words, when can a grower terminate the cover crop?

Site details

Location	Yanco Agricultural Institute
Soil type	Red–brown earth
Previous crop	Cotton
Sowing configuration	6 ft beds with John Deere Max Emerge 2 seeder
Mineral nitrogen (N)	114 kg N/ha (0–90 cm) at sowing
Fertiliser applied	• **Cover crop**: 100 kg/ha mono-ammonium phosphate (MAP) at sowing • **Cotton**: 260 kg N/ha as N26 water run in crop and 100 kg N/ha as urea broadcast

Variety	- **Cover crop**: Eurabbie oats (28%), Compass$^{\phi}$ barley (47%), Morava$^{\phi}$ vetch (19%) and Buster tillage radish (6%). - **Cotton**: Sicot 746B3F

Treatments

All plots (excluding the controls) were sown with the cover crop mixture in June 2019. The cover crops were terminated (sprayed out) as described in Table 1 and cotton was sown over the whole field on 9 October 2019.

Table 1 Spray out treatments and dates of termination.

Treatment	Description	Termination date
Control	Winter fallow	N/A
Early spray out	Cover crop terminated at cereal growth stage Z30 (pseudostem erect)	7 August 2019
Mid spray out	Cover crop terminated at cereal growth stage Z39 (flag leaf ligule visible)	3 September 2019
Late spray out	Cover crop terminated at cereal growth stage Z55 (ear half emerged)	30 September 2019

Results

Cover crop establishment

The cover crop mixture was sown at 80 kg/ha and achieved 200 plants/m^2. Plant proportion favoured cereals (barley and oats) up to 70% while the vetch averaged 14% of the mix and radish 11%. The crop was established on rainfall and was not irrigated through the season.

Cover crop biomass

The early spray out treatment returned 1.53 t/ha of dry matter (DM) consisting of green leafy material at almost complete ground cover and a normalised difference vegetation index (NDVI) reading of 0.8. There was 3.57 t/ha of dry matter produced from the mid spray out treatment, which returned an NDVI reading of 0.72 due to the large proportion of cereals undergoing stem elongation exposing the soil. The last spray out treatment returned an NDVI reading of 0.51 as the crop was drought stressed and undergoing premature senescence. It produced 5.46 t/ha of dry matter and was significantly lignified when terminated.

Cover crop soil water

Neutron moisture meter readings were taken from each plot intermittently throughout the experiment in both the cover crops and the cotton. From this, volumetric soil moisture was estimated and based on the calibration of the crop lower limit and drained upper limit. The plant available water (PAW) capacity was also calculated (Figure 1). Table 2 shows the PAW for each treatment and depth. Soil water just after sowing and at the early spray out treatment was not significantly different between treatments, indicating that the cover crops had not used a significant amount of water. When the mid spray out treatment was applied, the control and early spray out plots were equal. However, the mid and late spray out plots had used more water from the top 35 cm of the soil profile. Furthermore, the late spray out treatment had used the most water to grow the cover crop using 31.15 mm and 17.98 mm of PAW more than the early and mid-spray out treatments respectively.

Soil temperature

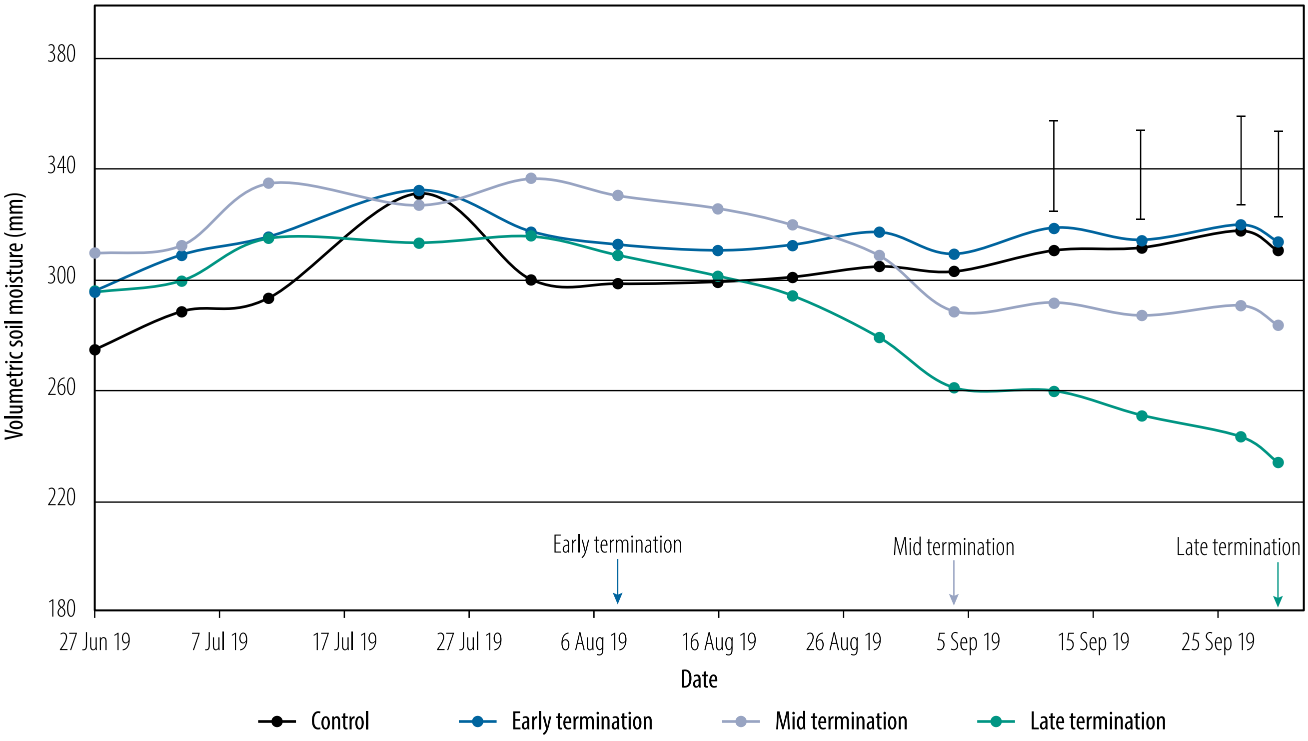
Following the cover crop treatment termination the soil temperature was recorded from 10 cm depth. Taken at 8:00 am on 8 October 2019 all plots averaged 19.1 °C. There were no significant differences detected at the alpha level of 0.05 between treatments. Exceeding the safe planting threshold temperature of 14 °C for cotton and having forecast average temperatures on a rising plane it was decided to plant on 9 October 2019. The bay was then irrigated on 10 October 2019 to germinate the seed. The irrigation resulted in an average soil temperature of 17.9 °C (n.s.), dropping by 1.1 °C. This small, insignificant drop in temperature is a function of the red–brown earth lacking clay content and having the ability to heat up faster.

Water run times

At the first irrigation, the time taken for water to reach the end of each furrow was recorded and converted to speed in cm/s. The control, having no cover present in the furrows, allowed the water to travel at a speed of 1.24 cm/s. The early spray out treatment travelled at 0.93 cm/s, which was not significantly different from the control. The mid and late spray out treatments significantly slowed the water speed to 0.56 cm/s and 0.51 cm/s respectively, however, they were not significantly different from each other.

Cotton establishment

From the germination date of 10 October 2019, it took six days for the seedlings to emerge on 16 October. The control, having no cover load present, established the most plants/m^2 averaging 12.83. The early spray out treatment resulted in 11.45 plants/m^2, but was not significantly different from the control. The mid and late spray out treatments established 10.34 and 8.08 plants/m^2 respectively, which differed significantly from the control. The decrease in plant numbers with increasing cover loads is largely due to the stubble and soil moisture content affecting seed placement. The larger cover loads reduced soil water resulting in a very dry seed bed meaning seed placement was variable causing dry down and poor germination.



Ι Error bar: least significant difference (l.s.d.) at *P*<0.05 for that date.
Data points with no error bars for that date are not significantly (n.s.) different.
↓ Arrows indicate the date each termination treatment was applied.

Figure 1 Volumetric soil moisture of the total soil profile from 0–100 cm for the period that cover crops were growing.

Table 2 Plant available water in millimetres across depth and spray out treatments for the period that cover crops were growing.

Date	Depth (cm)	Plant available water (mm)				
		Control	Early spray out	Mid spray out	Late spray out	l.s.d.
Post sowing 27 June 2019	0–25	37.77	38.01	38.63	38.45	n.s.
	25–35	12.30	12.56	12.58	12.71	
	35–45	7.35	8.60	8.34	8.72	
	45–55	4.34	6.62	6.56	6.79	
	55–65	4.09	5.66	6.24	6.29	
	65–80	9.04	10.53	12.79	11.13	
	80–100	17.65	16.78	19.98	17.15	
	Total	93.23	99.87	105.19	100.07	n.s.
Early spray out 8 August 2019	0–25	38.96	37.46	37.43	36.34	n.s.
	25–35	13.05	12.97	13.15	12.90	
	35–45	8.72	9.11	9.49	9.34	
	45–55	5.77	7.50	8.01	8.17	
	55–65	5.08	6.78	7.63	7.32	
	65–80	10.48	12.52	14.59	12.40	
	80–100	18.82	18.23	21.40	18.09	
	Total	101.70	105.50	111.70	103.60	n.s.
Mid spray out 4 September 2019	0–25	38.55	37.54	29.37	27.98	2.882
	25–35	13.06	12.70	9.78	9.29	
	35–45	8.37	8.83	6.97	6.72	
	45–55	5.55	7.13	6.28	5.80	
	55–65	5.36	6.67	7.10	6.18	
	65–80	10.96	12.48	14.38	11.49	
	80–100	19.63	18.42	21.26	18.23	
	Total	103.33^{b}	104.47^{b}	95.12^{ab}	85.01^{a}	12.224
Late spray out 30 September 2019	0–25	37.36	37.30	26.80	23.80	2.964
	25–35	13.05	12.74	9.15	7.74	
	35–45	8.41	8.83	6.88	5.47	
	45–55	6.13	7.42	6.11	4.38	
	55–65	5.96	6.91	7.10	5.01	
	65–80	11.95	13.10	14.75	10.43	
	80–100	20.19	19.10	22.26	18.20	
	Total	105.42^{bc}	105.93^{c}	92.76^{b}	74.78^{a}	11.676

Least significant difference (l.s.d.) *P*-value <0.05 presented on the interaction between spray out treatment × depth and separately for total.
n.s. = not significant.
Letters presented on means of the total profile indicate which treatments differ significantly from each other.

Cotton biomass

Each plot was assessed for squaring date and a biomass sample taken. Across all treatments the date of first square averaged 17 December 2019 (n.s.). The biomass was heaviest for the control, achieving 687.7 kg DM/ha (Table 3). The reduced biomass recorded for the early spray out treatment was not significantly different from the control. The mid and late spray out treatments had accumulated 427.4 and 358 kg DM/ha respectively and differed significantly from the control, but not from each other.

The first flower date was recorded as 17 January 2020. The differences identified at first square mainly resulted from the established plant numbers and were still evident at flowering with almost 1200 kg DM/ha difference between the control and the late spray out treatment.

By defoliation there were no significant biomass differences between treatments and the biomass averaged 15,024 kg DM/ha. Cotton is very good at compensating growth and maximising the available space and water by producing vegetative branches. First pass defoliation was applied on 15 April 2020 and the crop required three defoliations to drop leaf and open bolls.

Table 3 First square and first flower biomass taken across each treatment.

Treatment	Biomass first square (kg DM/ha)	Biomass first flower (kg DM/ha)
Control	687.7	4600
Early spray out	544.7	4111
Mid spray out	427.4	3843
Late spray out	358.0	3410
l.s.d. ($P<0.05$)	147.52	711.8

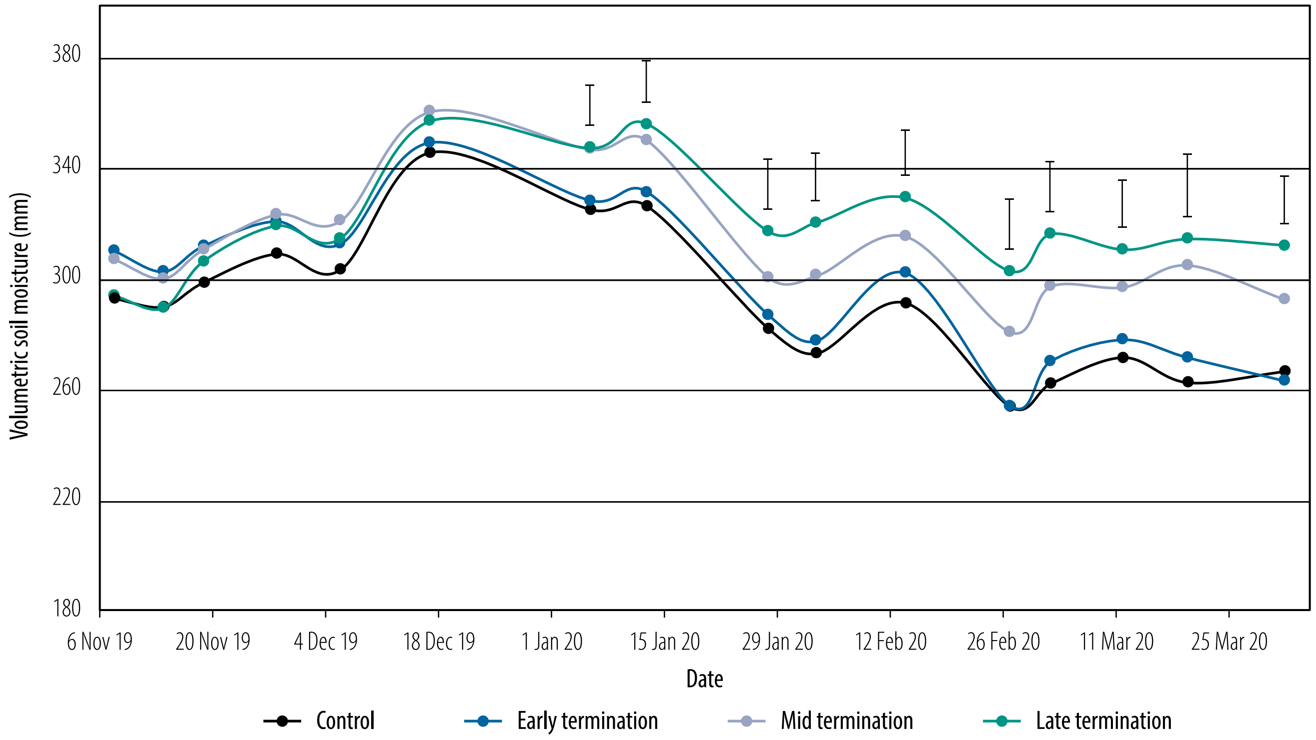
l.s.d. = least significant difference.

Cotton soil water

Once the cotton was planted and flushed up, the soil water deviations seen at the end of the cover cropping period were eliminated. There were no significant differences between treatments for PAW until flowering when the crop started using large amounts of water. Both the mid and late spray out treatments measured more water in the profile compared with the control and early spray out treatments (Figure 2). This can be explained by the reduced plant stand in both treatments as there were not enough plants to extract the available moisture present in the profile. It could also be a function of the cover crop residues improving water infiltration under irrigation, however, these inferences cannot be assumed in this experiment.

Towards the end of the season the control and early spray out treatments started to extract moisture from depth more than the mid and late spray out treatments (Table 4). The higher plant stands in these treatments probably resulted in the crop depleting soil moisture sooner than the mid and late spray out treatments, forcing root growth to explore the soil profile in search of moisture.

Changes in PAW over time (Figure 3) shows the additions and depletions of soil water from sowing the cover crop to defoliating the cotton. The extraction of soil water from the spray out treatments is clearly depicted here and reflects the total soil moisture data presented in Figure 1. Once the cotton crop was irrigated to germinate the planted seed, all treatments returned to an equal level of soil moisture. Once the crop started extracting larger amounts of water it was evident that there was a treatment effect. As mentioned above, this treatment effect could be a function of improved infiltration or poor plant stand.



Error bar: least significant difference (l.s.d.) at $P<0.05$ for that date.
Data points with no error bars for that date are not significantly (n.s.) different.

Figure 2 Volumetric soil moisture of the total soil profile from 0–100 cm for the period that the cotton crop was growing.

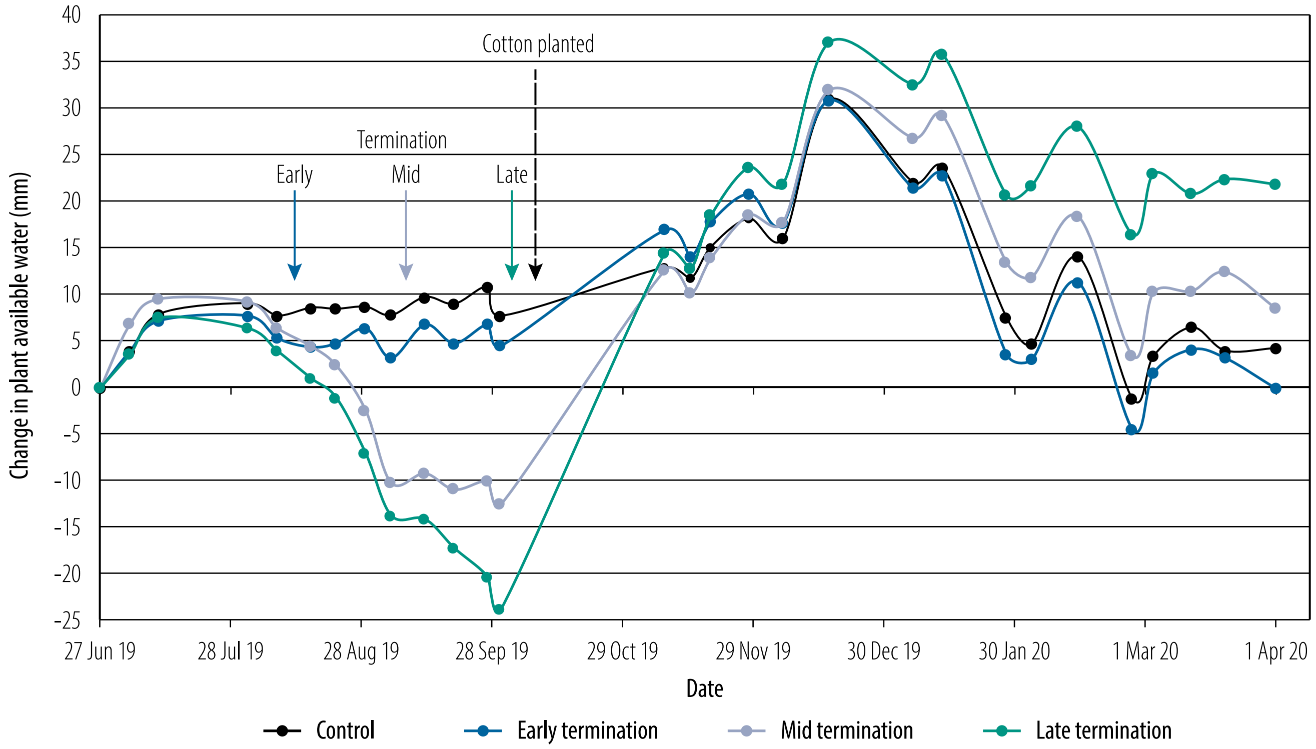


Figure 3 Change in plant available water (PAW) during the cover crop growth period and during the cotton season.

Table 4 Plant available water in millimetres across depth and spray out treatments for the period that the cotton crop was growing.

Date	Depth (cm)	Plant available water (mm)				
		Control	Early spray out	Mid spray out	Late spray out	l.s.d.
Early season growth 8 November 2019	0–25	39.20	38.59	39.53	39.93	1.268
	25–35	12.66	13.06	13.12	13.58	
	35–45	9.26	9.83	9.82	9.98	
	45–55	8.22	9.43	9.19	9.20	
	55–65	8.29	9.41	9.25	8.32	
	65–80	15.06	16.70	16.38	14.07	
	80–100	19.69	21.25	20.13	18.31	
	Total	112.7	118.4	117.6	113.0	n.s.
First square 17 December 2019	0–25	41.20	39.60	41.41	41.27	n.s.
	25–35	14.35	14.18	14.69	14.78	
	35–45	10.91	11.14	11.40	11.54	
	45–55	10.92	11.18	11.25	11.48	
	55–65	10.71	11.08	11.28	11.19	
	65–80	19.16	19.77	20.56	20.02	
	80–100	24.46	25.41	26.16	25.23	
	Total	131.6	132.4	136.8	135.5	n.s.
First flower 13 January 2020	0–25	36.04	36.93	38.65	39.75	n.s.
	25–35	12.04	12.68	13.39	14.34	
	35–45	9.88	10.17	10.76	11.38	
	45–55	10.37	10.40	11.08	11.44	
	55–65	10.33	10.70	11.16	11.57	
	65–80	19.25	19.23	20.47	20.47	
	80–100	25.42	25.71	26.19	25.95	
	Total	123.4^{a}	125.4^{a}	132.4^{b}	134.7^{b}	5.52
Defoliation 1 April 2020	0–25	37.28	37.45	38.66	40.47	n.s.
	25–35	10.44	11.34	11.92	13.02	
	35–45	6.77	8.27	8.08	9.48	
	45–55	5.73	6.81	7.13	8.80	
	55–65	7.40	7.03	7.85	8.87	
	65–80	14.39	12.66	15.84	16.81	
	80–100	21.18	20.18	22.33	22.32	
	Total	103.7^{a}	102.3^{a}	113.0^{b}	120.0^{b}	6.442

Least significant difference (l.s.d.) P-value <0.05 presented on the interaction between spray out treatment × depth and separately for total.
n.s. = not significant.
Letters presented on means of the total profile indicate which treatments differ significantly from each other.

Soil nitrogen

No significant difference in soil N was identified between cover crop spray out treatments. On average, there was 112 kg N/ha from 0–90 cm when the cover crops were sown. After all cover crops had been terminated, the soil was again analysed for N before cotton was planted. At this time there was 16 kg N/ha to 90 cm depth. The cotton crop was supplied with 360 kg N/ha via water run and broadcast methods and on average the soil retained 57 kg N/ha to 90 cm after crop destruction.

Yield

Machine-picked lint yields were above the district average of 11 bales/ha and, given the difficult season, the crop performed well. Lint yields harvested across all treatments had a 1.76 bale/ha decrease from the control (highest yielding) to the late spray out treatment (lowest yielding). All other treatments did not vary significantly from the control of 13.79 bales/ha (Table 5).

This negative yield response to the increased amount of biomass from a late spray out is likely to result from reduced establishment. Plant numbers per metre dropped 4.75 by spraying out late compared with the control. Similarly, the mid spray out treatment yielded statistically the same as the control and yet the number of plants established per meter in this treatment dropped by 2.49 from the control. It can be assumed that the plant compensatory growth under these circumstances can compensate for a loss of 2.5 plants/m, but fails to achieve the same yield potential with only 8.1 plants/m.

Table 5 Lint yields picked from each of the treatments expressed as 227 kg bales per hectare.

Treatment	Lint yield (bales/ha)
Control	13.79 (100) [a]
Early	13.56 (98) [a]
Mid	13.49 (98) [a]
Late	12.03 (87) [b]
l.s.d. ($P<0.05$)	1.242

Figures in parentheses indicate the percentage of control.
Letters presented indicate which treatments differ significantly from each other.

Summary

There were no benefits of cover cropping reflected in cotton yields after just one season. It is safe to assume that the improvement of soil structure and health takes longer than 12 months to have a significant influence on crop yields. The best performing treatment was the mid spray out treatment where the cover crop was terminated at growth stage Z39 and produced 3.57 t/ha of dry matter. The yields in this treatment were not significantly different from the control. It slowed the movement of water through the furrow and resulted in more PAW towards the end of the cotton season. Given the availability of water and assuming no other limiting factors, if the number of established plants per metre could be compensated for with a higher sowing rate, then the yields under this system could potentially be improved above the control.

Acknowledgements

This experiment was part of the 'Cover crops in grain and cotton farming systems' project, DAQ00211, 2018–21, a joint investment by the Cotton Research and Development Corporation (CRDC), NSW DPI, GRDC and the Queensland Department of Agriculture and Fisheries (QDAF).

Thanks to the technical assistance of Alan Boulton, John Dando and Sam Hopper.

Contact

David Trohdahl
Yanco Agricultural Institute, Yanco
david.troldahl@dpi.nsw.gov.au
0447 276 997

Managing competition and lucerne persistence with sowing configuration

Richard Hayes[1], Dr Guangdi Li[1] and Matthew Newell[2]
[1] NSW DPI, Wagga Wagga
[2] NSW DPI, Cowra

Key findings

- Lucerne target establishment density for dryland environments should not exceed 50 plants/m^2; or 28 plants/m of drill row.
- Changing row configuration did not increase lucerne persistence.
- Sowing lucerne with a cover crop reduced final lucerne density by 39%.
- Lucerne mortality is affected more by summer conditions than the presence of winter-growing companion species, such as phalaris or subterranean clover.

Introduction

Lucerne is a key pasture species underpinning mixed farming enterprises in southern and central NSW. Optimising lucerne productivity and persistence offers substantial benefits to both grazing livestock and subsequent crops in the rotation. Confining lucerne to particular drill rows could help manage competition between pasture components or crop species when undersowing, and improve lucerne persistence. The re-configuration of most seeders is relatively easy and represents a negligible increase in pasture establishment costs. However, very little objective data exists to determine the extent to which drill row configuration at sowing affects lucerne persistence.

Site details

Location	Riverina and central west NSW
Riverina sites	Three sites at Eurongilly, Mirrool and Wagga Wagga; all sown in May 2012.
Central west sites	Six sites at Bogan Gate, Condobolin and Cowra; all sown in April–May 2013 and repeated in 2014.
Riverina treatments	• Lucerne only in every drill row [Luc-only] • Lucerne/subterranean clover in mixed rows [Luc-sub(mix)] • Lucerne/subterranean clover in alternate rows [Luc-sub(1:1)] • One row of lucerne to every two rows of subterranean clover [Luc-sub(1:2)] • Phalaris/lucerne in mixed rows [Phal-luc(mix)]* • Phalaris/lucerne in alternate rows [Phal-luc(1:1)] * • One row of phalaris to every two rows of lucerne [Phal-luc(1:2)]* * Note: Subterranean clover was included in every drill row
Central west treatments	• Lucerne/subterranean clover in mixed rows (pasture only) • Crop only (wheat, barley, canola or lupins) • Pasture–crop mix in every drill row (mix) • Pasture–crop in alternate drill rows (1:1)

Sowing method	The same cone seeder was used for all experiments: • 25 cm row spacings • Narrow points and press wheels.
Seeding rate	Seeding density, of all species remained constant for a given area. That is, if the number of drill rows into which a species was sown was halved (i.e. the 1:1 treatments), the concentration of seed of that species within a drill row was doubled.
Fertiliser	Broadcast at the surface.
Replicates	Each treatment was replicated three times.

Cultivars and sowing rates

Riverina sites

- Lucerne (sown alone or with subterranean clover): 3 kg/ha (50% cv. Aurora, 50% cv. Genesis)
- Lucerne (sown with phalaris): 1.5 kg/ha (50% cv. Aurora, 50% cv. Genesis)
- Phalaris: 1.5 kg/ha (100% cv. Sirolan)
- Subterranean clover: 4 kg/ha (cultivars sown in equal proportions by weight)
    - Eurongilly: cvv. Gosse, Goulburn, Coolamon
    - Mirrool: cvv. Trikkala, Bindoon, Dalkeith
    - Wagga Wagga: cvv. Riverina, Bindoon, Coolamon

Central west sites

- Wheat cv. Suntop: 23 kg/ha (68 kg/ha at Cowra)
- Barley cv. Hindmarsh: 23 kg/ha (68 kg/ha at Cowra)
- Canola cv. Stingray: 0.6 kg/ha (2.4 kg/ha at Cowra)
- Lupin cv. Mandelup: 40 kg/ha (80 kg/ha at Cowra)
- Lucerne cv. Pegasus: 3 kg/ha (8 kg/ha at Cowra)
- Subterranean clover: 6 kg/ha (cultivars sown in equal proportions by weight)
- cvv. Seaton Park and Izmir at the Bogan Gate and Condobolin sites
- cv. Coolamon at Cowra (at 8 kg/ha)

Full details of this study are available online: Sowing configuration changes competition and persistence of lucerne (*Medicago sativa*. L) in mixed pasture swards (Hayes et al. 2021).

Results

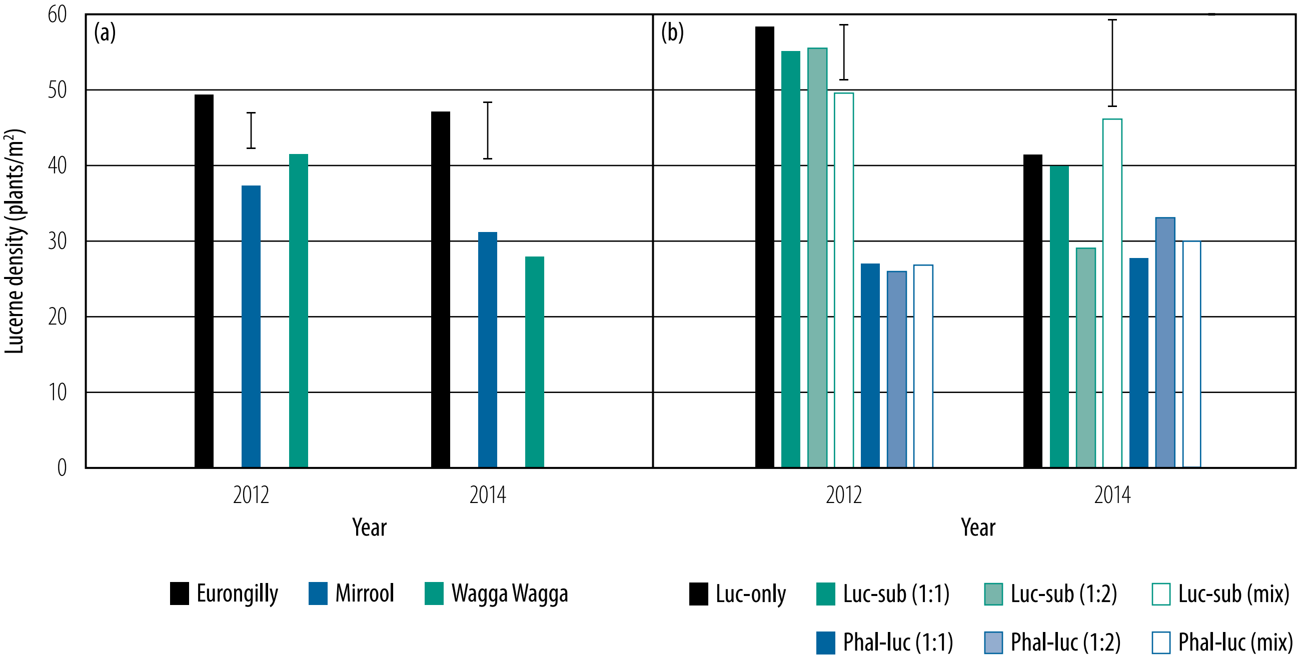
Final lucerne density at the Riverina sites

There was a significant effect of site × sowing configuration on lucerne density in years one and three of the pasture phase.

Lucerne density was higher at the Eurongilly site at both sampling times compared with Mirrool and Wagga Wagga (Figure 1a).

Lucerne density in treatments sown with phalaris was approximately 50% of that where lucerne was sown alone or with subterranean clover, reflecting the reduced sowing rates when phalaris was added to the sward (Figure 1b).

There was little reduction in lucerne density from years 1–3 in the phalaris-based swards, but density declined in the lucerne only and lucerne/subterranean clover swards with time. This was especially evident in the Luc-sub(1:2) treatment indicating that intraspecific competition (lucerne competing with itself) led to increased lucerne mortality associated with the concentration of lucerne seed from three drill rows into just one. There was little evidence of interspecific competition from phalaris or subterranean clover affecting lucerne persistence.



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

Figure 1 The effect of a) site, and b) row configuration on lucerne density at the start (2012) and at the conclusion (2014) of the Riverina experiments.

Final lucerne density at the central west sites

At each site, lucerne density was higher in the 2014-sown experiments compared with the 2013-sown experiments where stands were one year younger at the time of sampling (Figure 2, see also Figure 5b).

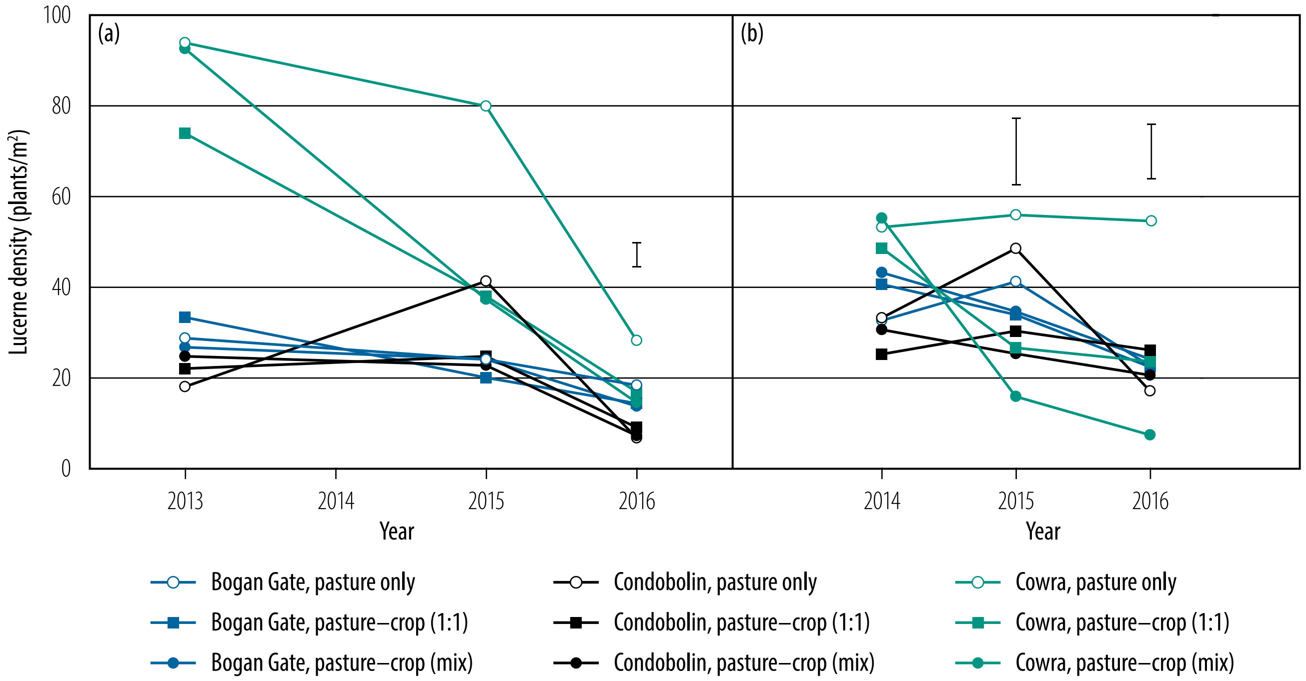
Averaged across sites, lucerne density was 39% greater ($P<0.05$) in the pasture-only treatment (27.4 plants/m^2) compared with where it was sown with a crop, regardless of whether the crop was sown in mixed (19.7 plants/m^2) or alternate rows (20.4 plants/m^2) with the pasture.

Averaged across sites, the final lucerne density was significantly higher where it was sown in mixtures with lupins (30.1 plants/m^2) compared with where it was sown with wheat, barley or canola (19.3, 20.7 and 22.3 plants/m^2, respectively).

There was no significant crop × row configuration interaction ($P>0.05$).

Lucerne populations had generally declined to densities of 10–20 plants/m^2 after four years in the 2013-sown experiments in the central west, and to 20–30 plants after three years in the 2014-sown experiments (Figure 2).

Lucerne densities generally remained higher in the pasture-only treatments compared with where wheat was sown with the pasture, regardless of whether the wheat was sown in mixed or alternate drill rows, especially at Cowra in the 2014-sown site where there was no decline in density during the pasture phase.



I Vertical bars represent l.s.d. ($P = 0.05$) on dates where a significant site × treatment interaction was observed

Figure 2 Change in lucerne density through time due to spatial configuration associated with wheat crop only at experiments sown at three sites in the Central West in a) 2013, and b) 2014.

The summer of 2013–14 was the driest at each of the sites compared with any other year, especially at the Riverina sites (Figure 3).

All sites in the central west received ≥100 mm rainfall in each of the years with little apparent difference at Cowra compared with the other sites.

By contrast, Cowra was consistently the site with lower summer temperatures, especially in the final two years (Figure 4). This probably contributed to superior lucerne persistence at this site in the pasture-only treatment (Figure 2b).

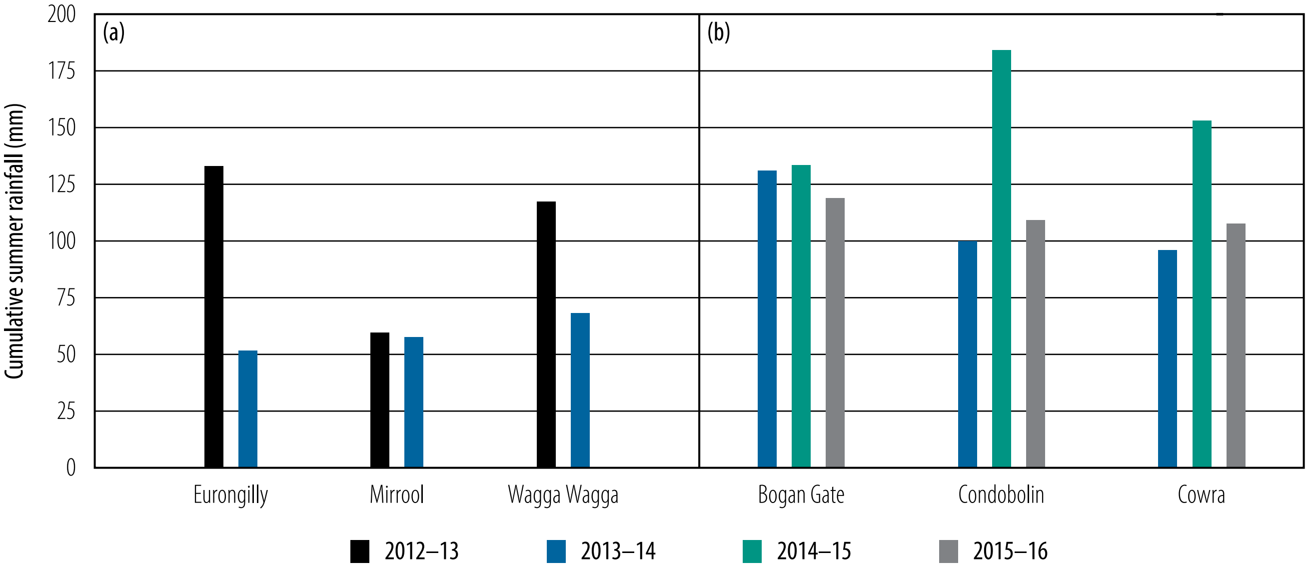
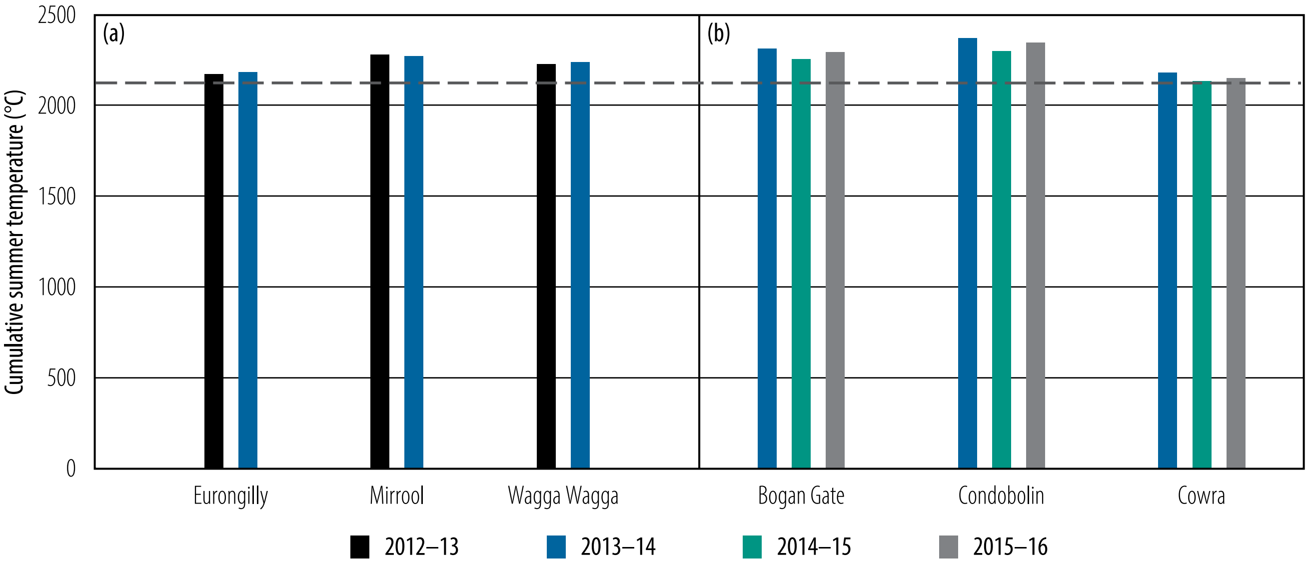


Figure 3 Cumulative summer rainfall (mm) received at a) the Riverina, and b) the central west sites during the experiment.

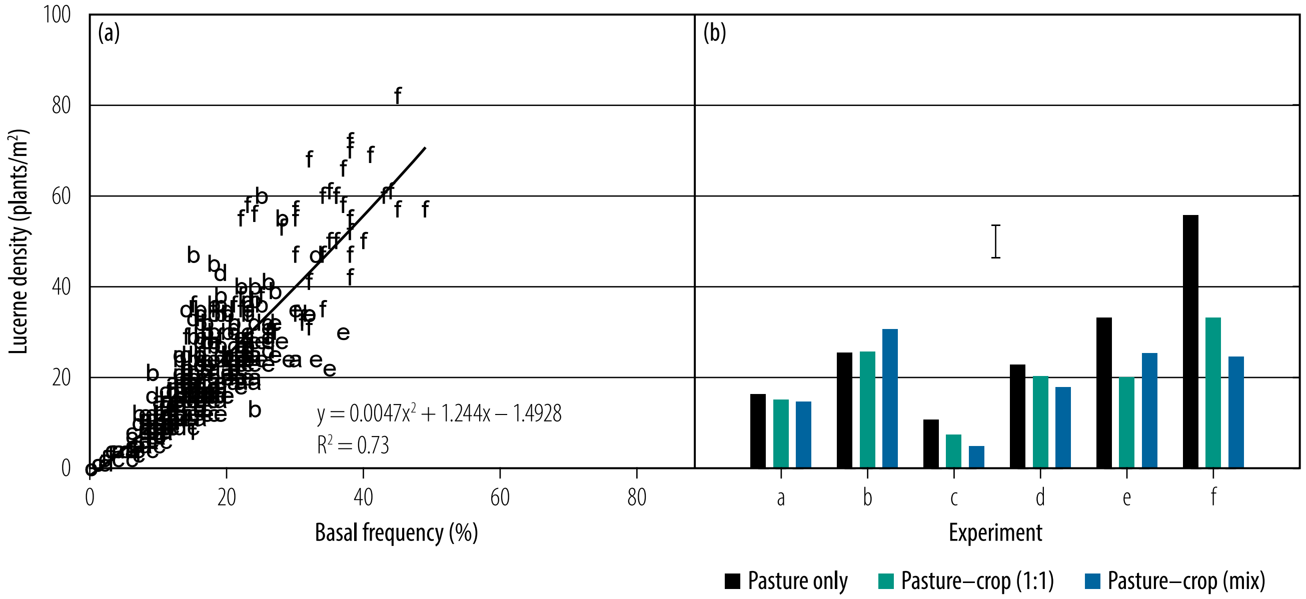


The dashed line marks 2150 °C

Figure 4 Cumulative summer temperature (day degrees °C) at a) the Riverina, and b) the central west sites during the experiment.

Estimation lucerne density with basal frequency

A total of 8540 plants were excavated from 382 quadrats at the six sites at the conclusion of the experiments to determine final lucerne density. There was a strong correlation ($P<0.001$; $R^2 = 0.73$; n = 382) between lucerne density and basal frequency (Figure 5a). When all sites and treatments were included, basal frequency generally reflected lucerne density up to around 15 plants/m², but underestimated lucerne density by 20–25% in the range of 15 to 30 plants/m² and by 25–30% in the range of 30 to 80 plants/m².



Vertical bars represent l.s.d. ($P = 0.05$)

Data from individual experiments are marked according to letter; Bogan Gate sown in 2013 (a) and 2014 (b), Condobolin sown in 2013 (c) and 2014 (d), Cowra sown in 2013 (e) and 2014 (f).

Figure 5 a) The relationship ($P<0.001$) between basal frequency and lucerne density (n = 188), and b) site × spatial configuration effects on final lucerne density across the six experiments in the central west.

Summary

Spatial sowing configuration had no effect on lucerne persistence in alternate row configuration (1:1) compared with lucerne sown in every drill row. However, where lucerne was confined to every third row (1:2 configuration), there was an increase in mortality attributable to intraspecific competition at lucerne densities greater than 28 plants/m of drill row. A lucerne sowing rate of ~6 kg/ha, when delivered to every drill row at 25 cm row spacings, is likely to achieve maximum lucerne production in the semi-arid environments tested, but subject to the chance event of receiving favourable conditions in the period after sowing to maintain adequate lucerne densities.

Favourable conditions at the Cowra site included cumulative summer rainfall exceeding 100 mm and cumulative summer day degrees below 2160 °C. In drier environments, where the frequency of favourable seasonal conditions is likely to be lower, we suggest that more emphasis should be placed on the winter-growing species as opposed to the lucerne component of the sward to improve productivity, as interspecific competition from winter-growing forage species had little effect on lucerne persistence.

By contrast, interspecific competition from vigorous cover crops established in year one consistently increased lucerne mortality compared with where pastures were sown without a cover crop.

Acknowledgements

The New South Wales Department of Primary Industries (NSW DPI) and the Grains Research and Development Corporation (GRDC) contributed the necessary financial support for this research through the EverCrop project (CSA 00044).

The technical support provided by Susan Langfield, Richard Lowrie (NSW DPI), and Tony Swan (CSIRO) is gratefully acknowledged. Comments from two anonymous reviewers on previous drafts of this manuscript were greatly appreciated.

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Contact

Richard Hayes
Wagga Agricultural Institute, Wagga Wagga
richard.hayes@dpi.nsw.gov.au
0448 231 704

Using second generation hard-seeded legumes in pasture crop rotations

Josh Hart[1], Tyson Wicks[2], Daryl Reardon[3] and Dr Belinda Hackney[4]

[1] NSW DPI, Yanco
[2] NSW DPI, Wagga Wagga
[3] NSW DPI, Condobolin
[4] NSW DPI, Cowra

Key findings

- Sowing header-harvested (minimally processed) seed of second generation annual legumes in summer can provide benefits for biomass and seed production in the establishment year by opening the sowing window for pastures.
- When grown under severe drought conditions, second generation legumes were able to support grain yields in following wheat crops of 4–5 t/ha without additional nitrogen (N) fertiliser, whereas wheat grown following traditional legumes required the same N-fertiliser input as continuous cropping treatments to achieve a similar grain yield.
- When grown under extreme drought conditions, second generation legumes established via summer sowing significantly increased potential livestock production compared with conventional pasture legumes sowing in late autumn.
- In the higher than average rainfall over 2020, summer sowing increased herbage availability compared with conventional sowing to the extent that excess herbage for silage or hay could be cut without adversely affecting seed production and future regeneration capacity of most legumes.

Introduction

Over the past few decades a range of new annual legumes for use in Australian and international agriculture have been developed. These legumes, termed 'second generation legumes', including biserrula, serradella (French and yellow) and the clovers (arrowleaf, bladder and gland) were selected based on the following attributes:

- capacity to harvest on farm using a cereal header
- increased hard seed levels
- deeper root systems and/or improved tolerance to soil physiochemical constraints (Loi et al. 2005).

Further research, starting almost a decade ago, based on:

- the capacity of such legumes to facilitate on-farm harvest of large quantities of minimally processed seed (seed undergoes minimal scarification or is retained in pod segments)
- understanding hard seed breakdown patterns
- the development of robust inoculant delivery technology

resulted in the development of summer sowing as a mechanism to establish annual legume pastures (Howieson et al. 2021; Nutt et al. 2021).

Summer sowing involves sowing header-harvested (minimally processed) seed in mid to late summer along with granular inoculant. A proportion of the hard seed breaks down over summer and early autumn and is able to germinate on early rains, meaning seedlings emerge while temperatures are still favourable for growth. Surviving early germination, which is often much earlier than when traditional annual legumes are sown as scarified seed, is predicated on the seedlings' capacity to rapidly form their root system and/or improved capacity to better regulate transpiration losses (Carr et al. 1999; Foster et al. 2012).

Essentially, summer sowing, using appropriate legumes species and cultivars within species, reduces pasture establishment costs where seed is produced on-farm and significantly opens the sowing window for pastures.

For traditional annual legumes species such as subterranean clover, summer sowing is not an option as a relatively high proportion of seed is scarified during suction harvesting (Nutt et al. 2021). The seedlings of traditional legumes are prone to loss where they emerge early under marginal moisture (false break) conditions due to their relatively slow-forming root system and poor ability to regulate transpiration losses (Loi et al. 2005).

Over recent decades, autumn rainfall conditions have become more variable and there has been increasing competition for on-farm resources (labour, sowing equipment) from winter cropping programs, forcing traditional pasture sowing later in autumn and often into winter (Hogg and Davis 2009; Hackney et al. 2021a). Legume seedlings that emerge under low temperatures in late autumn and early winter produce little herbage over winter and small seedlings are more susceptible to adverse spring soil moisture conditions, particularly for species with relatively shallow root systems. Consequently, late sown traditional annual legumes can fail to set useful quantities of seed, which is vital for future regeneration.

Nutt et al. (2021) showed significant advantages in herbage and seed production with summer sowing compared with conventional sowing, overcoming significant barriers to pasture renovation such as:

- cost
- poor herbage and seed production of first-year pastures established conventionally
- removal of competition for labour and machinery resources which occurs when trying to fit conventional pasture renovation in around the winter cropping program. Summer sowing allows pasture renovation to be completed ahead of the winter cropping program (Hogg and Davis 2009).

While the research of Howieson et al. (2021) and Nutt et al. (2021), reported significant advantages from summer sowing compared with conventional sowing, their research was completed in years with near average rainfall. The recent extreme drought conditions of 2019 and the above average rainfall in 2020 offered capacity to test the flexibility of summer sowing against conventional sowing as a mechanism for pasture establishment and supporting livestock production systems under contrasting seasonal conditions. Additionally, given hardseeded legumes are generally used in rotation with crops, there was also the opportunity to compare the ability of a range of legumes, both traditional and second generation, established under the extreme drought conditions of 2019 to supply sufficient nitrogen to support wheat production in the following above-average rainfall year.

Experiment details

Treatments and methods

Sites were established at Kikoira (2019) and Condobolin (2020), NSW using a range of hardseeded legumes sown either as minimally processed seed in late summer (summer sowing) or as scarified seed in late May (conventional sowing) using rates as per Nutt et al. (2021; Table 1) in replicated (n = 4) experiments with individual plots measuring 4.3 x 30 m. Subterranean clover and burr medic were included as industry standard controls sown only in late May due to their susceptibility to false breaks. At each sowing date, granular inoculant of the appropriate group for each species was included. As both experiment sites were to be used in on-going rotations, wheat was also included as a treatment at both sites sown at 40 kg/ha to represent a continuous cropping treatment in later years.

At Condobolin in 2020, two summer sowing treatments were included for biserrula:

- minimally processed seed as per 2019
- a seed mix containing 70% minimally processed seed and 30% scarified seed (SSM).

The latter treatment was included as some growers in low rainfall regions choose to lightly scarify biserrula seed to increase germinability as breakdown rates can be slow if rainfall is very low or absent over late summer and early autumn (Hackney and Quinn 2015; Nutt et al. 2021).

Table 1 The sowing rates (kg/ha) of second generation and traditional annual legumes sown either as minimally processed seed in late summer or as scarified seed in late May at the Kikoira (2019) and Condobolin (2020) sites.

Species	Cultivar/accession	Sowing rate (kg/ha)			Inoculant group (all sown at 10 kg granules/ha)
		Summer – minimally processed seed	Summer – scarified seed	Late May scarified seed	
Arrowleaf clover	Cefalu	12	–	7	Group C
Biserrula	Casbah	12	–	7	Biserrula special
Biserrula SSM	Casbah	8.4	3.6	7	Biserrula special
Bladder clover	Bartolo	12	–	10	Group C
Gland clover	Prima	12	–	7	Group C
French serradella	Fran2o	20 (pod segments)	–	10	Group G/S
Yellow serradella	87GEH72.1a	20 (pod segments)	–	10	Group G/S
Subterranean clover	Dalkeith	–	–	10	Group C
Burr medic	Cavalier	–	–	10	Group AM

Note: For biserrula, the modified summer sowing treatment (SSM) sowing rates are also shown along with the inoculant group for each species.

At Kikoira, herbage biomass was assessed four times though the growing season via calibrated visual assessment with herbage collected at peak spring production for herbage quality analysis. The peak herbage biomass data for Kikoira in 2019 was used to predict the liveweight gain potential of merino weaners (initial weight 25 kg) using Grazfeed, as severe drought conditions meant growers were considering the best use of available feed resources.

In April 2020, soil cores were taken to 40 cm for mineral N analysis from each plot with wheat sown over the entire site in mid April. Each plot was subdivided into two with one half being left to assess regeneration (data not reported here) and the other sown to wheat for a N application experiment. Three nitrogen treatments were implemented on the wheat:

1. N withheld
2. 15 kg N/ha – applied at sowing only
3. N applied at sowing plus topdressing of 75 kg N/ha at GS30–31 and 50 kg N/ha at GS51.

Soil tests for soil mineral N were also taken and the effect on wheat yield and protein assessed.

At Condobolin in 2020, the experiment was established as per Kikoira in 2019. As a result of vigorous growth in the summer sown treatments, each plot was subdivided into three treatments:

1. silage cut (mid September)
2. hay cut (late September)
3. control (uncut).

The total herbage yield (including regrowth on the cut treatments) was then determined. Seed yield was determined by collecting seed from two quadrats within each subplot. Rooting depth was also quantified at this site. It should be noted that with the exception of conventionally sown arrowleaf clover, gland clover and biserrula, all other conventionally sown treatments were below cutting height at both the silage and hay cutting times. For those conventionally sown species above cutting height, less than 20% of available biomass was removed via cutting. For brevity, only the herbage yields of the uncut portion of the conventionally sown plots is shown in this paper. It should be noted that cutting did not result in an increase or decrease in herbage yield of the conventionally sown plots compared with the uncut control.

Seasonal growing conditions

Rainfall, both annual and growing season, were well below average in 2019 at Kikoira and well above average at both Kikoira and Condobolin in 2020 (Table 2). This enabled evaluation of legume species and pasture establishment methodology under contrasting seasonal conditions.

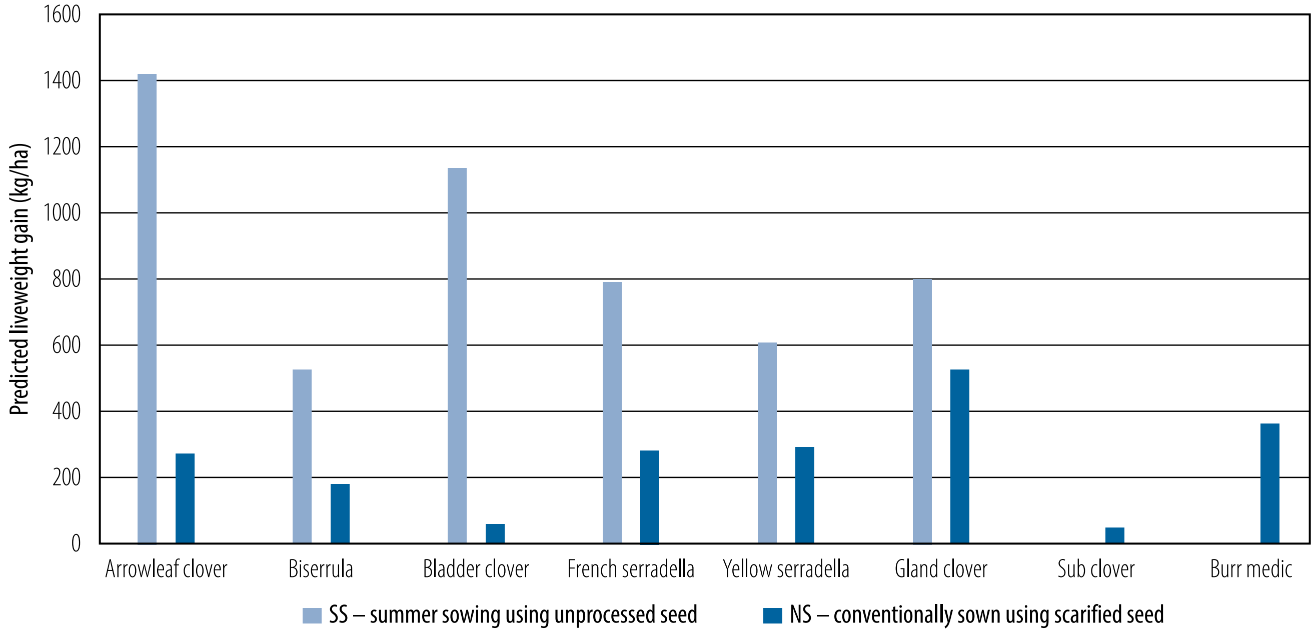
Table 2 Growing season and annual rainfall (mm) with figure in parentheses showing percentage of long-term average for Kikoira and Condobolin sites.

Establishment year	Location	Rainfall (mm) (% of long-term average)			
		Annual 2019	Growing season 2019	Annual 2020	Growing season 2020
2019	Kikoira	255 (50%)	89 (36%)	555 (123%)	347 (134%)
2020	Condobolin			735 (161%)	347 (142%)

Results

Biomass and potential liveweight gain 2019

Hackney et al. (2021b) has previously reported herbage production at Kikoira. When herbage yield and quality data was used to predict weaner merino lamb liveweight gain, summer sowing increased potential productivity by 1.5 to 20 times over conventional sowing (Figure 1). Overall, average liveweight gain from conventional sowing was 255 kg/ha compared with 844 kg/ha in the summer sown treatments (Figure 1). Within the conventional sowing treatments, all species except bladder clover gave an increase in potential production of 4- to 11-fold compared with the subterranean clover which had a predicted liveweight gain of 48 kg/ha.



Liveweight gain was calculated in Grazfeed using peak spring biomass and herbage quality during 2019.

Figure 1 Grazfeed predicted liveweight gain (kg/ha) of merino lambs with an initial liveweight of 25 kg for a range of annual legume species established either via summer sowing using unprocessed seed (SS) or conventionally sown using scarified seed (NS) in May.

Effect on wheat rotation

Grain yields at Kikoira in 2020 reflected mineral N availability and were lowest under the continuous cereal treatment (Figure 2). While the continuous cropping and subterranean clover treatments responded to increasing rates of N-fertiliser application, there was no statistical difference in yields achieved for wheat grown after the hardseeded legumes between applied N treatments. This indicates that the hardseeded legumes, despite growing under extreme drought conditions in 2019 had contributed sufficient N to support high grain yields in the wetter than average 2020 without additional N being applied.

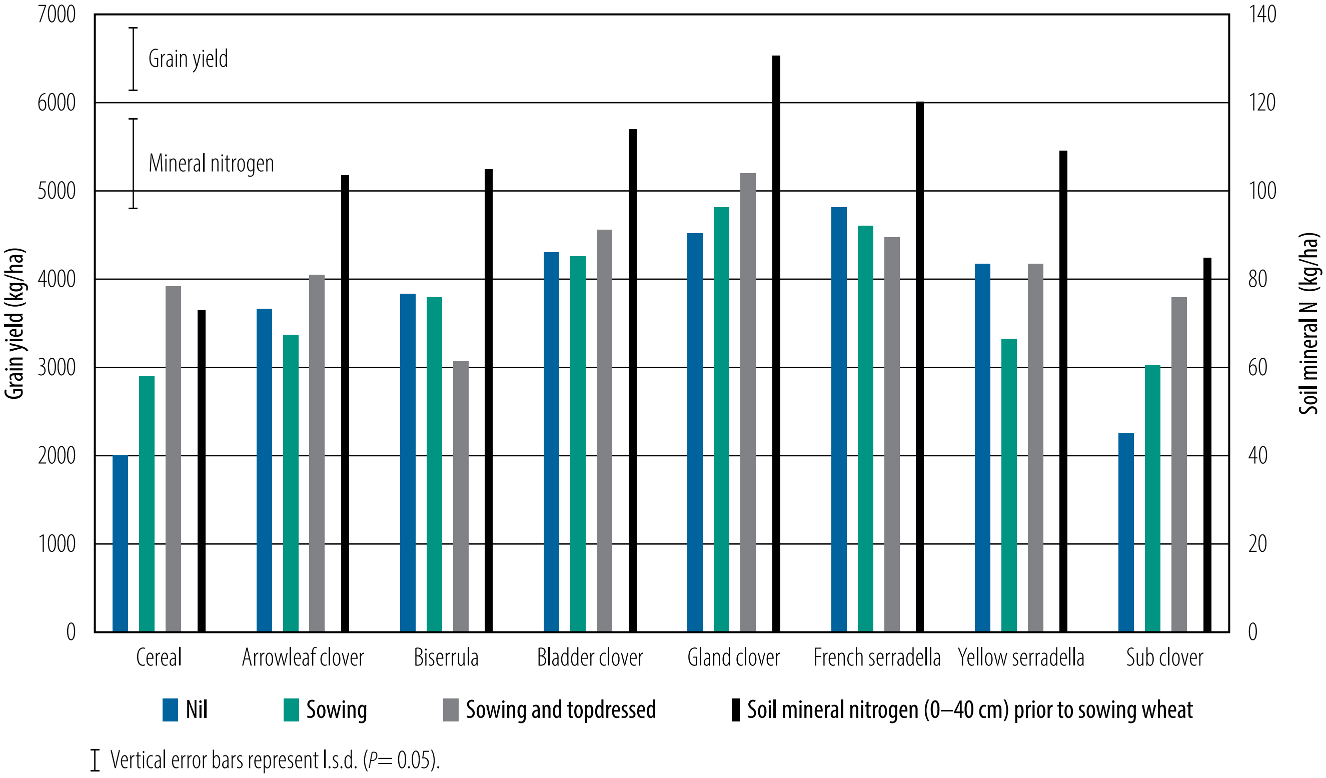


Figure 2 The grain yield (kg/ha) of wheat sown in 2020 following a range of annual legumes grown in 2019. Wheat was sown with no additional nitrogen, nitrogen applied at sowing only or nitrogen applied at sowing and topdressed at GS31 and GS51. Mineral nitrogen (0–40 cm) immediately prior to sowing is also shown.

Biomass production at Condobolin in 2020

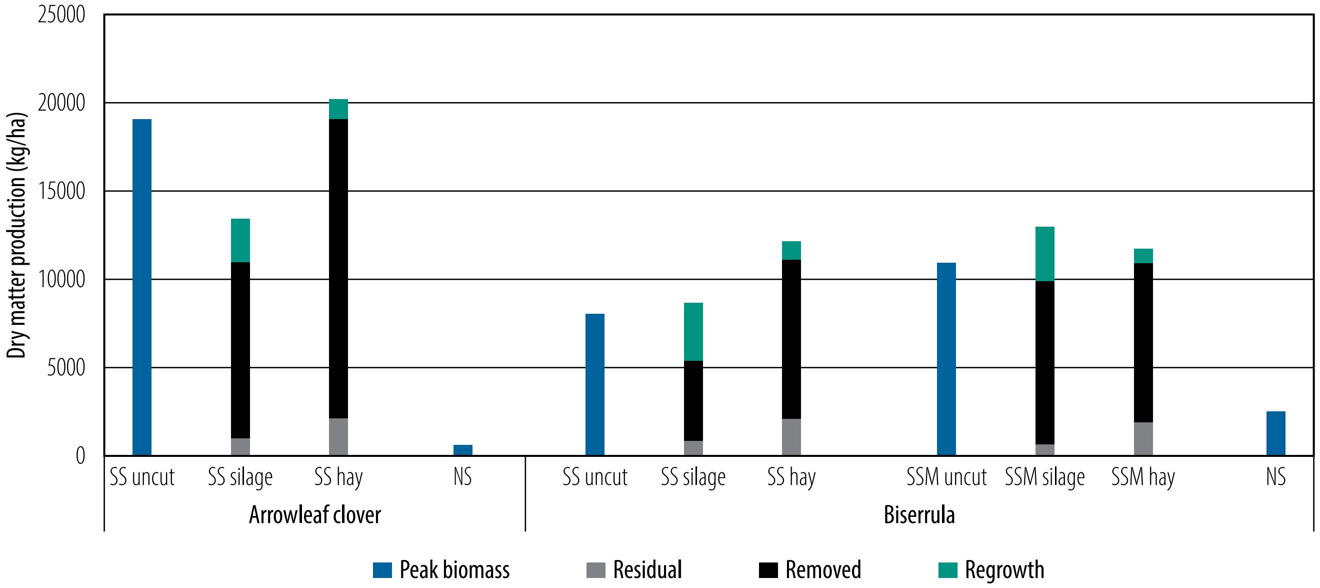
In the interest of brevity, only the results for arrowleaf clover and biserrula treatments are shown for the 2020 Condobolin site (Figure 3). For both species, there was a significant advantage from summer sowing with a 3- to 4-fold increase in herbage production of biserrula (summer sown and summer sown modified treatments) and a 30- to 40-fold increase in arrowleaf herbage production compared with the respective conventionally sown treatment. This trend was common in the other hardseeded legume species, with conventionally sown peak biomass ranging from 200 to 3,000 kg dry matter (DM)/ha (av. 1,600 kg DM/ha) and summer sown peak biomass ranging from 3,800 to 19,000 kg DM/ha (av. 9,200 kg DM/ha).

Figure 3 also shows the negligible difference in the biomass between using 100% minimally processed seed (header harvested) and a mixture containing 30% scarified seed for the biserrula summer sowing treatments. Both subterranean clover and burr medic produced less than 1,000 kg DM/ha. The results show that using minimally processed seed in a summer sowing operation can significantly increase herbage production from first year pasture stands. Forage quality was also analysed throughout the season and was found to be comparable to traditional legume species.

Cutting arrowleaf clover for silage resulted in reduced total cumulative biomass produced over the year (Figure 3). For the summer sown biserrula treatments, cutting either had no effect on cumulative production or resulted in an increase. This was also recorded in all other species that were summer sown. Seed yields for the uncut summer sown swards ranged from 480 to 1,960 kg/ha. Seed yield following cutting for silage or hay from summer sowing treatments (except the late cut gland clover) all reached and surpassed the threshold of 150 kg seed/ha described by Nutt et al. (2021) as necessary for ensuring seed bank formation suitable for adequate regeneration.

Seasonal conditions following defoliation are likely to affect recovery and seed production so they need to be considered when evaluating the possible effects of silage or hay cuts on seed yields. Interestingly, all the second generation legumes that were conventionally sown also attained the 150 kg seed/ha threshold. However, subterranean clover produced less than 80 kg seed/ha.

The resilience of second generation legumes to variable climatic conditions is partially attributable to their increased rooting depth compared with traditional annual legumes. At Condobolin biserrula and yellow serradella had a rooting depth of 1.8 m, French serradella 1.7 m, gland clover 1.4 m, bladder clover and arrowleaf clover both 1.3 m, compared with subterranean clover and burr medic, both 90 cm. The rooting depths recorded at Condobolin on a red chromosol are similar to those reported by Carr et al. (1999) in coarse sandy soils of Western Australia. The capacity to form deep root systems across a range of soil types indicate good adaptation characteristics resulting in improved capacity of second generation legumes to form productive, persistent pastures.



SS – summer sowing using unprocessed seed

NS – conventionally sown using scarified seed

SSM – contained 70% minimally processed and 30% scarified seed

Figure 3 Cumulative dry matter (kg DM/ha) for the 2020 growing season for arrowleaf clover and biserrula sown either in summer as minimally processed seed or in May as scarified seed where the summer sown treatments were either left uncut, cut for silage or cut for hay in spring at Condobolin NSW.

Conclusion

Summer sowing legumes with appropriate hard seed breakdown attributes and the capacity to survive moisture stress once emerged resulted in significant increases in herbage production during the severe drought year of 2019. The combination of increased herbage biomass production (Hackney et al. 2021b) from summer sowing combined with the high nutritive value of the herbage resulted in prediction of significantly higher livestock production even under extreme drought conditions. That these legumes, growing under such adverse conditions (36% of long-term growing season rainfall in 2019) were then able to support wheat grain yields of 4–5 t/ha in 2020 without adding N-fertiliser is remarkable and contrasts sharply with the yield results following subterranean clover or that of the continuous cropping treatment.

A new experiment sown at Condobolin in 2020 again confirmed the robustness of summer sowing as a mechanism to significantly increase herbage production. In this above average rainfall year, summer sowing provided growers with other options for using the large quantities of biomass produced via fodder conservation. Our results support those of Nutt et al. (2021) that summer sowing is a robust method of pasture establishment able to significantly increase production within the sowing year with the opportunity to support both livestock and crop production.

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Acknowledgements

This experiment was part of the 'Boosting profit and reducing risk on mixed farms in low and medium rainfall areas with newly discovered legume pastures enabled by innovative management methods – southern region; NSW component' project, 9175959, 2018–22.

Funded under the Rural Research and Development for Profit Program (Department of Agriculture and Water Resources) with investment from GRDC, Meat and Livestock Australia (MLA), Australian Wool Innovation (AWI). Project partners Murdoch University, Department of Primary Industries and Regional Development (DPIRD), Graham Centre for Agricultural Innovation, Commonwealth Scientific and Industrial Research Organisation (CSIRO), South Australian Research and Development Institute (SARDI), Frontier Farming Systems.

The work of Matt Clarke and Karen Brangwin on this project is gratefully appreciated.

Contact

Josh Hart
Yanco Agricultural Institute, Yanco
josh.hart@dpi.nsw.gov.au
0436 362 172

Survey for pulse and canola diseases in southern NSW in 2020

Dr Kurt Lindbeck and Ian Menz

NSW DPI, Wagga Wagga

Key findings

- Changes in farming practices in the past 15 years have increased crop disease pressure in southern NSW.
- Annual crop surveys are important for monitoring disease incidence and severity between districts and years. They also identify emerging disease issues and provide forewarning of potential problems.
- Sclerotinia diseases were widespread in broadleaf crops across the region in 2020, especially in narrow-leaf lupin and canola crops. This will have implications in 2021 and beyond.
- Blackleg was observed in every canola crop assessed as part of the integrated disease management (IDM) crop survey.
- Canola sown into a double break scenario will potentially require pre-emptive management to minimise disease risk.
- The decision to use fungicides is not always clear and should be assessed every year, depending on your crop's disease risk profile.

Introduction

In the past 20 years grains production in southern NSW has changed significantly. Many landholders now prefer to move entirely into grain production enterprises, removing livestock and pastures from the farming system. Agronomic practices have changed including stubble retention, minimum tillage and crop sequences. These changes have increased the disease burden across the farming system. Disease management in the cropping system is now an important consideration for many grain producers in southern NSW.

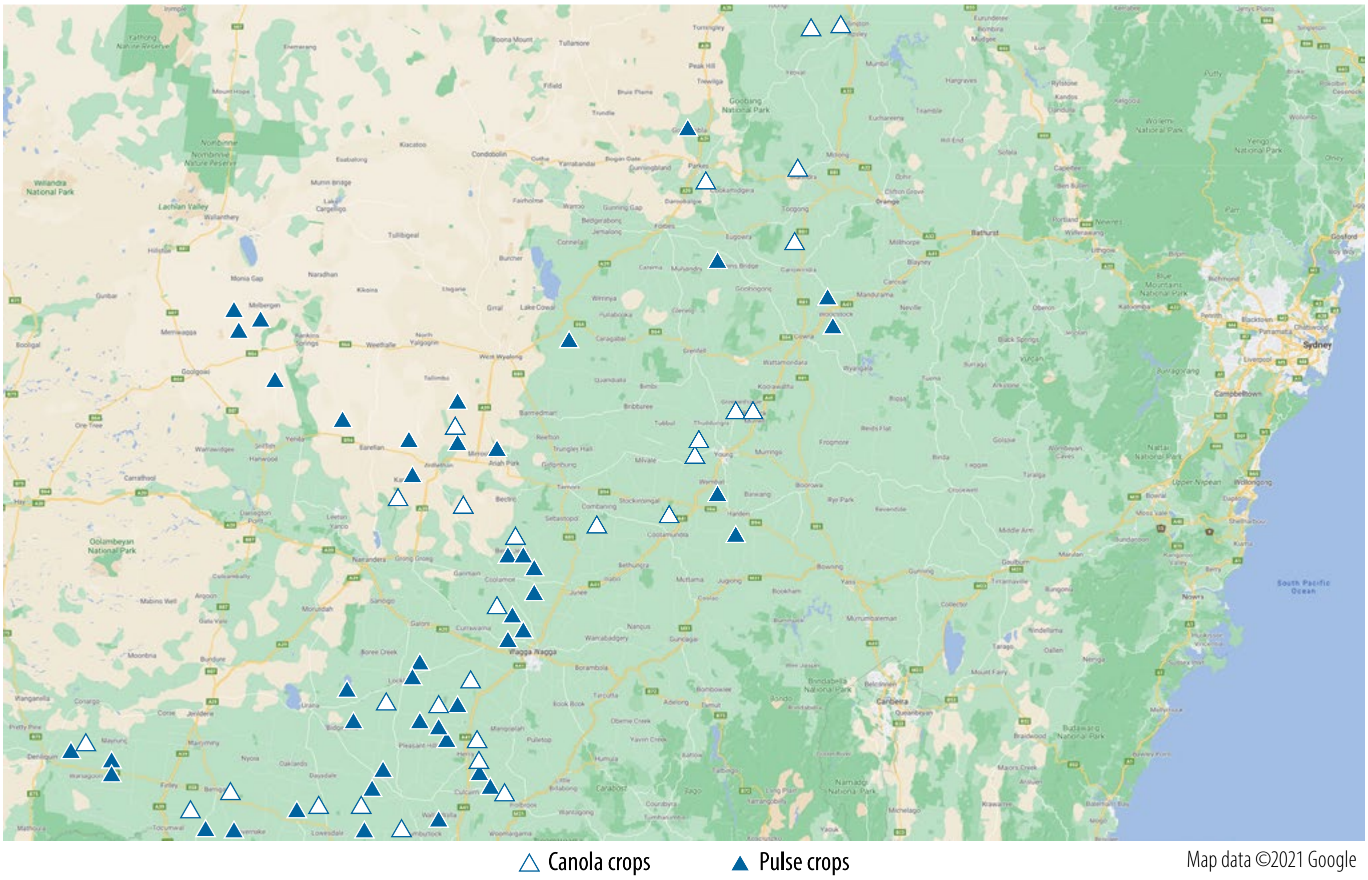
In 2020, sowing conditions were considered ideal across many districts and crops were sown on time. Rainfall patterns and mild temperatures across the south provided ideal conditions for developing crops and resulted in some of the best crop yields for many years. These conditions also allowed root and foliar diseases to develop in broadleaf crops across the region. In many instances, even low levels of pathogens were able to develop into epidemic levels despite the dry conditions in 2018 and 2019. In general, disease management practices across the region were very good, but there will be disease implications to consider in 2021.

Crop surveys have been undertaken for several years in southern NSW to monitor changes in disease prevalence, distribution and impact across farming systems and districts. Surveys are a valuable tool for identifying emerging disease threats, monitoring IDM strategies, guiding priorities for future research effort, and provide a mechanism for industry awareness and preparedness.

This paper reports on the priority diseases identified in the 2020 crop surveys and highlights implications for grains producers in 2021.

Methodology

With the assistance of local agribusiness, 45 pulse crops and 30 canola crops were sampled in 2020 at early flowering and early pod filling growth stages (early August to late September). Crop details were collected including GPS location, previous cropping history and herbicide use. Crop locations were restricted to the southern half of NSW between Dubbo and the Victorian border (Figure 1).



Map data ©2021 Google

Figure 1 Distribution of pulse and canola paddocks assessed as part of the 2020 IDM crop survey.

Six pulse crop species were surveyed (albus lupin, narrow-leaf lupin, faba bean, field pea, lentil and chickpea) and one oilseed crop (canola). There were no targets set for each species, but rather the number of crops sampled reflected the frequency of crops across the region (Table 1).

At each crop a diagonal transect was followed starting at least 25 m into the crop from the edge, to avoid any double sown areas, roadsides, dams or trees. At 10 locations long the transect, a row of 10 random plants was assessed for foliar disease symptoms and any other abiotic issues that might also be present. Assessment locations along the transect were at least 25 m apart. At five locations (every second assessment point) along the transect, five random whole plants along a row were collected for detailed disease and root health assessment. The samples were prepared for fungal DNA concentrations assessment at the South Australian Research and Development Institute (SARDI).

Table 1 Breakdown of commercial crops assessed and sampled as part of the 2020 IDM crop survey.

Region	Narrow-leaf lupin	Albus lupin	Chickpea	Field pea	Faba bean	Lentil	Canola	Total
Riverina	6	2	4	5	4	2	9	32
South West Slopes	8	3	2	2	3	2	16	36
Central West Slopes and Plains	2						6	8
Total	16	5	6	7	7	4	31	76

Results – What did the survey find?

Sclerotinia (all pulses)

Sclerotinia diseases (stem rot and white mould) were the most prevalent diseases detected across all pulses in this season's survey (Table 2). A combination of exceptional crop growth and frequent rain periods during late winter and spring provided ideal conditions for this pathogen to develop on a range of broadleaf crops across a wide region of southern NSW.

Disease symptoms included basal infections, stem lesions and pod infections. Basal infections are the result of plants directly infected by mycelium from germinating sclerotia. As sclerotia in the soil soften in winter from wet soil conditions, mycelium is produced that grows along or just under the soil surface. Once this mycelium encounters a plant stem, direct infection occurs that can kill the plant. Symptoms appear as a fluffy white collar around the stem base at soil level (often referred to as collar rot). Newly formed sclerotia will also be produced in this tissue.

Stem and pod lesions are the result of infection via ascospores, in a similar way to the infection process in canola. Apothecia (flattened golf tee-like fruiting structures of the *Sclerotinia* fungus) germinate from sclerotia in the soil. The apothecia produce and release airborne ascospores that land on and infect suitable plant tissues including old senescent leaf and flower tissue or pods. Symptoms appear as fluffy white mycelium on the outside of stems and on pods (particularly lupin), often killing the plant above the lesion. Newly formed sclerotia often develop either within infected stems or on the outside, if conditions are favourable.

Table 2 Proportion of pulse crops inspected and found to have *Sclerotinia* spp. present as part of the 2020 IDM crop survey.

	Narrow-leaf lupin	Albus lupin	Chickpea	Field pea	Faba bean	Lentil
No. of crops sampled	16	5	6	7	7	4
No. of crops with Sclerotinia	13	3	3	3	5	1
% of crops infected	81%	60%	50%	43%	71%	25%

Future implications

Sclerotia produced within infected crops in 2020 will pose a significant disease threat in 2021 and beyond. It is well known that sclerotia are long lived and can survive within soils for at least five years. Growers, agronomists and advisors should pay attention to crop choice and management for the next few seasons, especially those growers incorporating a 'double break' into their cropping system.

Blackleg (canola)

Blackleg, caused by the fungus *Leptosphaeria maculans*, was the most common disease observed in canola in the 2020 IDM crop survey. Each of the 31 crops inspected had disease symptoms at varying levels of severity. Symptoms ranged from leaf infection to stem-cankered plants.

The high incidence of blackleg within commercial canola crops is not surprising in 2020 given conditions were conducive for the disease to develop this year. Differences in severity could be attributed to crop variety, fungicide use and proximity to old canola stubble. Frequent wet days throughout winter and spring provided multiple leaf wetness periods for infections to occur and proliferate. At the time of observation (mid August to early September), those leaf infections that had developed towards the top of the crop canopy had the potential to develop into upper canopy infection (UCI).

Future implications

Disease management in canola changes seasonally depending on the variety, seasonal conditions and frequency of canola in the rotation.

Consideration must be given to disease risk factors that affect the new season crop. For example, is seedling protection important, do I need to apply fungicides for UCI, or are there diseases other than blackleg to consider? Often these cannot be addressed at the start of the season and require on-going crop monitoring and scouting for disease symptoms to allow a decision that is going to provide an economic outcome. Scouting for symptoms is a powerful way to keep abreast of blackleg development within crops and make decisions around fungicide applications. This is particularly important in the management of UCI.

Botrytis grey mould (narrow-leaf lupin)

Botrytis grey mould (BGM), caused by the fungus *Botrytis cinerea*, is a disease normally associated with lentil, chickpea and faba bean production. Crop surveys in 2020 also recorded this disease within narrow-leaf lupin crops with 43% of crops infected. Outbreaks of BGM are initiated on senescent plant tissues, such as old leaves and flower parts before developing into larger, more damaging lesions. The large, dense crop canopies produced by narrow-leaf lupin crops in 2020 favoured senescent tissue development following canopy closure when light penetration into the canopy was hindered.

Disease symptoms included stem and leaf infections and infections of old flower parts and pods. While the disease can be confused with sclerotinia white mould, the fluffy mycelium produced by the fungus is grey rather than white and no sclerotia are produced. Outbreaks of BGM are considered rare in narrow-leaf lupin, but the causal fungus is ubiquitous. Extraordinary seasonal conditions in 2020 favoured disease development.

Future implications

Old lupin stubble affected by BGM present a significant inoculum source. The BGM fungus can infect other pulses including chickpea, lentil and faba bean. BGM pathogen spores are airborne and will form readily on old infected stubble and be blown into surrounding crops. Care should be taken to avoid growing pulse crops (especially chickpea, lentil and faba bean) adjacent to old pulse stubble. If this cannot be avoided, the crop should be managed as a medium to high disease risk and considerations made for foliar fungicide use where economically justified.

Virus (all pulses)

Virus diseases were evident in many pulse crops across central and southern NSW in 2020. All major pulse viruses require an aphid vector to infect host plants and virus disease severity depends on aphid movement through a crop. Aphids require a living host plant to survive crop-free periods (‘green bridge’). For the 2020 season, good summer and autumn rainfall, and mild winter temperatures allowed aphid activity to build-up and continue across the region. This resulted in virus symptoms appearing in many pulse crops by late winter and early spring. Within the survey, virus symptoms were most noticeable in narrow-leaf lupin and lentil crops.

Symptoms in narrow-leaf lupin crops ranged from plants with shortened internodes and bunchy tops (typical for *Cucumber mosaic virus*, CMV) to plants with a withered top, bright yellow leaves and premature death (typical for *Bean yellow mosaic virus*, BYMV). Lentil crops featured shortened plants, bunchy growth and premature yellowing. Virus diseases in southern NSW during 2020 were not as severe as in northern NSW where BYMV resulted in serious yield losses in many faba bean crops. Narrow-leaf lupin crops in central NSW also suffered severe yield losses caused by CMV and *Alfalfa mosaic virus* (AMV).

Yield loss due to virus infections are not always easy to estimate compared with fungal disease. Early virus infections tend to result in greater yield loss and subsequent plant death compared with infections later in the season when plants are more developed.

Future implications

Viruses in pulse crops in 2020 demonstrated how dynamic these diseases can be within the cropping system and the influence of environmental conditions on the build-up and movement of virus vectors. Using virus-free seed is important for narrow-leaf lupins as CMV can be transmitted at high levels. Sowing crops with virus-infected seed can result in poor establishment and seedling vigour, in addition to becoming a source of virus infection throughout the crop.

Other diseases

Ascochyta blight

This most serious disease of chickpea in Australia was recorded in 30% of chickpea crops surveyed in 2020, however reports of damaging levels of the disease in southern NSW were minimal. Strategically using fungicides is highly effective at managing the disease where rainsplash spreads spores. Be aware of the significant inoculum sources as the pathogen survives on old infected chickpea stubble and seed.

Blackspot

Blackspot is the most common disease of field pea in Australia and most damaging in paddocks with a high frequency of field pea production. Fungus spores survive on old field pea stubble and in soil. While blackspot was observed in 71% of field pea crops surveyed, only one surveyed crop developed the disease to a damaging level. Avoid sowing next season's crop adjacent to last year's stubble and observe a four-year break between field pea crops in the same paddock.

Chocolate spot

Chocolate spot is potentially the most damaging disease of faba bean and responsible for the nickname 'failure beans' in the 1990s. The 2020 crop survey reported the disease in 43% of crops at low to moderate levels. Improvements in variety resistance and the range of foliar fungicide options available have significantly improved disease management and reduced the potential for yield loss.

Bacterial blight

Mild winter conditions and few damaging frosts resulted in limited outbreaks of this disease compared with 2018 and 2019. Bacterial blight was reported in 28% of field pea crops inspected in the survey. The disease generally appears in low lying areas of field pea crops, which are most prone to frost and freezing injury. The disease is challenging and relies on pre-emptive disease management strategies such as maintaining at least a three-year rotation between field pea crops and sowing disease-free seed because there are no effective post emergent disease management options. The pathogen survives on old field pea stubble and seed.

Phomopsis stem blight

While this disease does not cause significant yield loss, presence of the disease within lupin crops poses a significant risk to livestock health. The causal fungus, *Diaporthe toxica*, produces a toxin as it grows within lupin plants that can kill grazing livestock, especially young sheep. Care should be taken when grazing lupin stubbles following harvest and especially following summer rain, which stimulates fungus growth within stubble. It is rare to observe the disease while lupin plants are still green, however a single narrow-leaf and a single albus lupin crop were reported to have the disease during the 2020 survey. Typically, fungus growth becomes most apparent following harvest and after rain when fruiting structures of the fungus develop on lupin stubbles.

Conclusions

The results from the survey in 2020 demonstrate the ability of pathogens to persist between years even when conditions are unfavourable. Environmental conditions in 2020 allowed low levels of disease to build up quickly and become potentially damaging in broadleaf crops across the region. No new emerging disease threats were identified in 2020 from surveys, but several common diseases occurred at significant levels that will have a potential effect for the next few seasons including sclerotinia stem rot, blackleg and botrytis grey mould.

Where possible, an integrated approach should be used to manage disease in grains crops. More than ever we are becoming reliant on fungicides to maintain tight cropping rotations and high yields. Fungicides removed from the system due to resistance development or residue detection in end products will limit growers' options in the future.

Acknowledgements

This experiment was part of the 'Integrated disease management (IDM) for broadleaf crops in southern and central NSW' project, BLG206, a joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

Thanks to Joop van Leur (NSW DPI Tamworth) for his contribution to the virus information in this paper.

The authors wish to thank all producers in NSW who were part of the 2020 crop survey.

Contact

Dr Kurt Lindbeck
Wagga Wagga Agricultural Institute, Wagga Wagga
kurt.lindbeck@dpi.nsw.gov.au
02 6938 1608

National Variety Trials (NVT) disease screening – a project snapshot from 2020

Brad Baxter[1], Dr Natalie Moore[2], Sean Bithell[3], Dr Steven Simpfendorfer[3], Dr Joop van Leur[3], Dr Kurt Lindbeck[1], Dr Ben Ovenden[1] and Dr Andrew Milgate[1]

[1] NSW DPI, Wagga Wagga
[2] NSW DPI, Grafton
[3] NSW DPI, Tamworth

Key findings

- Yearly screening is required to quantify and monitor the reaction of current and new varieties to diseases of economic importance.
- Natural changes in virulence occur in pathogen populations or when exotic pathotypes are introduced to Australia. These can affect host plant (variety) resistance ratings in both cereal and broadleaf crops.
- Five wheat stripe rust pathotypes of significance were detected in the NSW cropping regions during 2020; four were present in NSW Department of Primary Industries (NSW DPI) stripe rust nurseries.
- Host resistance can vary significantly depending on the stripe rust pathotypes present.
- Growers and advisers are kept up to date with latest resistance ratings each year through nationally co-ordinated National Variety Trials (NVT) pathology trials across a wide range of crops and diseases.

Introduction

Under the new NVT Pathology Services Agreement 2019–23, the total number of diseases and crop species being screened in NSW has increased. Eight different crop types, both cereal and broadleaf, are annually screened for a total of 17 different diseases across three climatically and agronomically diverse sites within NSW (NSW DPI research stations based at Grafton, Tamworth and Wagga Wagga).

Inherent diversity between the three screening sites facilitates matching optimal climatic conditions with different pathosystems to maximise disease development, spread the risk of nursery failure and fill current crop species knowledge gaps.

The data generated from this project forms part of national, state or regional resistance ratings that appear in publications such as the NSW Winter crop variety sowing guide (NSW DPI 2021) and on the NVT website (NVT GRDC 2021).

What do we do?

Each year, cereal and pulse seed from a common source are sent out to NVT service providers across Australia through a coordinated national process. NSW DPI receives seed sets for screening against 17 different diseases across cereal (Table 1) and pulse varieties (Table 2).

Individual crop seed sets are made up of commercially available varieties and near-release lines from breeders. There are two seed sets within each crop type: AUS and NVT. There are sets for wheat, barley, oat and the pulse crops. The AUS sets (such as AUSBAR i.e. AUS barley set) are a collection of commercially and regionally important varieties. The NVT sets are breeding lines made up of retention or first lines. Retention lines are breeding lines that have been in the NVT set for more than one year. First lines, as the name suggests, are lines that are in the NVT set for the first time. Resistance ratings for first lines are generally marked as provisional until more data is available in subsequent years of evaluation. Current commercial varieties can receive provisional ratings for new pathotypes or new diseases with limited data sets. By including near-release breeding lines, the NVT system provides growers with independent disease ratings to inform their variety choice and the necessary management required for a new variety once it is commercially available. This prevents a lag in developing disease resistance ratings once a new variety is released.

Table 1 Cereal diseases screened annually in NSW under the NVT Pathology Services Agreement 2019–23.

Disease	Scientific name	Crop type	Screening location	Type of screening
Barley scald	*Rhynchosporium secalis*	Barley	Wagga Wagga	Field
Net form of net-blotch	*Pyrenophora teres f. teres*	Barley	Wagga Wagga	Field
Spot form of net-blotch	*Pyrenophora teres f. maculata*	Barley	Grafton and Wagga Wagga	Field
Leaf rust	*Puccinia hordei*	Barley	Wagga Wagga	Field
Bacterial blight	*Pseudomonas syringae spp*	Oats	Wagga Wagga	Field
Leaf or crown rust	*Puccinia coronata var. avenae*	Oats	Grafton and Wagga Wagga	Field
Septoria blotch	*Phaeosphaeria avenaria*	Oats	Wagga Wagga	Field
Stem rust	*Puccinia graminis f. sp. avenae*	Oats	Grafton and Wagga Wagga	Field
Septoria tritici blotch	*Zymoseptoria tritici*	Wheat and triticale	Wagga Wagga	Field and glasshouse
Leaf rust	*Puccinia recondita*	Wheat and triticale	Wagga Wagga	Field
Stripe rust	*Puccinia striiformis f.sp. tritici*	Wheat and triticale	Grafton, Tamworth, Wagga Wagga	Field
Yellow leaf spot	*Pyrenophora tritici-repentis*	Wheat and triticale	Grafton and Wagga Wagga	Field

Table 2 Pulse diseases screened annually in NSW under the NVT Pathology Services Agreement 2019–23.

Disease	Scientific name	Crop type	Screening location	Type of screening
Botrytis grey mould	*Botrytis cinerea* *Botrytis fabae*	Chickpea* and lentil	Grafton and Wagga Wagga	Field and glasshouse
Ascochyta blight	*Phoma rabiei*	Chickpea	Tamworth and Wagga Wagga	Field and glasshouse
Faba bean rust	*Uromyces viciae-fabae*	Faba beans	Tamworth	Field
Phytophthora root rot	*Phytophthora medicaginis*	Chickpea	Tamworth	Field
Bacterial blight	*Pseudomonas syringae pv.pisi* *Pseudomonas syringae pv syringae*	Field peas	Wagga Wagga	Field

* Chickpea botrytis grey mould disease screening (field and glasshouse) will be discontinued from 2021 onwards at both Grafton and Wagga Wagga screening sites.

The seed sets are sown at the three screening sites from April through to June each year. A disease nursery is made up of one or more individual experiments screening the same pathogen. For example, single or multiple experiments screening yellow leaf spot in wheat is considered a disease nursery. Each screening site has multiple disease nurseries, one nursery for each pathogen. Disease nurseries which will not cross-infect each other, such as wheat and barley diseases, can be sown in the same paddock. Diseases that will cross-infect each other, such as two barley diseases, are grown in separate paddocks. To reduce the chance of cross-infection of non-target disease, management options such as separation by physical distance, paddock rotation and changes to sowing timing are implemented. The disease nurseries are managed to best agronomic practices to ensure uniform establishment and plant health before inoculation. No fungicides are applied to prevent confounding effects on disease expression.

Each pathogen has a specific set of abiotic conditions that must be met to promote initial infection and favour disease development. These are predominately rainfall, humidity and temperature requirements. Within the nurseries, supplementary overhead irrigation can be used to promote further infection events and drive the disease epidemic during the growing season. Supplementary watering can be tailored to suit each pathogen.

Plants within the disease nurseries are inoculated using pathogen specific techniques. These include stubble inoculation, spore suspensions, inoculated seed dispersal and mycelial broth, or a combination of two or more techniques. The inoculation of a disease nursery is undertaken at a time point where the crop is at a susceptible growth stage and environmental conditions are conducive to infection events. This generally occurs before or after a rainfall event. Some disease nurseries, such as the stripe rust nurseries, rely on natural infection from wind-blown spores to initiate a disease epidemic. Infected plants from susceptible spreader rows are then used to ensure even disease pressure across nursery sites. In the case of stripe rust, inoculation is only used as a last option after receiving reports of stripe rust in commercial crops from the local region.

At the height of the disease epidemic, generally August–November depending on the disease, the disease development is visually assessed to determine the relative levels of host resistance between entries and check varieties. These assessments are then submitted into the NVT system to be combined with results from other service providers across Australia. Final ratings are then developed through a national consultative process between pathologists and breeders using all available historic and annual nursery data. These annually reviewed and agreed ratings are what appear in state-based variety sowing guides such as NSW DPI's Winter crop variety sowing guide, on the NVT website (https://nvt.grdc.com.au/) and in other extension material.

Why do we screen diseases each year?

Due to interactions between host, pathogen, environment and agronomic management practices, pathogens naturally evolve. These changes can increase or decrease the pathogen's virulence on different host varieties depending on the host's genetic makeup; the host plant can have different reactions to individual pathotypes. Also, environmental influences can affect the severity of disease expressed by the same pathotype in different years.

It is critical for the agricultural industry to be able to monitor these changes. By annually screening commercially available varieties and near-release breeding lines, changes can be tracked in pathogen populations over time by measuring changes in the level of host resistance. In turn, this allows researchers to provide advisors, growers and the broader industry with current information on individual varietal resistance ratings, pathotype population dynamics and distribution.

This information is important for growers and industry to guide the formulation of appropriate economic disease-management strategies. It also enables pathologists to forecast potential disease issues for the upcoming growing season. Knowing what pathotypes are in the natural population and which varieties are widely grown or becoming more popular can provide insight about which disease/s could be an issue. This allows information to be communicated to industry groups during the season about available and appropriate management options.

Practical examples of why we screen annually

During 2020, in the NSW DPI stripe rust screening nurseries, four different pathotypes were detected. The rust strains were pathotyped by the Australian Cereal Rust Survey based at Sydney University. These being:

1. 198 pathotype, 198 E16 A+ J+ T+ 17+
2. 239 pathotype, 239 E237 A- 17+ 33+
3. WA pathotype,134 E16 A+17+ 27+
4. 64 pathotype, 64E0A-, Tamworth nursery only.

Some wheat varieties had different reactions to each of the four pathotypes found in the disease nurseries in 2020 (Table 3). In this case, two popular wheat varieties, Rockstar$^{\Phi}$ and Vixen$^{\Phi}$, have a spread of resistance ratings from resistant to moderately resistant (R–MR) to susceptible to very susceptible (S–VS) depending on the pathotype present. This is due to the genetic makeup of these varieties, i.e. the resistance genes within the plant. Each of the four stripe rust pathotypes are either virulent or avirulent to particular resistance gene/s within the host plant. This results in a range of stripe rust reactions and the need to have multiple resistance ratings.

Table 3 Differences in the reaction of wheat varieties Rockstar$^{\phi}$ and Vixen$^{\phi}$ to four different stripe rust pathotypes present in NSW DPI nurseries during 2020.

Variety	Resistance rating to stripe rust pathotypes			
	198 E16 A+ J+ T+ 17+	239 E237 A- 17+ 33+	134 E16 A+ 17+27+	64E0A-
Rockstar	MR	MS	MR–MS	S
Vixen	R–MR	MS–S	MR–MS	S–VS

When new pathotypes become more common in the environment, for example as the 198 pathotype did during 2020, all variety reactions are reviewed. This is important because as data from multiple environments is gathered, pathologists can assign ratings with greater confidence. This can lead to adjustments being made to a variety's rating to the same pathotype. For example, Catapult$^{\phi}$ was rated resistant to moderately resistant (R–MR) in 2019 to the 198 pathotype and adjusted to moderately resistant to moderately susceptible (MR–MS) in 2020 once an additional year of data was obtained (Table 4).

Also note, that Catapult$^{\phi}$ is S–VS to 64E04- stripe rust pathotype. This pathotype (64E0A-) is an older pathotype present in the Tamworth disease nursery during 2020. It (64E0A-) had a significantly higher reaction on many popular wheat varieties than their 2019 resistance rating indicated, including varieties such as Catapult$^{\phi}$, Corack$^{\phi}$, RockStar$^{\phi}$ and Vixen$^{\phi}$. Due to the popularity and size of plantings of these varieties, it is possible that 64E0A- (and 239 in the case of Vixen$^{\phi}$) could become more common in the stripe rust population during the 2021 cropping season.

Table 4 Change in the reaction of the wheat variety Catapult$^{\phi}$ to the 198 stripe rust pathotype between 2019 and 2020.

Year screened	Resistance rating to stripe rust pathotypes			
	198 E16 A+ J+ T+ 17+	239 E237 A- 17+ 33+	134 E16 A+ 17+ 27+	64E0A-
2019	R–MR	MR–MS	MR–MS	NA
2020	MR–MS	MR–MS	MR–MS	S–VS

NA = not applicable. 64E04- was not present in the population during 2019.

Growers and advisors should routinely check their varieties for changes in resistance ratings as pathotypes change over time. Varieties identified for change in 2021 include; Catapult$^{\phi}$, RockStar$^{\phi}$, Joey$^{\phi}$, Borlaug 100$^{\phi}$, Corack$^{\phi}$, Devil$^{\phi}$, DS Darwin$^{\phi}$, Emu Rock$^{\phi}$, Hatchet CL Plus$^{\phi}$, LongReach Cobra$^{\phi}$, LongReach Trojan$^{\phi}$, SEA Condamine$^{\phi}$, Sheriff CL Plus$^{\phi}$, Vixen$^{\phi}$, Wallup$^{\phi}$, Sting$^{\phi}$, Suncentral$^{\phi}$ and Denison$^{\phi}$ (Milgate et al. 2021).

Pulse crop disease screening

The broadleaf crop disease screening became a part of the NVT program in 2019. The program in its entirety screens chickpea, lentil, field pea, faba bean and lupin varieties and near-release lines. NSW DPI screen all the pulse crop types except for lupins to five different diseases (Table 2).

Within the program, NSW DPI screens agronomically important pulse diseases for northern NSW (nNSW) at Grafton and Tamworth. However, southern NSW (sNSW) is an emerging region for chickpea, faba bean and lentil crops, which have typically been considered nNSW, Victorian or South Australian pulse crops. The resistance ratings for these crop types are based on work completed outside the local region. These regions often have different farming systems and climatic conditions that are not entirely applicable to sNSW. NSW DPI is assessing host resistance under sNSW conditions at Wagga Wagga using local pathotypes to provide greater relevance for local growers.

Summary

Changes in pathogen virulence leading to a loss of effective host resistance genes can have disease management and economic effects on grower profitability. The ability to track and quantify these changes allows farm management decisions to be made with the most current knowledge. The ability to choose a more resistant variety to a particular disease and/or pathotype prevalent in a region has multiple flow-on effects for the farming system. It could increase yield while reducing the number of fungicides sprays required which, in turn, reduces machinery, labour and input costs. Minimising fungicide use also reduces the risk of developing fungicide resistance within both on-target and off-target fungal pathogen populations.

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Acknowledgements

The pathology screenings were undertaken as part of the 'NVT Pathology Services Agreement', DAN1097, 2019–23, a GRDC investment.

The authors wish to thank Sam Blanch, David Cram, Ram Devkota, Nicole Drone, Nathan Ensbey, Chrystal Finn, Finn Fensbo, Tony Goldthorpe, Ashely Moss, Michael McCaig, Paul Nash, Nguyen Nguyen, Gerard O'Connor and David Wark for their contribution to the success of the 2020 NVT screening project.

Contact

Brad Baxter
Wagga Wagga Agricultural Institute, Wagga Wagga
brad.baxter@dpi.nsw.gov.au
0428 294 121

Dr Andrew Milgate
Wagga Wagga Agricultural Institute, Wagga Wagga
andrew.milgate@dpi.nsw.gov.au
02 6938 1990

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Future proofing agricultural production through effective management of acidic soils

Dr Jason Condon and Helen Burns
NSW DPI, Wagga Wagga

Key findings

- Surface-applied lime that is only incorporated by the sowing operation has limited effect on increasing pH and decreasing exchangeable aluminium percent below the surface 0–5 cm layer.
- Incorporation of lime aids lime solubility, increasing pH to the depth of mixing.
- Analysed results within 12 months of lime application can be misleading, particularly in dry seasons; they do not capture the full effect of lime rate, incorporation method and reacidification processes.

Introduction

Producer and advisor surveys indicate that current approaches to managing soil acidity are based on research and guidelines from the 1990s that were developed under very different and less productive farming systems. Most fertiliser, lime and crop selection decisions are guided by analyses of soil samples collected at traditional depths of 0–10 cm. Depending on the crop or pasture sequence, the common trigger to apply lime is when soil pH_{Ca} is around 4.5–4.8. It is applied at minimal rates to remove toxic aluminium (target pH_{Ca} 5–5.2).

These traditional approaches and a failure to monitor the effectiveness of acid soil management programs are responsible for widespread, undetected subsurface acidification in marginally acidic soils; even in those soils with a long history of soil testing and lime application (Burns and Norton 2018). Recent studies challenge the short-term focus of current acid soil management programs:

- Li et al. (2019) recommended revising pH targets and re-liming intervals in order to address subsurface acidification, proposing maintenance of soil pH_{Ca} above 5.5 in the 0–10 cm surface layer to gradually increase subsurface pH.
- Condon et al. (2020) highlighted inadequacies of current acid soil management programs and reinforced the need for a shift from mitigating soil acidity to prevention, particularly in zero tillage farming systems.
- Conyers et al. (2020) concluded that ongoing reaction of limestone and reacidification processes influenced soil pH and that 'the slow but measurable improvement in subsurface acidity, and the sustained residual value to grain yield' required a long-term approach to amelioration efforts to manage and prevent subsurface acidification.

This paper reports preliminary soil test results from three large-scale, replicated field experiments established in October 2019 or February 2020. The sites near Lyndhurst, Culcairn and Canowindra were designed to monitor long-term changes in soil chemical properties and:

1. investigate the optimal rate of lime and application methods to prevent subsurface acidification via incorporation or enhanced movement of the lime effect
2. identify the longevity of the effect of lime application and the acidification rate of current farming practices.

Site details

Location

- Site 1: Approximately 5 km south of Lyndhurst, NSW.
- Site 2: Morven; approximately 15 km east of Culcairn, NSW.
- Site 3: Toogong; approximately 25 km north of Canowindra, NSW.

Soil type

- Site 1: Lyndhurst; Red Chromosol; soil pH_{Ca} range of 3.9–4.1 in subsurface layers (5–15 cm).
- Site 2: Morven; Yellow Chromosol; soil pH_{Ca} range of 4.0–4.3 in subsurface layers (5–15 cm).
- Site 3: Toogong; Red Kandosol; soil pH_{Ca} 4.8 in subsurface layers (5–15 cm).

The soil pH was severely acidic (pH_{Ca} <4.5) to a depth of 30 cm at Lyndhurst and to 20 cm at Morven. Neither site had a history of lime application, but had been prioritised for lime application. In comparison, the Toogong site had lime applications in 1997 (2 t/ha) and 2005 (2.5 t/ha). Paddock soil tests returned pH_{Ca} of 5.0 from 0–10 cm soil samples and was therefore not considered a high priority for liming based on current acid soil management principles. However, sampling in 5 cm increments indicated stratified soil pH and subsurface acidification: the 0–5 cm pH_{Ca} was 5.1, decreasing to 4.8 in the 5–15 cm subsurface layers, increasing to 5.2 at 15–20 cm and 6.0 in below 20 cm. It is an ideal site to test the effectiveness of early intervention in arresting subsurface acidification over the long term.

Soil sampling

Soil samples were collected 10 to 14 months after lime application for comprehensive chemical analysis. Soil cores were divided into 2.5 cm increments within depths of 0–20 cm and in 5 cm increments from 20–30 cm, to detect change in soil pH and movement of alkali down the soil profile. The effectiveness of each lime treatment is gauged by the increase in soil pH and decrease in exchangeable aluminium percent (Al_{ex}%) compared with the control (nil lime).

Previous crop

- Site 1: Lyndhurst; unimproved naturalised pasture.
- Site 2: Morven; degraded phalaris-based pasture.
- Site 3: Toogong; grazing wheat (drought affected).

Rainfall (2020)

- Site 1: Lyndhurst; 1030 mm.
- Site 2: Morven; 590 mm.
- Site 3: Toogong; 730 mm.

Treatments

Large-scale (2 ha), replicated field sites were established in late 2019 and early 2020 to monitor change in soil chemical properties from 0 to 30 cm, under high input, mixed farming systems. A range of lime and incorporation treatments (Table 2) were applied in December 2019 (Morven) and February 2020 (Lyndhurst and Toogong). Lime sourced from NSW crushers, with a neutralising value of 98 and fine particle size (90% passing through a 150 µm sieve) was applied using a direct drop lime spreader. Plot size was either 50 m or 75 m by 9 m wide, with four replicates of seven treatments.

Treatments were designed to answer the following questions raised by local growers and advisors:

- What is the optimal rate of lime and application methods to prevent subsurface acidification?
- Does incorporation increase the rate and depth of pH increase in the soil subsurface?

The lime rate and incorporation treatments applied at each site are described in Table 1 and summarised in Table 2.

Table 1 Incorporation treatments and descriptions.

Treatment ID	Incorporation treatment	Description
1	Control	Nil lime, not incorporated (NI)
2	NI	Maintain $\mathrm{pH}_{\mathrm{Ca}}$ of the 0–10 cm layer above 5.5, with $\mathrm{pH}_{\mathrm{Ca}}$ of 5.5 as the trigger to relime.
3	Incorporated (Inc)	
4	NI	Traditional approach – target $\mathrm{pH}_{\mathrm{Ca}}$ 5.2 in 0–10 cm layer, with trigger to relime when $\mathrm{pH}_{\mathrm{Ca}}$ decreases to <5.0.
5	Inc	
6	NI	Low initial rate of lime followed by more frequent applications, compared with Treatment 2 and 3; $\mathrm{pH}_{\mathrm{Ca}}$ of 5.5 in 0–5 cm layer as the trigger to relime. *When lime incorporation is not an option, can subsurface pH be increased by maintaining 0–5 cm* $\mathrm{pH}_{\mathrm{Ca}}$ *>5.5?*
7	Inc	Once-in-a-generation treatment. *When incorporation is an option will a high lime rate and one-off incorporation ameliorate and prevent subsurface acidity, while minimising application and incorporation costs, and limiting erosion risk to a single event?* *Does this treatment:* • *ameliorate and prevent subsurface acidification in the long-term; and/or* • *induce nutrient deficiencies?*

Crop and pasture schedule

All sites were sown to crop in 2020 using narrow-point tine seeders.

- Site 1: Lyndhurst; dual-purpose wheat; phalaris/legume pasture in 2021.
- Site 2: Morven; dual-purpose canola; dual-purpose wheat in 2021.
- Site 3: Toogong; dual-purpose canola; perennial pasture 2021.

Table 2 Lime rates and incorporation treatments applied to large-scale field sites at Lyndhurst, Morven, and Toogong.

Treatment ID	Incorporation treatment	Description	Site 1: Lyndhurst Incorporation: Horsch® Tiger	Site 2: Morven Incorporation: disc harrows	Site 3: Toogong Incorporation: disc harrows
			Rate of lime applied (t/ha)		
1	Control	Nil lime, not incorporated (NI)	0	0	0
2	NI	Target 0–10 cm $\mathrm{pH}_{\mathrm{Ca}}$ >5.5. Trigger for re-liming when $\mathrm{pH}_{\mathrm{Ca}}$ decreases to 5.5.	5.9	4.0	2.8
3	Incorporated (Inc)				
4	NI	Target 0–10 cm $\mathrm{pH}_{\mathrm{Ca}}$ > 5.2. Trigger for re-liming when $\mathrm{pH}_{\mathrm{Ca}}$ decreases ~ 5.0.	4.7	3.0	1.0
5	Inc				
6	NI	Maintain target in 0–5 cm at $\mathrm{pH}_{\mathrm{Ca}}$ >5.5. Trigger for re-liming: 0–5 cm $\mathrm{pH}_{\mathrm{Ca}}$ decreases to 5.5.	2.9	2.0	1.4
7	Inc	Once-in-a-generation*	7.0*	6.0*	3.8
Time lag between lime application and soil sampling (months)			11	14	10

* Despite the very high rates of lime applied in Treatment 7 at Lyndhurst and Morven there were no visual symptoms of induced nutrient deficiency; apparent plant vigour in these plots was at least equal to the most vigorous plots.

Lime application dates and incorporation method

Site 1: Lyndhurst; 5 February 2020; incorporation to estimated depth of 20 cm with Horsch® Tiger.

Site 2: Morven; 24–25 October 2019; incorporation to an estimated depth of 10 cm with initial pass with disc harrows in October 2019 (very dry, cloddy) and again in January 2020.

Site 3: Toogong; 6 February 2020; incorporation to about 10 cm with disc harrows.

Seasonal conditions

Exceptionally dry conditions throughout 2019 until late January 2020 (Decile 1) were followed by average to above average rainfall at all sites. This produced ideal conditions for incorporation at Site 1 (Lyndhurst) and Site 3 (Toogong) in February with a single pass. Two passes were required at Site 2 (Morven). Rainfall at Morven was near average from when lime was applied to sampling in December 2020; annual rainfall was approximately 30% above average at Lyndhurst and Toogong.

Results and discussion

Soil test results

Only soil pH and Al_{ex}% results are discussed here. Collecting crop production data is beyond the scope of this project.

Despite significant rainfall at all sites in 2020, a considerable proportion of the applied lime would not have reacted (Conyers et al. 2020). Therefore, the soil test results presented should be used as an early indication of the relative effectiveness of the lime and incorporation treatments. We expect that pH will continue to increase until most of the lime has dissolved. Eventually, ongoing acidification will outstrip the neutralising processes being driven by alkali released from the unreacted lime. When this occurs, the soil will reacidify and pH will decrease.

Site 1: Lyndhurst

Although the Horsch® Tiger disturbed the soil to an estimated depth of 20 cm, lime was only mixed to about 15 cm, as indicated by the depth to which soil pH was increased under all incorporated lime treatments compared with the nil lime treatment (Figure 1 and Table 3).

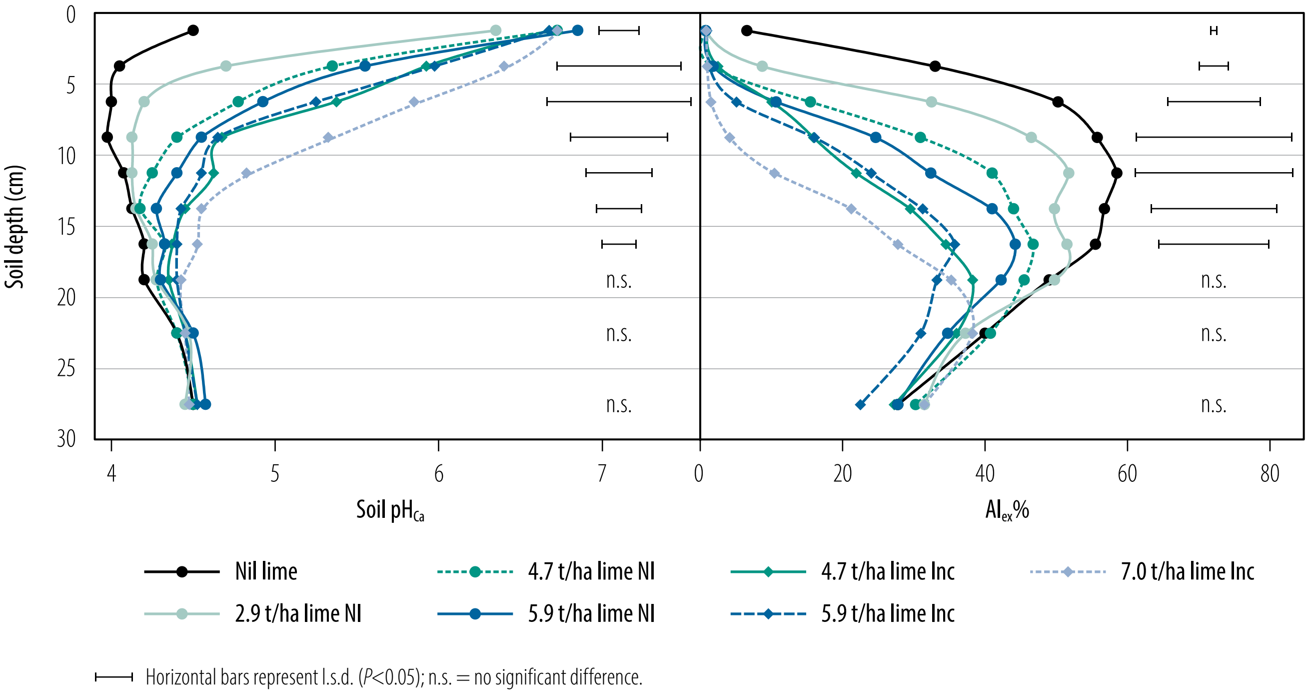


Figure 1 The soil profiles for pH_{Ca} and exchangeable aluminium percent (Al_{ex}%) at Site 1 (Lyndhurst, NSW) showing the effects of lime rates of Nil, 5.9, 4.7, 2.9 or 7 t/ha, with incorporation (Inc) or without incorporation (NI), 11 months after application.

There was a significant increase in soil pH$_{\text{Ca}}$ ($P<0.05$) of 0.3, 0.3 and 0.4 pH units down to the 12.5–15.0 cm layer for all incorporated lime rates of 4.7, 5.9 and 7 t/ha, respectively, which targeted 0–10 cm pH$_{\text{Ca}}$ >5.2, > 5.5 and ~ 6.2. However, where lime was not incorporated the depth to which pH increased was influenced by lime rate, i.e. pH increase was just significant down to the 7.5–10.0 cm layer for the highest lime rate targeting pH$_{\text{Ca}}$ >5.5 (5.9 t/ha NI). For a target pH$_{\text{Ca}}$ >5.2 (4.7 t/ha NI) the increase in pH was confined to the surface 0–5 cm. Treatment 6 (2.9 t/ha NI: target pH$_{\text{Ca}}$ >5.5 in 0–5 cm), which closely approximates traditional lime rates of 2.5 t/ha, only increased pH significantly in the surface 0–2.5 cm layer.

Figure 1 shows the influence of lime application on the Al$_{\text{ex}}$% profile below the depth of significant change in soil pH. The decrease in Al$_{\text{ex}}$% was significant for all incorporated treatments to a depth of 15.0–17.5 cm. However, only the 'once-in-a-generation' treatment (7 t/ha of lime) increased pH significantly to that depth. This observation indicates that some of the added alkali from lime reacted with Al$_{\text{ex}}$ and that alkali is no longer in solution to increase pH. That is, the reaction of Al$_{\text{ex}}$ to forms not available to plants buffers the pH change due to lime.

For the unincorporated lime treatments, the higher the lime rate, the deeper the effect on Al$_{\text{ex}}$%, with a significant decrease down to 10.0–12.5 cm for 5.9 t/ha (NI: target pH$_{\text{Ca}}$ >5.5), to 7.5–10.0 cm for 4.7 t/ha (NI: target pH$_{\text{Ca}}$ >5.2) and to 5.0–7.5 cm for 2.9 t/ha of lime. As was the case for change in soil pH, the magnitude of the lime effect on Al$_{\text{ex}}$% declined with depth for all treatments.

Table 3 Increase in soil pH$_{\text{Ca}}$ and decrease in exchangeable aluminium percent (Al$_{\text{ex}}$%) relative to nil lime applied (control treatment), demonstrating response to lime rate and incorporation treatment at Site 1 (Lyndhurst NSW), expressed as deviations from the control.

Depth (cm)[1]	**Treatment 2 5.9 t/ha NI**		**Treatment 3 5.9 t/ha Inc**		**Treatment 4 4.7 t/ha NI**		**Treatment 5 4.7 t/ha Inc**		**Treatment 6 2.9 t/ha NI**		**Treatment 7 7 t/ha Inc**		**l.s.d. Δ pH$_{\text{Ca}}$**	**l.s.d. Δ Al$_{\text{ex}}$%**
	pH$_{\text{Ca}}$	**Al$_{\text{ex}}$%**	**pH$_{\text{Ca}}$**	**Al$_{\text{ex}}$%**	**pH$_{\text{Ca}}$**	**Al$_{\text{ex}}$%**	**pH$_{\text{Ca}}$**	**Al$_{\text{ex}}$%**	**pH$_{\text{Ca}}$**	**Al$_{\text{ex}}$%**	**pH$_{\text{Ca}}$**	**Al$_{\text{ex}}$%**		
0–2.5	2.4*	5.8*	2.2*	5.6*	2.2*	5.8*	2.2*	5.7*	1.9*	5.8*	2.2*	5.7*	0.24	0.74
2.5–5.0	1.5*	31.2*	1.9*	31.7*	1.3*	31.4*	1.9*	30.5*	0.7	24.3*	2.4*	32.0*	0.76	4.02
5.0–7.5	0.9*	39.6*	1.3*	45.2*	0.8*	34.8*	1.4*	40.2*	0.2	17.8*	1.9*	48.7*	0.88	12.95
7.5–10.0	0.6*	31.1*	0.7*	39.7*	0.4	24.8*	0.7*	39.8*	0.2	9.3	1.4*	51.6*	0.59	21.80
10.0–12.5	0.3	26.1*	0.5*	34.5*	0.2	17.5	0.6*	36.6*	0.1	6.8	0.8*	48.1*	0.40	22.06
12.5–15.0	0.2	15.8	0.3*	25.5*	0.1	12.8	0.3*	27.3*	0.0	7.0	0.4*	35.5*	0.27	17.58
15.0–17.5	0.1	11.3	0.2	19.8*	0.1	8.9	0.2	21.0*	0.1	4.0	0.3*	27.8*	0.21	15.36

[1] Results below the 15–17.5 cm layers are not shown as there was no significant treatment effect on pH or Al$_{\text{ex}}$% below this depth.

* Significantly different ($P<0.05$).

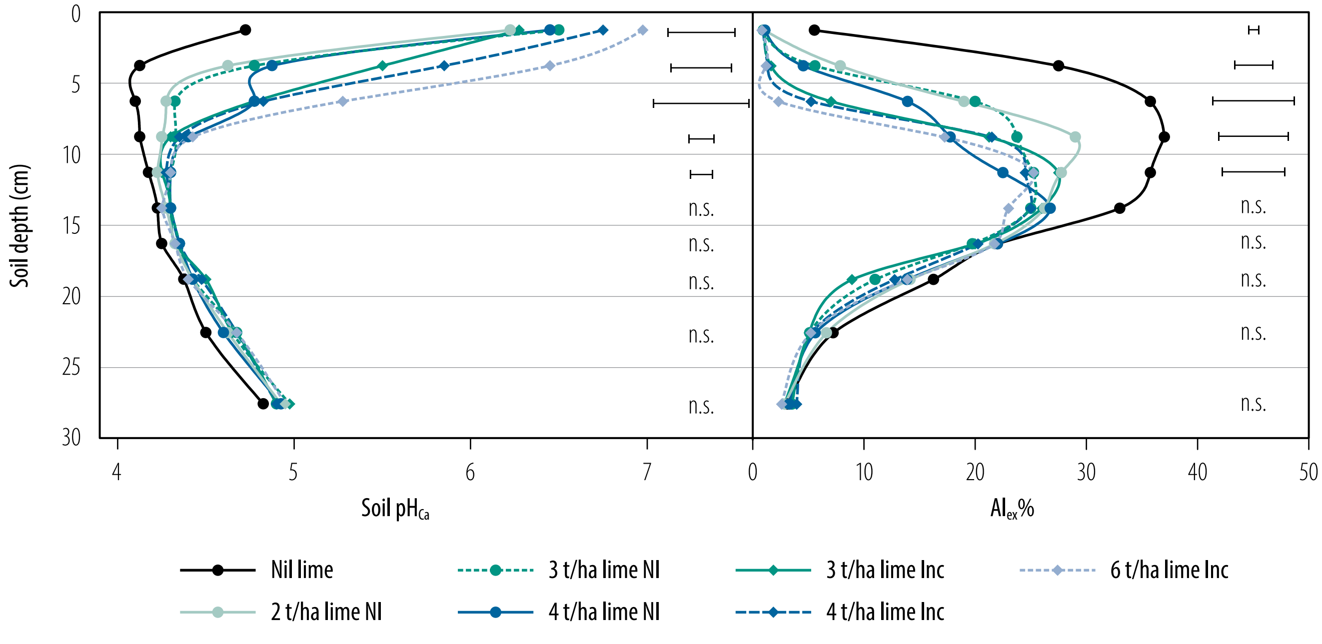
Site 2: Morven

Disc harrows used for incorporation at the Morven site were much less effective in mixing lime to depth than the aggressive mixing of the Horsch® Tiger used at the Lyndhurst site. However, while soil was estimated to have been disturbed to about 10 cm deep, soil tests for Al$_{\text{ex}}$% indicated a significant lime effect in layers from 0 cm to 12.5 cm for all lime treatments (Figure 2 and Table 4).

There was a significant change in pH down the profile to a depth of 10–12.5 cm for all incorporated lime treatments and at the highest rate of unincorporated lime applications (4 t/ha NI: target pH$_{\text{Ca}}$ >5.5). Where lime was not incorporated, change in pH relative to the nil lime treatment, indicates that the lime effect is concentrated in the surface 0–2.5 cm (Table 4) with a small change in pH at 2.5–5 cm. There was no significant change in pH below 5 cm at the lower unincorporated lime rates (3 t/ha NI: target pH$_{\text{Ca}}$ >5.2; and 2 t/ha NI: target 0–5 cm pH$_{\text{Ca}}$ >5.5). In contrast, incorporation appears to have effectively mixed the applied lime to a depth of at least 7.5 cm, with pH increasing by 0.7, 0.7 and 1.2 pH units in the 5–7.5 cm layer for the 3, 4, and 6 t/ha of incorporated lime, respectively, which targeted 0–10 cm pH$_{\text{Ca}}$ >5.2, >5.5 and ~ 6.2.

The change in Al_{ex}% mirrored pH change. Lime incorporation produced a greater and more uniform decrease in Al_{ex}% down the profile, particularly in the 2.5–7.5 cm layers. For example, at the same lime rate of 3 t/ha (target pH_{Ca} >5.5) Al_{ex}% decreased significantly by 25.9, 28.7 and 15.8% within the 2.5–5.2, 5.0–7.5 and 7.5–10 cm layers in the incorporated treatment, compared with 21.9, 15.8 and 13.3 for the corresponding depths in the 3 t/ha unincorporated treatment.

Changes in pH and Al_{ex}% for the incorporation treatments was of greater magnitude and more consistent down the profile compared with unincorporated treatments, at the same rates.



Horizontal bars represent l.s.d. ($P<0.05$); n.s. = no significant difference.

Figure 2 The soil profiles for pH_{Ca} and exchangeable aluminium percent (Al_{ex}%) at Site 2 (Morven NSW) showing the effects of lime rates of Nil, 4.0, 3.0, 2.0 and 6.0 t/ha, with incorporation (Inc) or without incorporation (NI), 10 months after application.

Table 4 Increase in soil pH_{Ca} and decrease in exchangeable aluminium percent (Al_{ex}%) relative to nil lime applied (control treatment), demonstrating the response to lime rate and incorporation at Site 2 (Morven NSW), and expressed as deviations from the control.

Depth (cm)[1]	Treatment 2 4.0 t/ha NI		Treatment 3 4.0 t/ha Inc		Treatment 4 3.0 t/ha NI		Treatment 5 3.0 t/ha Inc		Treatment 6 2.0 t/ha NI		Treatment 7 6.0 t/ha Inc		l.s.d. Δ pH_{Ca}	l.s.d. Δ Al_{ex}%
	pH_{Ca}	Al_{ex}%	pH_{Ca}	Al_{ex}%	pH_{Ca}	Al_{ex}%	pH_{Ca}	Al_{ex}%	pH_{Ca}	Al_{ex}%	pH_{Ca}	Al_{ex}%		
0–2.5	1.7*	4.5*	2.0*	4.6*	1.8*	4.6*	1.6*	4.4*	1.5*	4.5*	2.3*	4.7*	0.38	0.86
2.5–5.0	0.8*	23.0*	1.7*	26.1*	0.7*	21.9*	1.4*	25.9*	0.5*	19.6*	2.3*	26.3*	0.34	3.38
5.0–7.5	0.7*	21.8*	0.7*	30.5*	0.2*	15.8*	0.7*	28.7*	0.2	16.8*	1.2*	33.4*	0.53	7.22
7.5–10.0	0.3*	19.3*	0.2*	15.5*	0.2*	13.3*	0.2*	15.8*	0.1	8.0*	0.3*	19.8*	0.14	6.22
10.0–12.5	0.1*	13.3*	0.1	11.3*	0.1*	10.5*	0.1	8.3*	0.1	8.0*	0.1*	10.5*	0.13	2.77

[1] Results below the 10–12.5 cm layers are not shown as there was no significant treatment effect on pH or Al_{ex}% below this depth.

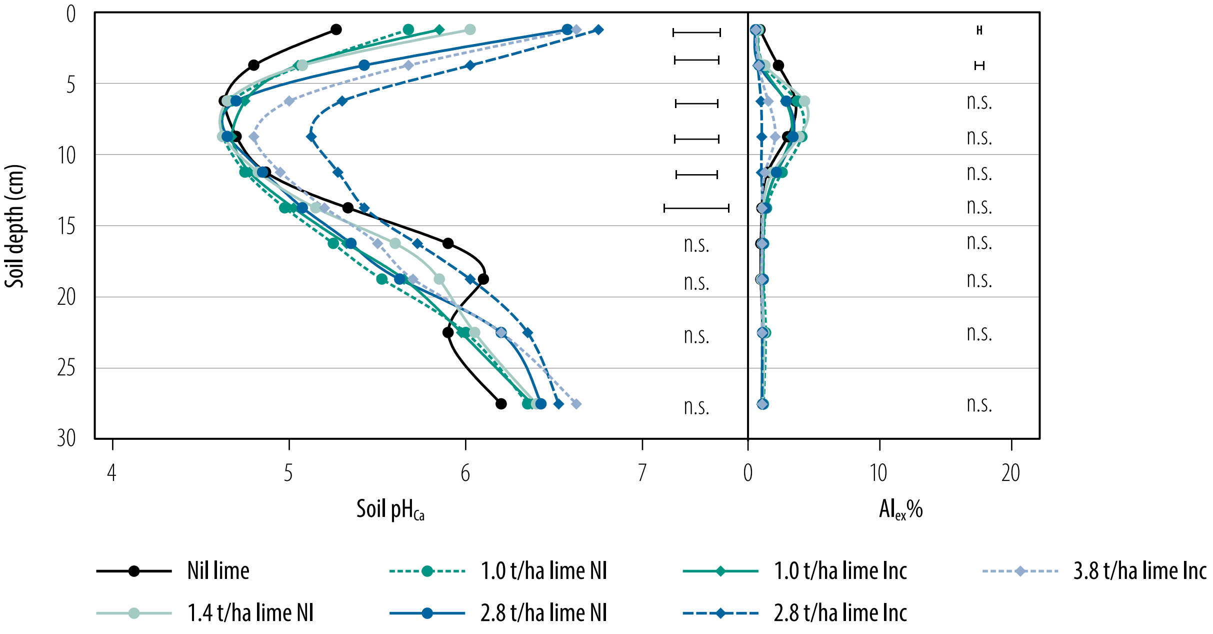
* Significantly different ($P<0.05$).

Site 3: Toogong

The Toogong site is typical of moderately acidic soils that support the highly productive farming systems in the medium to high rainfall zones of central and southern NSW, having no obvious chemical or physical soil constraints affecting productivity. The site was established to monitor the medium- to long-term benefit of early intervention acid soil management programs in preventing subsurface acidification.

There was a small, but significant response to lime rate and incorporation treatments (Figure 3 and Table 5). There was no significant change in pH and Al_{ex}% below 5 cm for unincorporated treatments 2, 4 and 6, or the incorporated treatment 5 (1 t/ha Inc: target pH_{Ca} >5.2). Treatments 3 and 7, which comprised incorporation of lime applied at rates to achieve a target pH_{Ca} >5.5 (2.8 and 3.8 t/ha), produced the greatest change in pH and Al_{ex}% in the layers from 0–7.5 cm. Note that despite being a lower rate of lime, treatment 3 produced significant change in pH and Al_{ex}% further down the profile, to the 10–12.5 cm layer. Analysing soil samples collected in the future will help explain whether this is an anomaly, or whether the high rate of lime applied in treatment 7 elevated pH sufficiently to reduce lime solubility.

The treatment responses at Toogong are not as distinct as at the severely acidic Lyndhurst and Morven sites. This is to be expected as lime solubility is influenced by starting pH, solubility being lower at higher pH, as is the case at the Toogong site. We anticipate that differentiation between treatments will develop over the next 2–10 years.



Horizontal bars represent l.s.d. ($P<0.05$); n.s. = no significant difference.

Figure 3 The soil profiles for pH_{Ca} and exchangeable aluminium percent (Al_{ex}%) at Site 3 (Toogong NSW) showing the effects of lime rates, with incorporation (Inc) or without incorporation (NI).

Table 5 Change in soil pH_{Ca} and exchangeable aluminium percent (Al_{ex}%) relative to nil lime applied (control treatment), demonstrating response to lime rate and incorporation treatment at Site 3 (Toogong NSW), expressed as deviations from the control.

Depth (cm)[1]	Treatment 2 2.8 t/ha NI		Treatment 3 2.8 t/ha Inc		Treatment 4 1.0 t/ha NI		Treatment 5 1.0 t/ha Inc		Treatment 6 1.4 t/ha NI		Treatment 7 3.8 t/ha Inc		l.s.d. Δ pH_{Ca}	l.s.d. Δ Al_{ex}%
	pH_{Ca}	Al_{ex}%	pH_{Ca}	Al_{ex}%	pH_{Ca}	Al_{ex}%	pH_{Ca}	Al_{ex}%	pH_{Ca}	Al_{ex}%	pH_{Ca}	Al_{ex}%		
0–2.5	1.4*	–0.4*	1.5*	–0.4*	0.5*	–0.2*	0.6*	–0.3*	0.8*	–0.3*	1.4*	–0.4*	0.27	0.14
2.5–5.0	0.6*	–1.5*	1.2*	–1.7*	0.3*	–1.1*	0.3*	–1.3*	0.3*	–1.1*	0.9*	–1.6*	0.27	0.60
5.0–7.5	0.1	–0.7	0.7*	–2.6	0.0	0.2	0.1	–0.7	0.0	0.7	0.4*	–2.2	0.24	n.s.
7.5–10.0	–0.1	0.4	0.4*	–2.0	–0.1	1.1	–0.1	0.3	–0.1	0.9	0.1	–0.9	0.25	n.s.
10.0–12.5	–0.1	0.8	0.4*	–0.4	–0.2	1.2	–0.1	0.8	–0.1	0.5	0.1	–0.1	0.23	n.s.

[1] Results below the 10.0–12.5 cm layers are not shown as there was no significant treatment effect on pH or Al_{ex}% below this depth.

* Significantly different ($P<0.05$).

Summary

Preliminary soil test results indicate that across all sites and treatments, targeting pH_{Ca} >5.5 results in greater depth of alkali movement (i.e. treatments 2, 3 and 7). When lime was incorporated, the magnitude of pH and Al_{ex}% change was accelerated to the depth of incorporation, or deeper. When lime was not incorporated the depth of lime effect increased with the rate of lime application, but even then, the greatest change in pH and Al_{ex}% was concentrated in the 0–5 cm surface layer.

At the Lyndhurst and Morven sites, treatment 6 unincorporated lime applied at rates of 2.9 and 2.0 t/ha, respectively, approximate traditional practices, i.e. unincorporated lime applied at rates of 2–2.5 t/ha and a 0–10 cm pH_{Ca} target of 5.2. These produced limited change in pH or Al_{ex}% below 2.5 cm.

Initial results indicate that:

- a target pH_{Ca} >5.5 in the 0–10 cm layers is needed to influence subsurface acidity
- incorporation will accelerate the lime reaction and increase the depth of the lime effect.

Average to above average rainfall at all sites following lime application aided lime reaction. The response to lime treatments in marginal years/seasons is yet to be investigated. Further monitoring of these sites is required to assess the role for more frequently applied, lower rates of lime in zero tillage systems, the residual value of lime and potential to prevent subsurface acidification through early intervention on marginally acidic sites.

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Acknowledgements

This experiment was part of the 'New approaches to tackling and monitoring soil acidity', project, NLP-12074, started: 1.07.2019; completion date: 31.03.2022.

This research is invested through the Australian Government National Landcare Program, supported by The Grassland Society of NSW, Holbrook Landcare Network and NSW Department of Primary Industries. The contribution of participating landowners hosting the field sites is greatly appreciated.

The technical support of NSW DPI Pasture Unit including Andrew Price, Peter Tyndall, Richard Lowrie, Adam Lowrie, Kylie Cooley and Lance Troy; and Phoebe Gulliver and Nick McGrath of Holbrook Landcare Network is greatly appreciated.

Contact

Helen Burns
Wagga Wagga Agricultural Institute, Wagga Wagga
helen.burns@dpi.nsw.gov.au
0427 721 816

Research update for ameliorating subsoil acidity using organic amendments

Dr Guangdi Li[1,3], Dr Jason Condon[1,2,3], Richard Hayes[1,3], Helen Burns[1], Richard Lowrie[1], Adam Lowrie[1], Andrew Price[1], Binbin Xu[1], Yan Jia[1] and Graeme Poile[1]

[1] NSW Department of Primary Industries, Pine Gully Road, Wagga Wagga, NSW 2650
[2] Charles Sturt University, Boorooma Street, Wagga Wagga, NSW 2650
[3] Graham Centre for Agricultural Innovation, Albert Pugsley Place, Wagga Wagga, NSW 2650

Key findings

- Lime increased soil pH and decreased the exchangeable aluminium percentage (Al_{ex}%) significantly.
- Organic amendments could be used to ameliorate soil acidity, but they were not as effective as lime.
- Crops responded more to nutrient addition than amelioration of soil acidity with organic amendments in the short term.
- The long-term effect of organic amendments on soil acidity and crop yield response needs further investigation.

Introduction

A range of organic amendments have been tested to assess their effectiveness on ameliorating soil acidity in the field. The crop yield was monitored over three years from 2018 to 2020.

Site details

Location Billa, Holbrook NSW

Soil type Yellow chromosol (Isbell and National Committee on Soil and Terrain 2021)

Crops

Previous crops	Crops in experiment period
2015, Hyola® 970CL canola	2018, SF Edimax® CL canola
2016, EGA Wedgetail⦸ wheat	2019, LongReach Kittyhawk⦸ wheat
2017, EGA Wedgetail⦸ wheat	2020, LongReach Kittyhawk⦸ wheat

Rainfall (mm)

Year	In-crop rainfall (April–October)	Fallow rainfall (November–March)	Annual rainfall
2018	213.6 mm	208.2 mm	421.8 mm
2019	242.6 mm	171.8 mm	414.4 mm
2020	509.5 mm	206.6 mm	716.1 mm
Long-term average	386.4 mm	243.1 mm	629.4 mm

Fertiliser

Year	At sowing	Top-dressing
2018	70kg mono-ammonium phosphate (MAP)	100 kg/ha urea
2019	70kg MAP	100 kg/ha urea
2020	70kg MAP	100 kg/ha urea

Ripping machine	3-D Ripper (5 tynes), designed and fabricated by NSW DPI (Li and Burns 2016)
Ripping width and depth	50 cm between rip lines; to 30 cm deep

Treatments

There were 20 treatments in this experiment. All organic amendments were applied in the 10–30 cm depth with and without lime in contrast with surface lime in February 2018.

All treatments were surface limed to pH 5.0 at 0–10 cm deep except for the surface lime treatment with a high lime rate (limed to pH 5.5). All surface lime was applied after deep ripping with amendments, then incorporated to 10 cm deep. Plot size: 5 × 20 m = 100 m^2. Buffer between plots: 2.5 m, buffer between blocks: 20 m.

Organic amendments used in this experiment:

- Deep lucerne hay pellet at 15 t/ha.
- Deep pea-hay pellet at 15 t/ha.
- Deep wheat straw pellet at 15 t/ha.
- Deep wheat straw pellet at 15 t/ha plus nitrogen [N], phosphorus [P] and sulfur [S] at 5N:2P:1.3S as per Kirkby et al. (2013).
- Deep poultry litter pellets as Yates Dynamic Lifter at 10 t/ha.
- Deep biochar pellet blended with pea hay 50:50 at 10 t/ha.

Measurements

Soil samples were taken in autumn using a multi-core sampler (Lowrie et al. 2018) at 0–60 cm deep across a rip line and a large soil core (44 mm in diameter) for the 60–100 cm depth on a rip line at two locations in each plot. The rip lines were located with permanent marks. Soil samples were bulked into 10 cm increments from 0–40 cm and 20 cm increments from 40–100 cm. Soil pH_{Ca} and exchangeable cations were analysed as per Gillman and Sumpter (1986). Grain yield was obtained with a plot header.

Results and discussion

Rainfall pattern

It was extremely dry in 2018 and 2019 with in-crop rainfall of 214 mm and 243 mm, respectively. In contrast, it was a wet year in 2020 with in-crop rainfall of 510 mm, compared with the long-term average in-crop rainfall of 386 mm (Figure 1).

Organic amendments

Results demonstrated that organic amendments could be used as soil ameliorants to increase soil pH and reduce aluminium (Al) toxicity in acidic soils. However, the magnitude of any pH increase varied between the type of organic amendments used, depending on their ash alkalinity, and the concentration of excess base cations, which reflects the concentration of stored organic acid anions (Tang and Yu 1999). All organic ameliorants slightly increased soil pH in 2018 and 2019 in the 10–20 cm and 20–30 cm depths where they were placed, but were not as effective as lime (Figure 2). The increase in pH was most likely due to OH^- being released during the decarboxylation process of organic matter and ammonification of organic nitrogen compounds. However, the subsequent nitrification process would decrease soil pH. Organic ameliorants also significantly reduced Al_{ex}% in the 10–20 cm and 20–30 cm depths in 2020, compared with the surface lime treatment (Figure 2). This is likely to be due to the soluble organic molecules from organic amendments combining with active Al^{3+} to form insoluble hydroxy-Al compounds (Haynes and Mokolobate 2001), which would reduce Al toxicity to plant root systems.

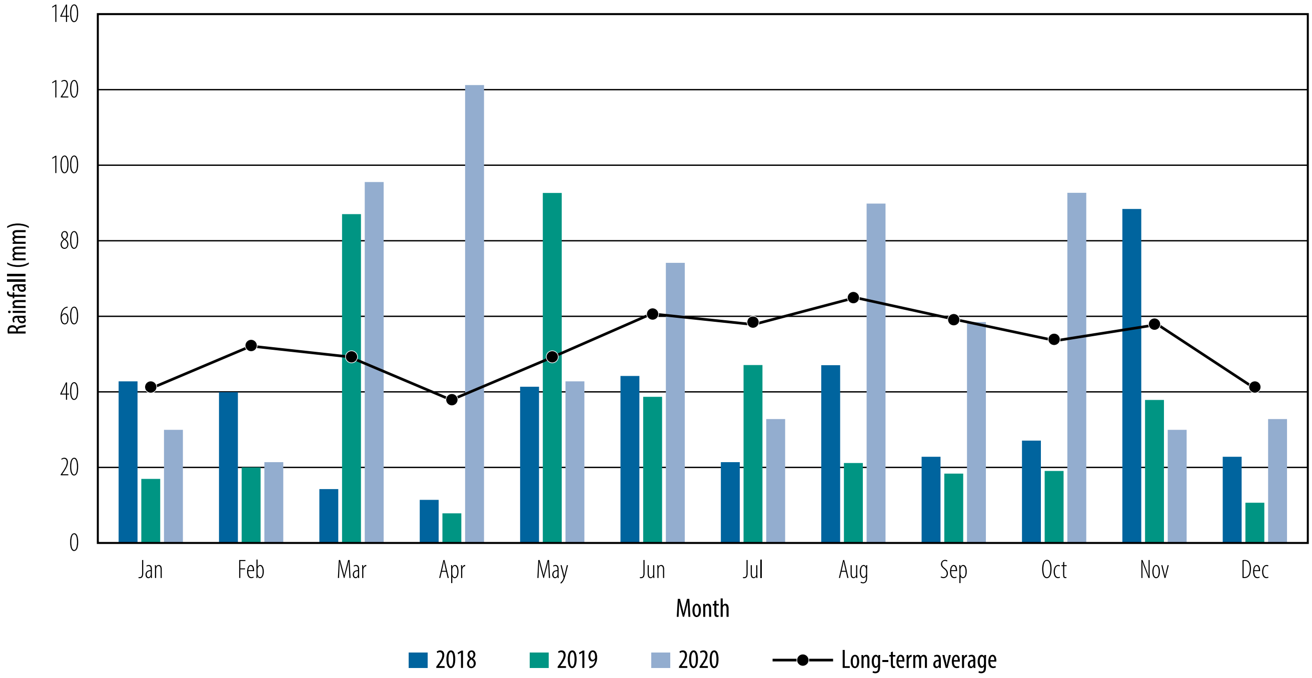
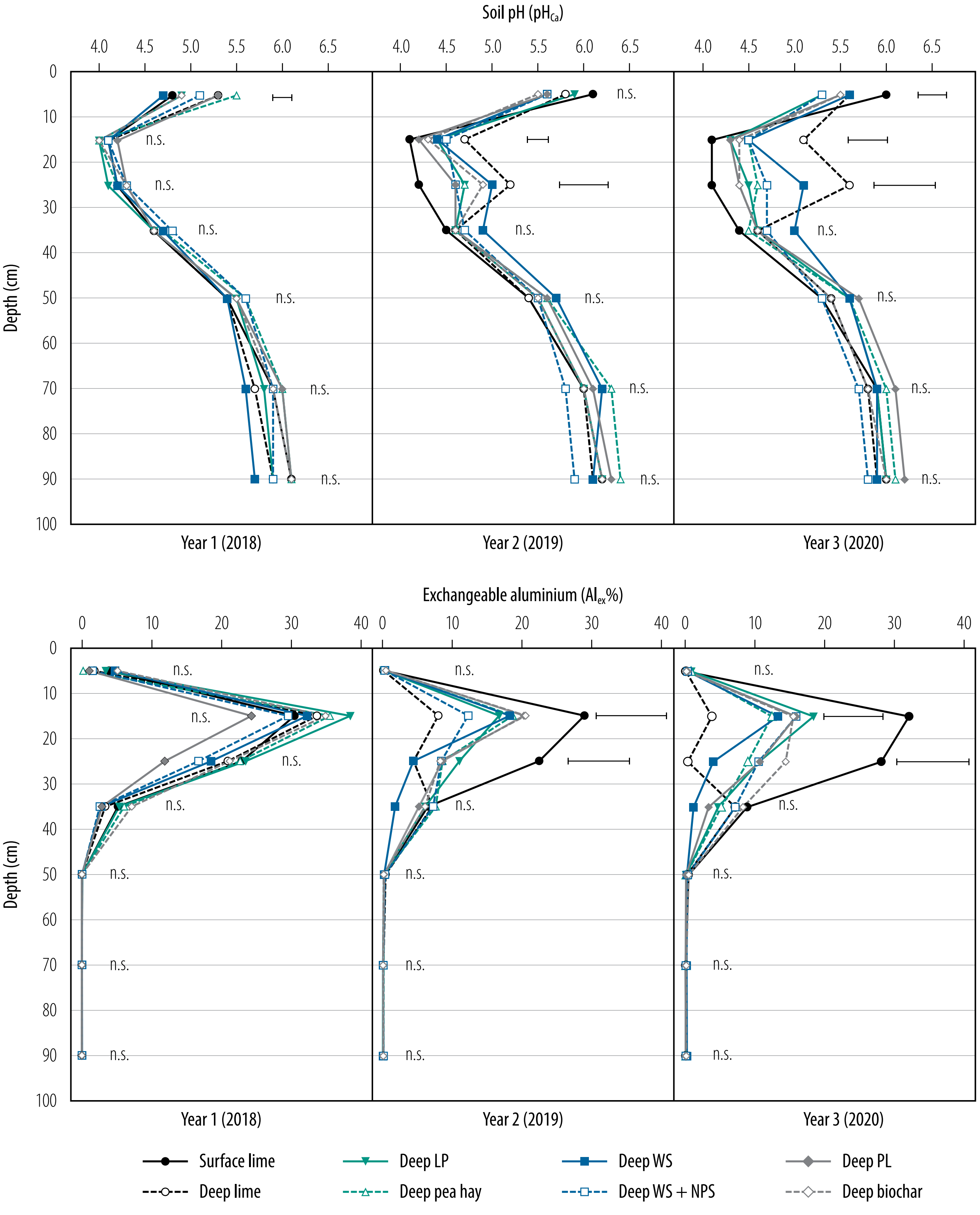


Figure 1 Monthly rainfall and long-term average rainfall at Holbrook, NSW.

Lime plus organic amendments

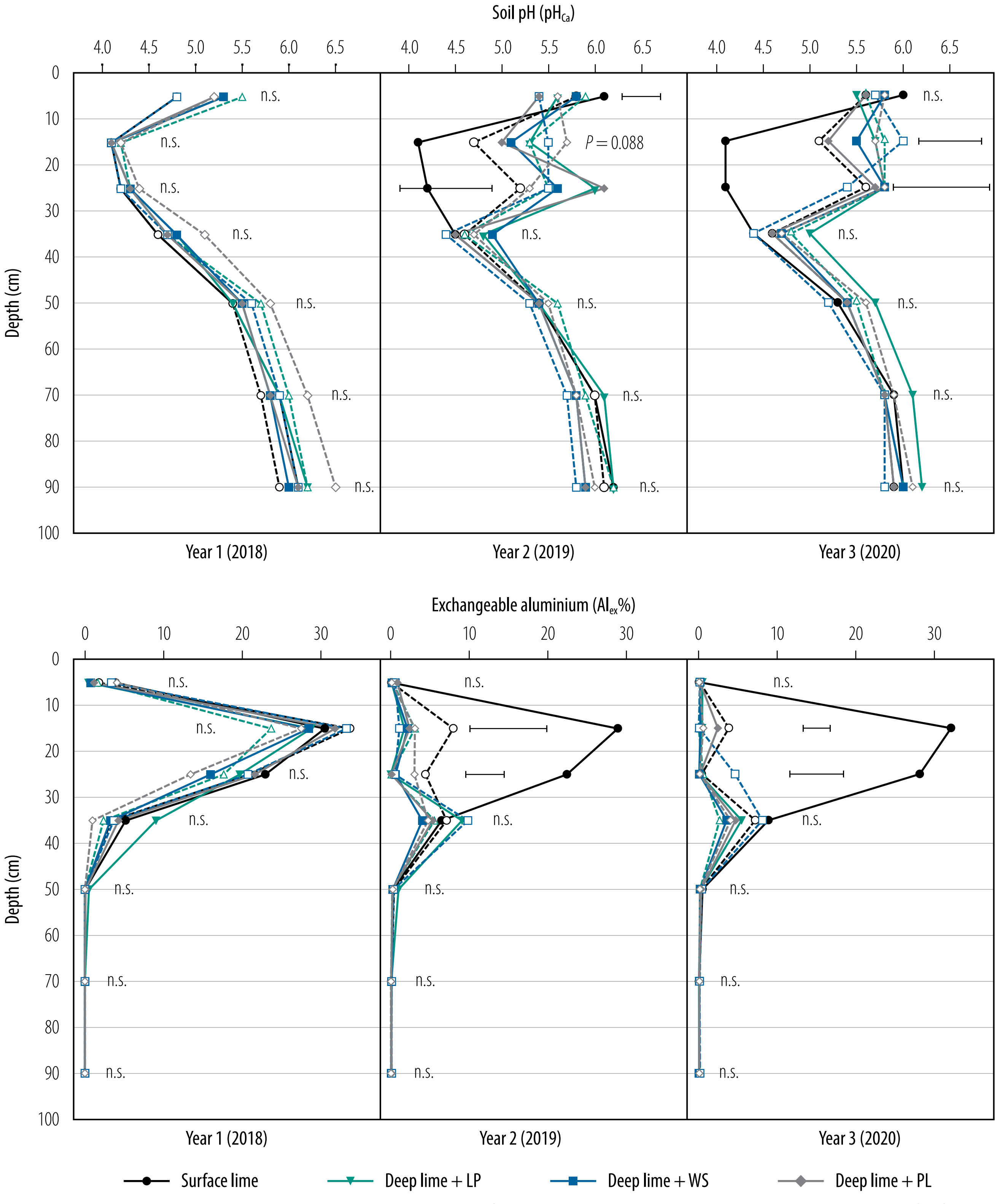
Adding lime to organic amendments increased soil pH in the 10–20 cm depth at $P = 0.09$ and 20–30 cm depth at $P<0.05$, and reduced Al_{ex}% significantly at both depths ($P<0.01$) compared with the surface lime treatment (Figure 3). There were no significant differences in soil pH and Al_{ex}% between deep lime only and deep lime combined with organic amendments, indicating that it was the lime rather than organic amendments that played the major role in ameliorating soil acidity. A number of soil column experiments demonstrated that adding lime with plant residues can facilitate alkalinity moving below the amended depth (Butterly et al. 2021). However, there was no evidence to show alkalinity movement down the soil profile in the field experiment (Figure 3).



LP, lucerne hay pellets; WS, wheat straw pellets; NPS, 5N:2P:1.3S; PL, poultry litter pellets.

⊢⊣ Horizontal bars represent l.s.d. at $P = 0.05$; n.s. = not significant.

Figure 2 Soil pH (pH_{Ca}) (top row) and exchangeable aluminium percentage (Al_{ex}%) (bottom row) under various organic ameliorants in years 1–3 at the Holbrook site, NSW.



LP, lucerne hay pellets; WS, wheat straw pellets; NPS, 5N:2P:1.3S; PL, poultry litter pellets.

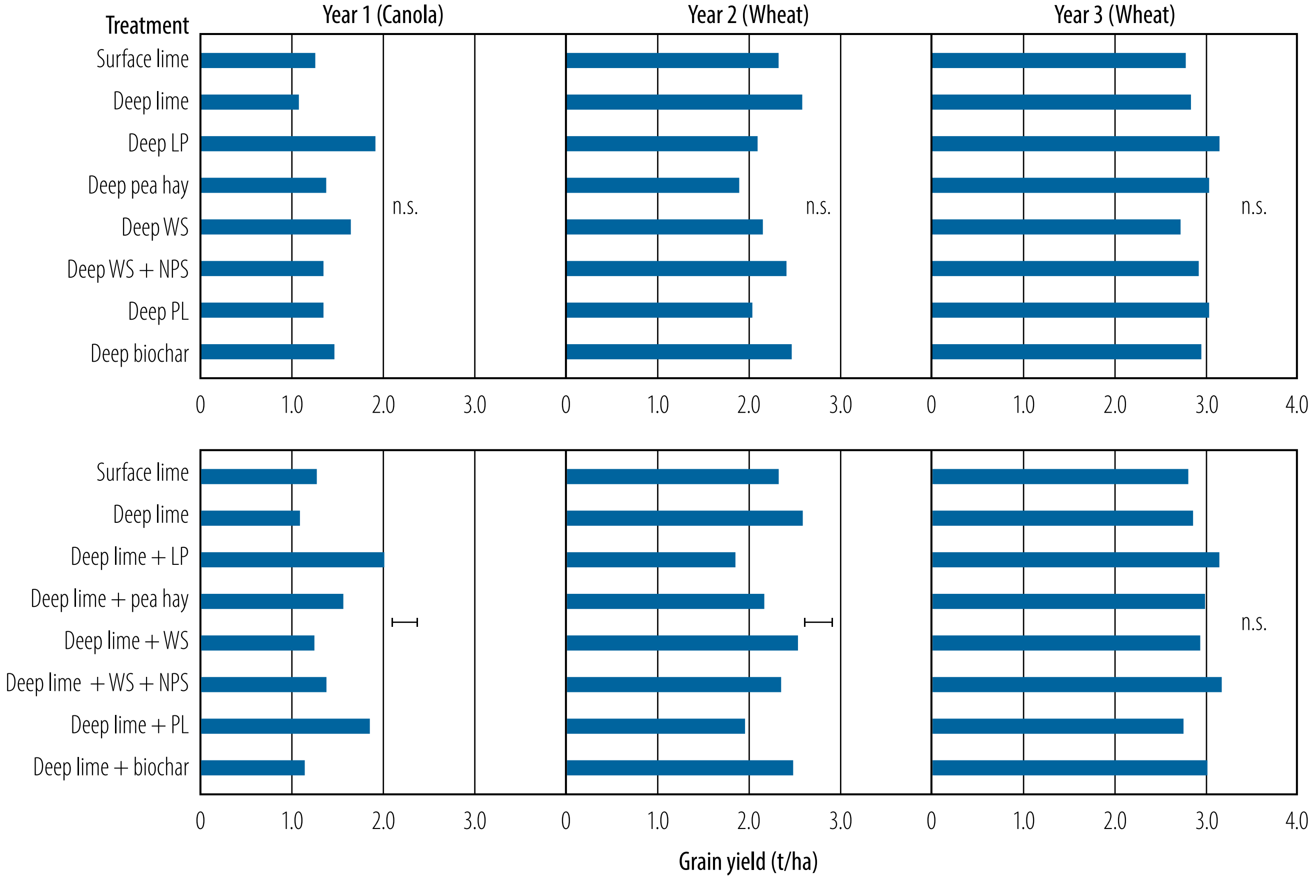
⊢⊣ Horizontal bars represent l.s.d. at $P = 0.05$; n.s. = not significant.

Figure 3 Soil pH (pH$_{Ca}$) (top row) and exchangeable aluminium percentage (Al$_{ex}$%) (bottom row) under various organic ameliorants with lime in years 1–3 at the Holbrook site, NSW.

Grain yield

The drought in 2018 and 2019 (Figure 1) greatly suppressed grain yield. The canola grain yield was less than 2.0 t/ha in 2018 and the wheat grain yield was under 2.6 t/ha in 2019 (Figure 4). In contrast, wheat yield was up to 3.2 t/ha in 2020 – a wet year (Figure 4).

In the first year, 2018, the deep lucerne hay pellet treatments with and without lime had the highest yield, followed by the deep poultry litter treatment with lime (Figure 4), probably due to nutrient effect rather than ameliorating soil acidity. Those treatments with higher grain yield in 2018 tended to have low yields in 2019 due to severe drought. For example, both the lucerne hay pellet and poultry litter with added lime treatments had lower grain yield compared with other organic amendments in 2019. This is probably related to soil water dynamics. In 2020, a wet year, no difference in grain yield was found between treatments at the site. It appeared that the effect of soil acidity on root function was much less when soil water was not a limiting factor.



LP, lucerne hay pellets; WS, wheat straw pellets; NPS, 5N:2P:1.3S; PL, poultry litter pellets.

⊢⊣ Horizontal bars represent l.s.d. at $P = 0.05$; n.s. = not significant.

Figure 4 Grain yield (kg/ha) under organic amendments (top row) and lime plus organic amendments (bottom row) in years 1–3 at the Holbrook site, NSW.

Conclusions

Deep lime increased soil pH and decreased Al_{ex}% significantly in the 10–20 cm and 20–30 cm depths in 2019 and 2020. Organic amendments could increase pH, but were not as effective as lime, however, organic amendment decreased Al_{ex}% significantly. Crop yields responded more to nutrients than to ameliorated soil acidity in the first year (2018). However, the nutrient effect under organic amendment treatments was suppressed by lack of soil moisture in the second year (2019). The long-term effect of organic amendments on crop yield needs further investigation.

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Acknowledgements

This experiment was part of the 'Innovative approaches to managing subsoil acidity in the southern region' project, DAN00206, 2015–20, with joint investment by NSW DPI and GRDC.

Our thanks extend to the landowner Tony Geddes for his ongoing cooperation during the experiment.

Contact

Dr Guangdi Li
Wagga Wagga Agricultural Institute, Wagga Wagga
guangdi.li@dpi.nsw.gov.au
02 6938 1930

Managing alkaline dispersive subsoil for improving farming productivity

Dr Shihab Uddin[1], Dr Wayne Pitt[1], Shane Hildebrand[1], Albert Oates[1], Dr Naveed Aslam[1], David Armstrong[1], Yan Jia[1], Qing Wei[1], Dr Yunying Fang[2] and Dr Ehsan Tavakkoli[1,3]

[1] NSW DPI, Wagga Wagga Agricultural Institute, Wagga Wagga
[2] NSW DPI, Elizabeth Macarthur Agricultural Institute, Menangle
[3] Graham Centre for Agricultural Innovation, Charles Sturt University, Wagga Wagga

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Key findings

- Crop residue deep placement in combination with chemical fertilisers and a low rate of gypsum demonstrated consistent yield improvement (27%; averaged for four successive years) in alkaline dispersive subsoil.
- Organic and inorganic amendment deep placement increased root growth, and soil water use from the deeper clay layers during the critical reproductive stages of crop development.
- Improvements in grain yield with organic and inorganic amendment deep placement were associated with a reduction in subsoil pH, exchangeable sodium percentage (ESP%) and increased microbial activity, which promoted soil aggregation.

Introduction

Among different soil constraints, alkaline dispersive subsoil is associated with the largest yield gap across the Australian grain belt, with an estimated yield loss of $A1,300 million per annum (Orton et al. 2018). The yield gap is caused by several physicochemical properties, which include:

- high exchangeable sodium (Na) concentrations
- dispersion
- poor structure
- waterlogging
- high soil strength
- in some circumstances pH higher than 8.2 (H_2O).

Applying large quantities of organic amendments, especially in the alkaline dispersive subsoil, has demonstrated increase in crop yields in high rainfall regions (Gill et al. 2008; 2009), but to date, practice change in the grain industry has been limited.

The major constraints for widespread subsoil amelioration adoption include:

- limited availability and high cost of suitable organic ameliorants delivered in-paddock
- lack of suitable commercial-scale machinery
- poor predictability of when and where the amelioration will consistently benefit crop productivity.

These factors can be significant as research to date in the high rainfall zones suggests that rates of up to 20 t/ha are required, and transport costs quickly become prohibitive if the amendments need to be sourced off-farm (Gill et al. 2008; Sale et al. 2019).

Therefore, solutions integrating complementary sources of organic amendments such as crop residue and cover crop biomass produced in-situ need to be investigated. This current experiment investigated the potential of using farm grown crop residues as ameliorants for alkaline dispersive subsoils in the medium rainfall region of southern NSW.

Site details

Location	Rand, southern NSW
Soil type	Sodosol
Previous crop	Canola
Design	Randomised complete block design (RCBD) with four replications
Sowing	Wheat (*Triticum aestivum* cv. Scepter(b)) was sown with an air seeder with rows spaced at 250 mm using a GPS auto-steer system (16 May 2020)
Seed rate	63 kg/ha
Fertiliser	• 78 kg/ha di-ammonium phosphate (DAP) (at sowing) • Urea 150 kg/ha (top dressed on 22 May 2020)
Rainfall	• Fallow (November 2019–March 2020): 170 mm • Fallow long-term average: 195 mm • In-crop (April 2020–October 2020): 401 mm • In-crop long-term average: 358 mm
Harvest date	7 December 2020

Treatments

Experiment treatments are shown in Table 1.

Table 1 Organic and inorganic amendments with their rate of application in February 2017.

Treatment	Organic/inorganic	Rate
Control	–	–
Deep gypsum	Inorganic	5 t/ha
Deep NPK (liquid nitrogen (N), phosphorus (P), potassium (K))	Inorganic	N to match poultry litter
Deep manure	Organic	Poultry litter 8 t/ha
Deep pea straw	Organic	15 t/ha
Deep pea straw + gypsum + NPK	Organic + inorganic	15 t/ha, 5 t/ha, N to match poultry litter
Deep pea straw + NPK	Organic + inorganic	15 t/ha, N to match poultry litter
Deep wheat straw	Organic	15 t/ha
Deep wheat straw + NPK	Organic + inorganic	15 t/ha, N to match poultry litter
Rip only	–	–
Surface gypsum	Inorganic	5 t/ha
Surface manure	Organic	Poultry litter 8 t/ha
Surface pea straw	Organic	15 t/ha

Deep amendments were incorporated at 20–40 cm depth in 50 cm bands.

Results

Growing conditions

In February 2017, a field experiment was established on-farm near the township of Rand in southern NSW. Treatments and physicochemical properties are detailed in Table 1 and Table 2, respectively. The paddock has a history of cereal-canola rotation as winter crop and summer fallow as per the local practices.

The soil is characterised as a sodosol (Isbell 2002), with increasing clay content at depth. The increasing levels of exchangeable sodium relative to calcium and/or magnesium in subsoil results in a decrease in soil structural stability and an increase in dispersion potential. The high clay content in this subsoil layer has a bulk density (BD) of 1.55 g/cm^3 that restricts water movement, and consequently the subsoil has very low saturated hydraulic conductivity.

Table 2 Soil chemical properties at different depths of the soil profile at the experiment site.

Soil depth (cm)	pH (1:5 water)	EC (µs/cm)	ESP (%)	CEC (cmol$_{(+)}$/kg)	Nitrate N (mg/kg)	BD (g/cm^3)
0–10	6.6	132.1	3.8	16.1	20.6	1.40
10–20	7.8	104.0	7.3	22.6	5.8	1.52
20–40	9.0	201.5	12.5	26.7	4.1	1.50
40–50	9.4	300.5	18.1	27.5	3.0	1.48
50–60	9.5	401.3	21.8	28.8	3.0	1.53
60–100	9.4	645.0	26.4	29.7	2.9	1.55

Values are means (n = 4).
EC = electrical conductivity; ESP = exchangeable sodium percentage; CEC = cation exchange capacity; BD = bulk density.

Grain yield

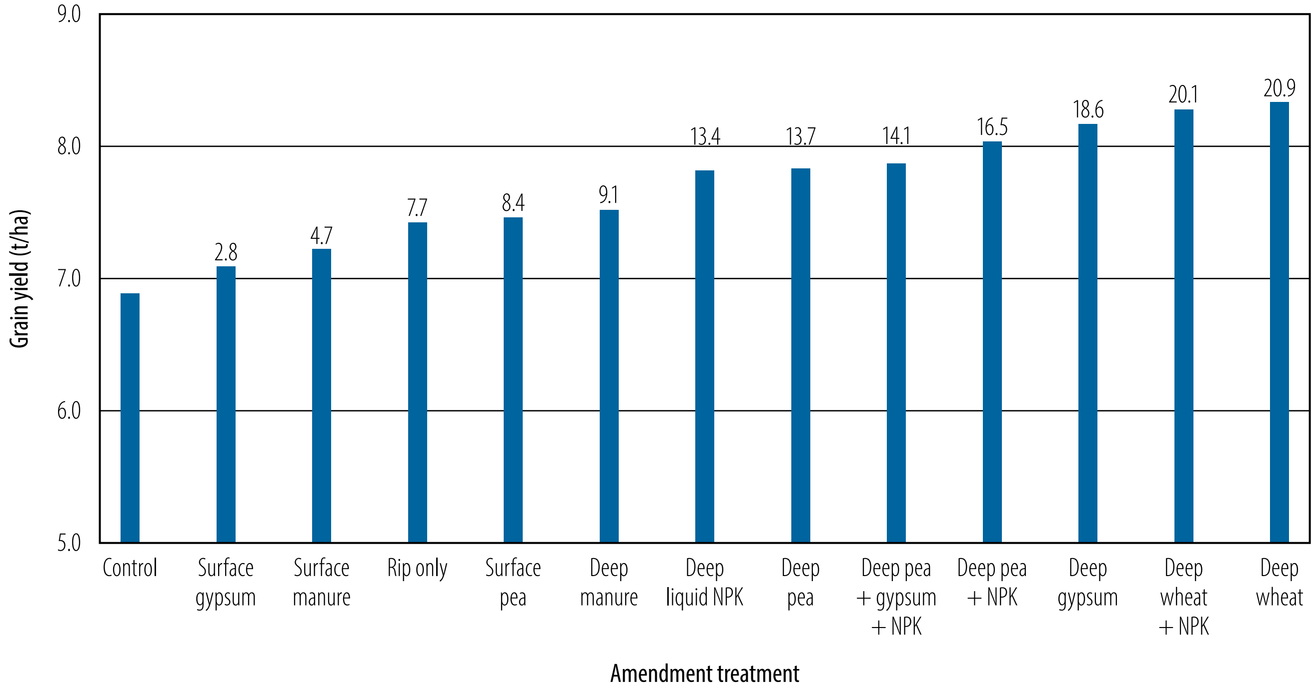
The single application of different amendments (Table 1) significantly affected the crop grain yield over four consecutive years. For example, in 2020, wheat grain yield (relative to control) increased following the deep placement of wheat straw, wheat straw + NPK and gypsum by 21%, 20% and 19% respectively ($P<0.001$) (Figure 1).

The yield variations in response to surface amendment application or rip only was not significantly different from the control.

A multi-year cumulative analysis of grain yield response (2017–20) from this experiment indicated that deep placement of plant-based straw, gypsum and their combinations with NPK resulted in significant and consistent improvements in crop yield. For example, the cumulative grain yield of deep pea + gypsum + NPK over the four successive years was 19.4 t/ha, which was 27% higher than the control (15.3 t/ha).

Soil pH

Variation in subsoil pH measured at the amended layer (20–40 cm) is shown in Figure 2. Compared with the control, gypsum deep placement reduced the soil pH by 0.86 units (8.99 to 8.13) at 20–40 cm depth, while deep placement of pea + gypsum + NPK reduced this value by 0.47 units (8.99 to 8.52). Along with greater infiltration rates, amendment deep placement significantly increased root growth and water extraction from the subsoil layers.

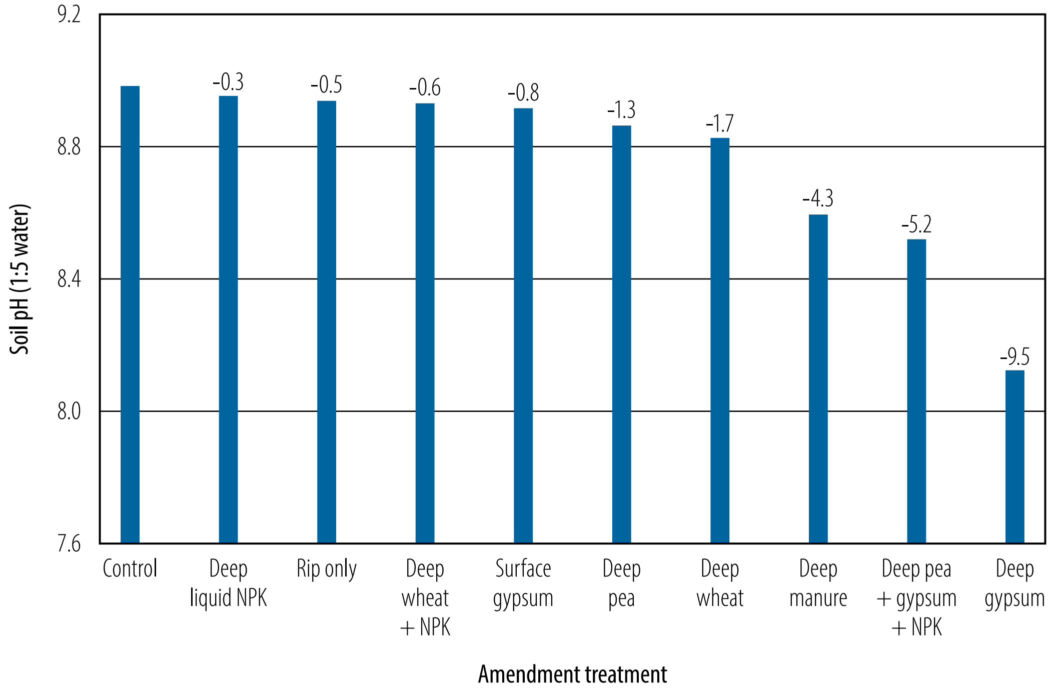


Values on the top of each bar represent the percent change in grain yield for individual amendments compared with the control.

Each data point is mean value of $n = 4$.

l.s.d. ($P = 0.05$) = 0.67 t/ha.

Figure 1 The mean effect of surface or deep-placed amendments on grain yield of wheat (cv. Scepter$^{(b)}$) grown in alkaline sodic subsoil in Rand, southern NSW in 2020.



Values on the top of each bar represent the percent change in soil pH for individual amendments compared with the control.

Each data point is mean value of $n = 4$.

l.s.d. ($P = 0.05$) = 0.27.

Figure 2 The mean effect of surface or deep placed amendments on soil pH at the amended layer (20–40 cm soil depth).

Conclusion

Grain yield improvement was observed in the four seasons subsequent to the deep placement of a range of amendments in a medium rainfall region of NSW. This strong residual effect was supported by the observations reported in a high rainfall region of Victoria (Gill et al. 2008).

Despite receiving 401 mm of in-season rainfall in 2020, when compared with the control the best performing treatment (deep wheat) yielded an increase in grain of 21%. This was lower than the best performing treatments for 2017, 2018 and 2019, all of which comprised incorporating deep pea + gypsum, which produced yield improvements of 27, 53 and 36% respectively, despite ongoing and intensive drought.

The better yield improvement in the drier growing seasons could be attributed to the accessibility of stored subsoil water, which was linked with greater root proliferation in the amendment layer. Furthermore, deep placement of crop residues and/or gypsum significantly increased macro-aggregation, water infiltration and subsoil water extraction in this experiment (data not presented).

The results indicate that independent modes of action of various amendments (e.g. crop residue vs gypsum) are required in the amendment mix in order to effectively ameliorate sodic subsoils. For example, adding gypsum reduced pH in the amended subsoil to below 8.5, which can result in significant improvement (reduction) in soil dispersion (Tavakkoli et al. 2015). Adding crop residues and nutrients provided substrate for enhanced biological activity resulting in increased macro aggregation and improved subsoil structure. The co-application of organic and inorganic amendments can result in additive effects to improve soil physical and chemical properties (Fang et al. 2020), thus creating a favourable condition for root proliferation (Uddin et al. 2020).

A promising finding from the experiment, is that readily available farm-grown products such as wheat and pea straws, when mixed with nutrients, can improve soil aggregation, root growth, water extraction and grain yield, and produce yield responses comparable with, or better than nutrient-enriched animal manures and gypsum.

The results of this experiment showed that grain growers already have a potentially large supply of relatively inexpensive organic ameliorants available in their paddocks, a factor that could increase application options and the viability of correcting subsoil sodicity.

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Acknowledgements

This experiment was part of the 'Understanding the amelioration processes of the subsoil application of amendments in the Southern Region' project, DAV00149, 2015–20. The project is a collaborative partnership between GRDC, Agriculture Victoria, NSW DPI, La Trobe University, University of South Australia, Southern Farming Systems, Primary Industries and Regions South Australia, South Australian Research and Development Institute and University of Tasmania.

Contact

Dr Shihab Uddin
Wagga Wagga Agricultural Institute, Wagga Wagga
shihab.uddin@dpi.nsw.gov.au
02 6938 1830

Predicting rice crop maturity using remote sensing

Brian Dunn, Tina Dunn, Craig Hodges and Chris Dawe

NSW DPI, Yanco

Key findings

- Grain moisture content was predicted with a high level of accuracy ($R^2 = 0.88$ to 0.94) for each variety using normalised difference vegetation index (NDVI), but predictions were different across varieties.
- This research is valuable as proof of concept, highlighting that the opportunity exists to potentially use NDVI to predict grain maturity across a rice field.
- The difficult decision of when to drain a rice crop could be improved by using remote sensing and within-field variability could be accounted for in the decision-making process.

Introduction

Deciding when to drain the water from a rice field as the crop nears physiological maturity is a very difficult decision. The field needs to be dry enough to be trafficable at harvest but draining too early can lead to haying off, poor grain quality, lodging and reduced grain yield, while draining late can delay harvest and reduce grain quality. Remote sensing has shown potential for predicting maturity in several crops (Hart et al. 2020). The aim of this project was to investigate if remote sensing technology could be applied to rice. Remote sensing also has the advantage of identifying spatial variability within a field, which is also important in making an accurate drainage timing decision.

Methods

Field experiment

A rice variety × nitrogen rate experiment was established on a self-mulching clay soil at Leeton Field Station in south-eastern New South Wales (NSW), Australia. The experiment consisted of three replications of three commercial rice varieties (Reiziq$^{(b)}$, Langi and Opus$^{(b)}$), which were split with four nitrogen rates (0, 60, 120 and 180 kg N/ha) to result in an individual plot size of 6.4 × 10 m. The experiment was drill sown at 20 cm row spacing on 11 October 2019 with permanent water applied on 20 December 2019.

Imagery collection

Remotely sensed imagery was collected each day that physical plant samples were collected from the experiment. Reflectance data from the experiment was measured using a Micasense RedEdge multispectral sensor mounted on a DJI Matrice 100 unmanned aerial vehicle (UAV). The Micasense RedEdge sensors band specifications are listed in Table 1.

Table 1 Band specifications for the Micasense RedEdge multispectral sensor.

Band	Wavelength (nm)	Bandwidth (nm)
Blue	475	20
Green	560	20
Red	668	10
Red edge	717	10
Near infra-red	840	40

Remote sensing imagery was collected within 2.5 hours of solar noon, in direct sunlight not impeded by cloud cover. The imagery was collected at 50 m above the ground, 5 m/s speed and 80% overlap of images. A calibration reflectance panel was imaged immediately before each flight and used in the image processing method. Ground control points were established at the four corners of the experiment and used to standardise the imagery location from each flight.

The reflectance data images were then compiled together using Pix4D, a photogrammetry software package for combining multiple images and the multiple layers from multispectral sensors. The average reflectance values for each band were then extracted from each plot using QGIS 3.21, a geographical information system (GIS) software package, to calculate vegetation indices. The primary index used in this project was normalised difference vegetation index (NDVI).

Results

There is a strong relationship between grain moisture content and thousand grain weight (TGW) in both the Reiziq⁽ᵝ⁾ and Opus⁽ᵝ⁾ varieties, but it was less pronounced in Langi, which is a thin, long grain variety. In the Reiziq⁽ᵝ⁾ 120 kg N/ha treatment (Figure 1) TGW increases as moisture declines until grain moisture of approximately 25% is reached at which point TGW plateaus. It can be assumed that 25% grain moisture is the point at which physiological maturity is reached for this variety.

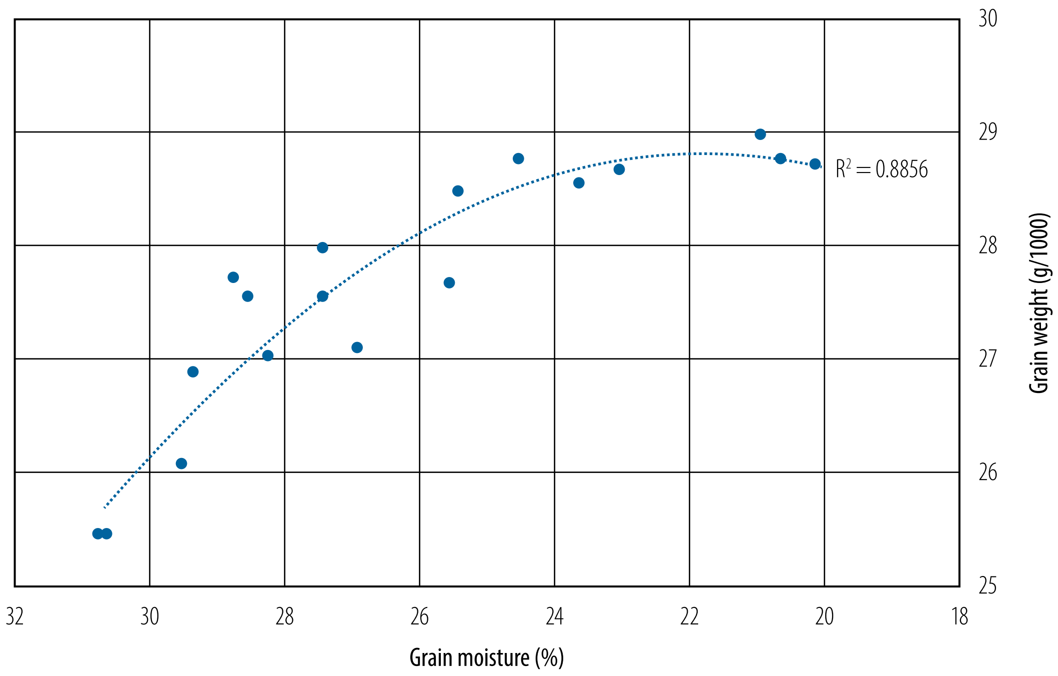

Figure 1 Regression between TGW and grain moisture for the Reiziq⁽ᵝ⁾ 120 kg N/ha treatment.

Three nitrogen rates (60, 120 and 180 kg N/ha), which represent the crop nitrogen status range common in commercial fields, were combined in the regressions shown in Figure 2. When NDVI is regressed against grain moisture, all three varieties show a strong relationship with NDVI declining as grain moisture declines (Figure 2).

It is important to note that the relationship between NDVI and grain moisture is different for each variety and if this relationship was to be used commercially, individual variety algorithms would need to be developed. This research is being conducted again in the 2020–21 rice season to identify if the relationships identified carry across seasons.

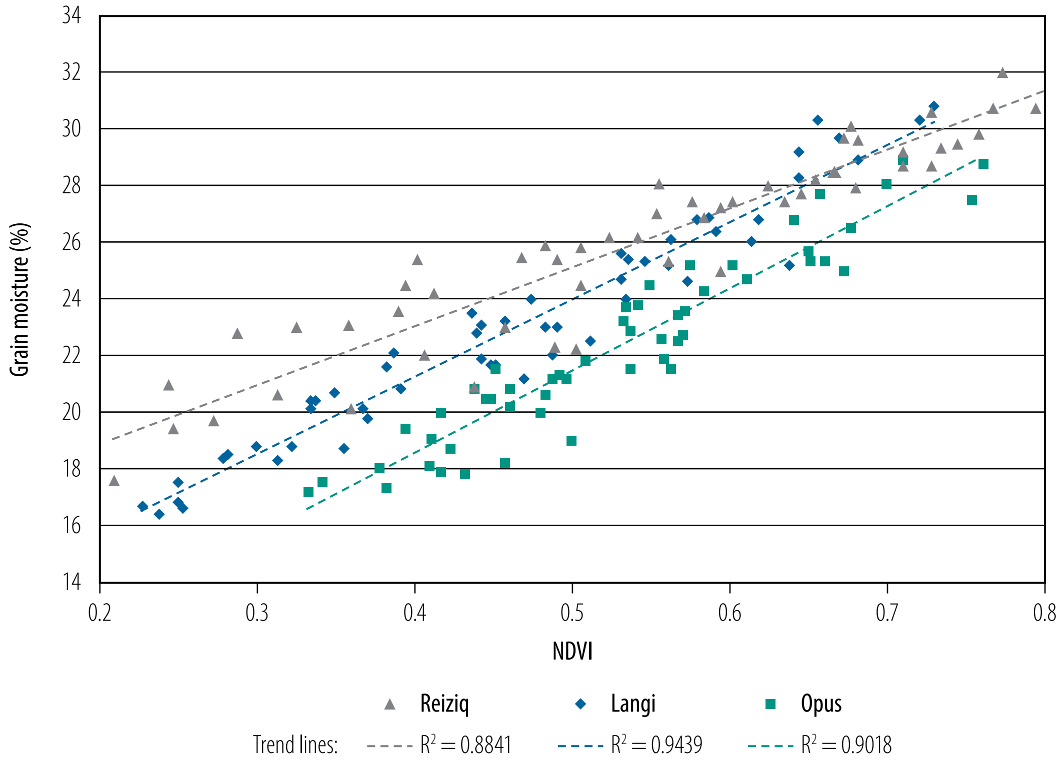

Figure 2 Regression analysis between NDVI and grain moisture for Langi, Opus$^{\phi}$ and Reiziq$^{\phi}$ varieties for the 60, 120 and 180 kg N/ha nitrogen treatments.

Conclusion

The research produced a strong correlation between NDVI collected from aerial imagery and grain moisture, but the relationship is different across varieties meaning individual algorithms would need to be developed for each variety. The relationships are currently being tested in a second season to determine if they are stable across seasons. The opportunity exists to use NDVI to predict grain maturity across a rice field. To be a valuable tool for the industry NDVI grain moisture algorithms would need to be developed between free sentinel 2 satellite imagery and grain moisture. This would improve the difficult decision of drainage time and allow for spatial variability to be included in the decision process.

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Acknowledgements

This experiment was part of the 'Improving mid-season nitrogen management of rice' project, PRJ-011058, 2018–21 with joint investment from AgriFutures and NSW DPI.

Contact

Brian Dunn
Yanco Agricultural Institute, Yanco
brian.dunn@dpi.nsw.gov.au
0428 860 204

Using KASP markers for molecular breeding of critical quality traits in rice

Dr Bert Collard, Kylie Elliot and Dr Prakash Oli

NSW DPI, Yanco

Key findings

- Marker validation is an essential testing step required for molecular breeding activities.
- Validated kompetitive allele specific PCR (KASP) markers for quality traits will be useful for routine screening in the rice breeding program, providing improved efficiency.

Introduction

DNA or molecular markers have been used in plant breeding programs for several decades. DNA markers are tools that can be used for trait selection saving time, labour, resources and money. This process is called marker-assisted selection (MAS). In rice, there are enormous opportunities for exploiting MAS due to the large body of research from the international rice community including marker development and genome sequencing. During the past 20 years, major advances in rice genetics and molecular technologies have prompted widespread use of single nucleotide polymorphism (SNP) markers. Markers located within or associated with actual genes can be used for MAS.

Breeding objectives for rice are driven by the need for developing new rice varieties with premium quality. For this objective, the Quality Evaluation Program (QEP) analyses about 7000 samples for physical quality traits and about 3000 for chemical and cooking quality traits. For physical quality, grain dimensions (length, width, thickness), grain colour and chalk are evaluated, whereas for evaluating chemical and cooking quality, amylose content, gelatinisation temperature and viscosity profiles are recorded. Implementing MAS and high-throughput methods such as near infrared (NIR) spectroscopy would significantly increase the sample throughput capacity and improve efficiency.

The Yanco rice breeding program has been using DNA markers to screen breeding material for many years. In the past 10 years, many new high-throughput SNP platforms have been developed; KASP markers have gained popularity in the international crop breeding community. To date, many markers for key quality parameters are publicly available. The International Rice Research Institute (IRRI) Philippines has recently invested in marker development for KASP with many reports of their use in rice. Further, service laboratories have been established for this system.

Published markers reported in the scientific literature need to be validated in breeding germplasm before routine use in the breeding program. The aim of this research was to validate markers for fragrance, amylose, gelatinisation temperature and grain size.

Methods

Validation material

Three sets of *Oryza sativa* germplasm were used for validation:

1. a quality validation set (QVS)
2. an elite group of long grain (LG) breeding material
3. an elite set of medium grain (MG) material.

The quality validation set consisted of 175 varieties including *indica* tropical and *japonica* temperate varieties (i.e. different subspecies) selected for their distinctive quality attributes. This set also included Australian varieties, advanced breeding lines, international varieties, and important donor parents (i.e. with specific traits). The LG material consisted of 270 elite breeding lines, whereas the MG set consisted of 94 entries.

Marker genotyping

Seed tissue was used for all samples (1 seed/line). Markers were selected from the IRRI Service Laboratories genotyping menu (https://isl.irri.org/services/genotyping/trait-based-genotyping). A list of gene targets and markers is shown in Table 1. Genotyping including DNA extraction, PCR and automated data analysis was performed by Intertek Labs (Adelaide).

Table 1 Summary of KASP markers tested.

Trait	Gene targets	Details	KASP markers
Fragrance	fgr (BADH2)	Major gene for aroma	snpOS00022, **snpOS00031**
Amylose content	Waxy	Main determinant of rice eating quality and 'stickiness'	snpOS00039, snpOS00037, snpOS00038, snpOS00445, snpOS00446, **snpOS00448**
Gelatinisation temperature	Starch synthase IIa (SSIIa)	Important for cooking quality	snpOS00036, snpOS00450
Grain size and shape	GS3, GW5, TGW6	Major genes controlling grain length and width	snpOS00033, snpOS00440, snpOS00441, **snpOS00452**

Markers in **bold** did not work.

Trait data and analysis

Data was obtained for routinely analysed traits within the QEP. Limited funds meant that using available trait data was the most cost-effective way to validate markers. For the diverse validation set, recent historical data was compiled from QEP records. For the LG and MG sets, QEP data generated from material harvested in 2020 was used.

Single marker analysis was performed using analysis of variance (ANOVA), and regression analysis used Genstat (VSN International). Standard statistical methods for markers were used to confirm trait-marker associations. For traits with multiple SNPs within target genes, haplotypes consisting of multiple KASP markers were used.

Results

A total of 14 markers were tested. KASP genotypic data was returned within 10 days from receipt of samples. Raw KASP marker data was returned in an Excel file. When genotypic data was examined, markers that were monomorphic in the diverse validation set or had high rates of missing data were excluded from analysis and deemed unsuitable for routine MAS. Based on these criteria, data from 11 KASP markers were used for the analysis. Heterozygote calls, which were rare, were also excluded from data analysis because all varieties/lines should be homozygous, and a heterozygote call probably indicates a problem with the PCR or a clustering error. This finding clearly indicates the importance of initially validating all markers before use.

Fragrance

The major compound responsible for the characteristic aroma found in fragrant rice is 2-acetyl-1-pyrroline (2AP). This compound led to the identification of a single major locus on chromosome 8 (*fgr*) associated with fragrance. Fine mapping and sequence analysis identified a betaine aldehyde dehydrogenase gene, BADH2, as the major gene controlling fragrance. The fragrance SNP is a polymorphism in exon 7 of the gene that encodes betaine aldehyde dehydrogenase2. Non-fragrant rice contains a fully functional copy of the gene. The KASP marker snpOS00022 was perfectly associated with fragrance, as all known aromatic varieties had the allele for fragrance. A summary of some fragrant and non-fragrant varieties tested is shown in Table 2.

Table 2 Summary of results for fragrant marker screening.

Variety	Country of Origin	snpOS00022	MAS Call
Amber_33	Iraq	TATAT:TATAT	Fragrant
Azucena	Philippines	TATAT:TATAT	Fragrant
Basmati370	India	TATAT:TATAT	Fragrant
Dellmont	USA	TATAT:TATAT	Fragrant
Hom_mali_niaw	Thailand	TATAT:TATAT	Fragrant
Jasmine85	Vietnam	TATAT:TATAT	Fragrant
Kyeema	Australia	TATAT:TATAT	Fragrant
RD6	Thailand	TATAT:TATAT	Fragrant
Sen_Pidao	Cambodia	TATAT:TATAT	Fragrant
Topaz	Australia	TATAT:TATAT	Fragrant
Amaroo	Australia	AAAAGATTATGGC:AAAAGATTATGGC	Not fragrant
Doongara	Australia	AAAAGATTATGGC:AAAAGATTATGGC	Not fragrant
Langi	Australia	AAAAGATTATGGC:AAAAGATTATGGC	Not fragrant
Opus	Australia	AAAAGATTATGGC:AAAAGATTATGGC	Not fragrant
Reiziq	Australia	AAAAGATTATGGC:AAAAGATTATGGC	Not fragrant
Sherpa	Australia	AAAAGATTATGGC:AAAAGATTATGGC	Not fragrant
Urakaka	Australia	AAAAGATTATGGC:AAAAGATTATGGC	Not fragrant
Viand	Australia	AAAAGATTATGGC:AAAAGATTATGGC	Not fragrant

Amylose

Five SNP markers within the *Waxy* gene were used to construct an amylose marker haplotype. There were nine haplotypes identified in the QVS that were clearly associated with high, intermediate or low amylose (Table 3). When the LG material was genotyped, only five haplotypes were detected. In both sets, the "T:T-A:A-C:C-T:T-A:A" haplotype was by far the most commonly-detected, indicating a low–intermediate amylose class for short-, medium- and long-grain varieties. The alleles of some notable varieties are shown in Table 3.

Table 3 Summary of results for amylose content.

Waxy haplotype	QVS amylose		LG amylose		MG amylose		Australian germplasm	International varieties
	Mean	n	Mean	n	Mean	n		
G:G-A:A-C:C-C:C-A:A	27.8	2	–	–	28.6	3		
G:G-A:A-C:C-C:C-G:G	27.8	3	–	–	26.6	1	YUA16=V030	
G:G-A:A-C:C-T:T-A:A	25.7	2	28.4	1	29.2	4		L203
G:G-A:A-T:T-C:C-A:A	26.4	10	–	–	–	–	YDP14=V044	L205, Vandana, Vietnam4
G:G-C:C-C:C-C:C-A:A	25.5	1	–	–	–	–		
G:G-C:C-C:C-T:T-A:A	23.0	20	26.3	69	25.0	7	Doongara, YRL127	Basmati370, Tachiminori, PSBRc9
T:T-A:A-C:C-C:C-G:G	10.9	4	23.2	1	–	–		Phka Rumdoul
T:T-A:A-C:C-T:T-A:A	19.9	98	20.8	120	21.9	78	Kyeema, Langi, Opus, Reiziq, Sherpa, Topaz, Viand, YRE16=V071, YRL39	Koshihikari
T:T-C:C-C:C-T:T-A:A	12.4	2	18.4	70	–	–	YRL118, YRL128	
Total number		139		260		93		
P (ANOVA)	<0.001		<0.001		<0.001			
R^2 (%)	50.8		81.3		72.6			

Gelatinisation temperature

The SNP markers for the starch synthase gene (*SSIIa*) targeted two adjacent SNPs in exon 8. This pair of markers explained a large proportion of the phenotypic variance in the QVS, but less in the LG set. In the LG material, most of the lines were fixed for the "G:G-C:C" haplotype. This was also the most common haplotype in the QVS. The alleles of some notable varieties are shown in Table 4.

Table 4 Summary of results for gelatinisation temperature (gel. temp.).

Gel. temp. haplotype	QVS gel. temp.		LG gel. temp.		MG gel. temp.		Australian germplasm	International varieties
	Mean	n	Mean	n	Mean	n		
A:A-C:C	68.5	13	–	–	66.8	8	Koshihikari, Opus, Uraraka	Nipponbare
G:G-C:C	75.1	83	75.3	260	73.9	6	Doongara, Kyeema, Langi, YRL39	Basmati370, IR36, IR64, L201, L202, L203, L205
G:G-T:T	68.1	72	70.2	9	65.5	32	Reiziq, Sherpa, Topaz, Viand	Calrose76, Hom mali niaw, Jasmine85, Khao Dawk Mali 105
Total		168		269		46		
P (ANOVA)	<0.001		<0.001		<0.001			
R^2 (%)	73.3		34.0		65.0			

Grain size (length and width)

The major genes *GS3* and *GW5*, located on chromosomes 3 and 5 respectively, have been previously characterised to control grain size. Data analysis confirmed that both genes were associated with grain length and width, which are routinely measured physical quality traits in the QEP and are critical for domestic and export markets.

Not surprisingly, the proportion of the marker alleles was different when comparing the QVS with the LG set. The LG material appears to be nearly fixed for the *GS3* allele, but there is more allelic variation for *GW5*, implying that this gene would be a suitable target for MAS.

Table 5 Summary of associations for *GS3* and *GW5*.

Grain length

Gene(s)	Marker allele/ haplotype	QVS length (mm)		LG length (mm)		MG length (mm		Australian germplasm	International varieties
		Mean	n	Mean	n	Mean	n		
GS3	G:G	5.4	35	5.8	6	5.3	77	Sherpa, Viand, Opus	Koshihikari
GS3	T:T	6.5	52	6.5	221	5.7	17	Reiziq, Illabong	
	Total		87		227		94		
	P (ANOVA)	<0.001		<0.001		<0.001			
	R^2 (%)	65.6		24.7		14.4			
GW5	C:C-A:A	6.2	122	6.5	221	5.6	56	Sherpa, Viand, YRE=V071	M205
GW5	C:C-G:G	5.5	3	6.9	1	5.5	1		Vandana
GW5	T:T-G:G	5.3	55	6.4	40	5.1	36	Illabong, Opus	Koshihikari
	Total		180		262		93		
	P (ANOVA)	<0.001		n.s.		<0.001			
	R^2 (%)	33.8		0.3		43.9			

Grain width

Gene(s)	Marker allele/ haplotype	QVS width (mm)		LG width (mm)		MG width (mm)		Australian germplasm	International varieties
		Mean	n	Mean	n	Mean	n		
GS3	G:G	Data not available		2.4	6	2.6	77	Sherpa, Viand, Opus	Koshihikari
GS3	T:T			2.2	221	2.5	17	Reiziq, Illabong	
	Total				227		94		
	P (ANOVA)			0.002		0.019			
	R^2 (%)			3.2		4.8			
GW5	C:C-A:A	Data not available		2.2	227	2.5	56	Sherpa, Viand, YRE=V071	M205
GW5	C:C-G:G			2.0	1	2.3	1		Vandana
GW5	T:T-G:G			2.5	40	2.7	36	Illabong, Opus	Koshihikari
	Total				262		93		
	P (ANOVA)			<0.001		<0.001			
	R^2 (%)			55.0		32.6			

n.s. = not significant.

Conclusion

These results indicate the potential of these markers for routine MAS for quality traits for the Yanco rice breeding program. The most effective strategy would be to screen early generation populations and to discard lines with the undesirable quality parameters (i.e. eliminate junk lines). The KASP marker system is quick, cheap and does not require much sample (e.g. only a single seed). In principle, this would permit large populations (e.g. panicle rows) to be screened before evaluation in unreplicated or replicated field trials in yield plots. Another strategy would be to use these markers during single seed descent (SSD) to permit trait selection in glasshouse conditions during generation advancement, which is not possible without markers. Both methods would increase accuracy and breeding efficiency.

Full physical and wet chemistry evaluation would be performed from the unreplicated trial stage onwards, since the markers indicate categorical parameters. Quantitative measurements of quality traits are required at the more advanced stages to obtain an accurate measurement and to verify MAS.

This would also permit the QEP to undertake a more focused evaluation on breeding lines, and more efficient use of fixed resources. It should be noted that MAS does not eliminate the need for quality evaluation. Highly accurate and more extensive quantitative methods used in the QEP are needed. Furthermore, there are currently no available markers for specific cooking quality parameters such as 'setback' or 'viscosity'.

To screen for all traits, a total of 11 KASP markers would be required. Based on current costings for KASP markers, this is between $6 and $8 per sample and depends on the total number of samples (i.e. discounts are provided for larger sample numbers). Depending on the objectives, a subset of these markers could be used in a step-wise selection MAS scheme.

The validated KASP markers show potential for MAS implementation in the rice breeding program. It is hoped that additional KASP markers will be available in the future to expand the existing arsenal and enable more marker-based screening options and higher accuracy screening of quality traits.

Acknowledgements

We sincerely thank Dr. Fong "Frankie" Lam from Intertek. The Australian Rice Partnership is a joint investment between NSW DPI, AgriFutures and SunRice.

Contact

Kylie Elliott
Yanco Agricultural Institute, Yanco
kylie.elliott@dpi.nsw.gov.au
0437 829 111

In-silico oligonucleotide primers developed for improving DNA barcoding of the stored grains pest khapra beetle *Trogoderma granarium* (Coleoptera: Dermestidae)

Dr David Gopurenko

NSW DPI, Wagga Wagga

Key findings

- The significant pest khapra beetle can be identified by their DNA barcodes for improved biosecurity outcomes.
- Five novel oligonucleotide primers were designed to improve specificity and amplification of DNA barcodes from khapra beetle and related taxa.
- The primers will enhance using DNA barcoding for verifying khapra beetle when detected by other diagnostic protocols.

Introduction

Khapra beetle, *Trogoderma granarium* Everts (Coleoptera: Dermestidae) is an internationally significant invasive pest in stored grains and dry foodstuffs. It was listed as Australia's number two National Priority Plant Pest (https://www.agriculture.gov.au/pests-diseases-weeds/plant/national-priority-plant-pests-2019) and recognised as a serious threat to the whole of the Australian grain industry (www.planthealthaustralia.com.au/pests/khapra-beetle/). Incursion of the pest into Australia's grain industry would lead countries free of the pest to enforce restricted market access for Australia's grain exports. Therefore, rapid and accurate pest identification is critical to the success of Australian biosecurity efforts to ensure any incursion into the country is detected, contained, and eradicated.

Khapra beetle is one of over 120 globally described species of *Trogoderma*, of which 52 endemic species and one naturalised pest (*T. variabile* Banks) are in Australia (Rees et al. 2003). *Trogoderma* species are difficult to distinguish and exotic pests such as khapra beetle can be mistaken for local fauna. Keys for identifying larval and adult khapra beetle (Banks 1994) require microscopy and specialist taxonomic expertise. Alternatively, common use systems of DNA analysis advantageously allow rapid genetic detection of the pest across its life stages and from trace samples (Furui et al. 2019).

DNA barcoding (Hebert et al. 2004) of the mitochondrial cytochrome *c* oxidase I (COI) gene is a comparative sequence analysis system for species identification and delimitation (Gopurenko et al. 2015). DNA barcodes unique to vouchered khapra beetles allow accurate species detection when matching barcodes are identified in query specimens. The methodology of DNA barcoding and many other genetic systems of species diagnostics require using short synthetic oligonucleotide primers. These hybridise to DNA targets in polymerase chain reaction (PCR) amplification of species informative DNA regions. Poor match or specificity of primers to target pest DNA can confound reliability or accuracy of PCR-based pest diagnostics. For example, universal COI primers available for arthropod DNA barcoding have PCR success rates below 60% from khapra beetle (Olson et al. 2014).

Primers designed in silico from khapra beetle sequences are reported here to improve PCR amplification of the khapra beetle DNA barcode region.

Methods and results

- DNA sequence accessions (N = 62) overlapping the 5′ COI DNA barcode region of khapra beetle and other *Trogoderma* were imported from public sequences repositories (GenBank and BOLD) and aligned to a khapra beetle mitochondrial genome accession (MT113335).

- tRNA^{Tyr} gene sequence accessions (N = 23) adjunct to the COI DNA barcode region from *Trogoderma* and relatives were imported as an additional region for primer design.
- Forward and reverse orientation oligonucleotide primer sequences reported in DNA barcode campaigns (refer sources, Table 1) were imported and aligned to accessions.
- Nucleotide mismatches between aligned sequences and primers sites were flagged.
- Flagged sites in primers were modified to directly match fixed nucleotide sites among *Trogoderma* accessions, or incorporate degenerate bases matched to variable sites among the taxa.
- Five novel primers (three forward and two reverse strand orientations) were designed with modified sites matched to khapra beetle and other *Trogoderma* (Table 1 and Figure 1).
- Novel primers were predicted to have melt temperatures and low primer-dimer formation suited to PCR (using OligoEvaluator™; http://www.oligoevaluator.com/OligoCalcServlet).
- Six combinations of novel primers allowed full or partial DNA barcoding for khapra beetle species identification (Table 2).
- Novel primer (Trog-tRNA-TyrF) in the tRNA^{Tyr} gene abutting the 5′ COI gene region in most insects (Figure 1) was designed for use with reverse primers for exclusive PCR amplification of DNA barcodes from khapra beetle and potentially other Dermestidae (Table 1 and Table 2).

Table 1 List of novel primers designed for improved match to *Trogoderma granarium*, their direction in PCR, nucleotide sequence and predicted primer melt temperature (Tm°C). Name of original primers modified here and their source.

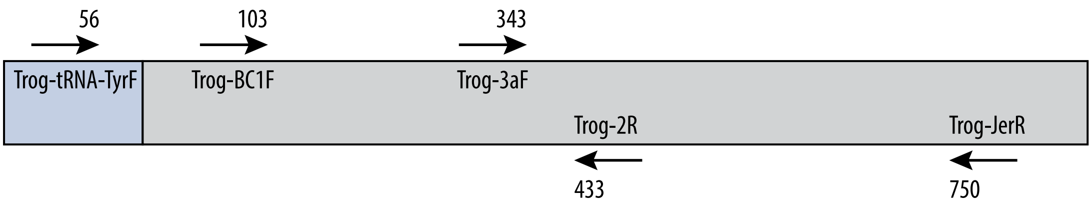
Primer name	Direction	Sequence 5′ – 3′	Tm°C	Original primer (source)
Trog-tRNA-TyrF*	forward	caatctagcgcctaaactcagcc	66.8	LepFm (Cho et al. 2008)
Trog-BC1F	forward	tccacaaaccacaargayatygg	68.4	BC1Fm (Cho et al. 2008)
Trog-3aF	forward	gchcchgayatrgcwttyccamg	71.3	AMbc3f1m (Mitchell 2015)
Trog-2R	reverse	gahardggdggrtanacdgtyc	63.5	AMbc5r1m (Mitchell 2015)
Trog-JerR	reverse	tgtccaaaraaycaraayarrtgttg	66.7	JerR2m (Bellis et al. 2013)

*primer and direction unmatched outside of Dermestidae.

Table 2 Primer combinations, base pair (bp) sequence length (primer truncated) and utility for DNA barcoding of *Trogoderma granarium*.

Primer combination	Length (bp)	DNA barcode utility
Trog-tRNA-TyrF & Trog-2R	377	left half portion of DNA barcode*
Trog-tRNA-TyrF & Trog-JerR	694	full length DNA barcode*
Trog-BC1F & Trog-2R	330	left half portion of DNA barcode
Trog-BC1F & Trog-JerR	647	full length DNA barcode
Trog-3aF & Trog-2R	90	mini-DNA barcode
Trog-3aF & Trog-JerR	407	right half portion of DNA barcode

*primer combination unlikely to amplify taxa outside of Dermestidae.



Arrows indicate primer anneal orientation (5′ – 3′) and numbers indicate primer 3′ positions aligned to Trogoderma granarium (GenBank accession MT113335 positions:1320–2988) sequence spanning entire tRNATyr gene (blue shaded) and partial 5′ COI DNA barcode (grey shaded).

Figure 1 Relative positions of novel primers (Table 1) to the COI DNA barcode region of khapra beetle.

Discussion

Using DNA barcoding for identifying khapra beetle

DNA barcoding is a sequence-based system of species identification under consideration by the Australian National Plant Biosecurity Diagnostic Network for inclusion into a National Diagnostic Protocol (NDP) for khapra beetle. Query specimen barcodes can be compared against voucher species barcodes to obtain a matched identification. DNA barcode species identifications are accurate when the maximum levels of sequence variation within vouchered species are less than the minimum distance to their nearest neighbour species. The Barcode of Life Data (BOLD) systems public sequence repository lists 34 khapra beetle DNA barcodes (5′ mitochondrial COI gene region). These barcodes vary little as a species (<0.5% sequence difference) but differ by >10.9% to DNA barcodes of other available *Trogoderma* (N = 28) and species in the repository. This relationship indicates DNA barcoding can confidently be used as a standalone genetic test for identifying khapra beetle among query specimens.

DNA barcoding costs are high. This limits its practicality for pest diagnostics during a pest incursion when hundreds or thousands of query specimens need to be tested. More cost expedient PCR-based genetic diagnostic systems, such as quantitative real time PCR (qPCR) allow fast sample processing (and highly sensitive detection) and are preferred as gold standard approaches for pest diagnostics at laboratories. They can also be used with portable equipment allowing rapid pest detections in the field and other point of need environments. Spurious or non-specific amplifications from other taxa can confound diagnostic qPCR tests, yielding false positive results. Therefore, DNA barcoding remains critical for follow-up confirmation of khapra beetle species detections indicated by qPCR assay or other means.

Improved primer specificity for PCR amplification of DNA barcodes from khapra beetle

Universal oligonucleotide primers hybridise to small 17–30 base pair (bp) sequence targets that are partially conserved across taxa. They are critical to PCR amplification of targeted gene regions. A variety of universal primers used for DNA barcoding have broad use allowing moderate to high rates of PCR success across diverse taxa (Folmer et al. 1994; Hebert et al. 2004; Mitchell 2015).

Mismatches between universal DNA barcode primers and *Trogoderma* DNA might affect PCR success from this genus. Universal primer combination LC01490 & HC02198 (Folmer et al. 1994) are often used in DNA barcode campaigns but had <60% PCR amplification success from khapra beetle and several other *Trogoderma* (Olson et al. 2014). This shortcoming prompted use of a more conserved gene region for development of khapra beetle diagnostics (Olson et al. 2014), and ultimately losing the facility for comparative sequence diagnostics against the diverse public library of species informative COI barcodes available at BOLD. The specificity of five universal insect DNA barcode primers for hybridisation to *Trogoderma granarium* DNA were improved here to maintain facility for comparative COI DNA barcoding in khapra beetle diagnostics.

This was done by in-silico alignment and modification of the insect primers against sequence libraries of khapra beetle and related taxa. Primers were modified to eliminate nucleotide mismatches and or minimise their degeneracies against *Trogoderma*. One primer matched to the $tRNA^{Tyr}$ gene adjoining COI was designed for specific hybridisation to DNA of khapra beetle and potentially a few other Dermestidae. This primer will be useful where DNA barcodes are selectively required from khapra beetle to the exclusion of non-target taxa and or contaminations.

Also, novel primers reported here allow amplification of size variant DNA barcodes from khapra beetle. These primers included full length barcodes (>500 bp) required at BOLD for voucher specimen compliancy, partial length barcodes (330–407 bp), and a mini-DNA barcoding region (90 bp). All these primers contain sufficient levels of sequence variation to allow accurate species identification of a query specimen to khapra beetle. This latter need is critical in cases where DNA quality is degraded and unlikely to provide quality PCR amplification of standard sized DNA barcodes.

Ultimately, the in silico designed primers reported here represent a first step in their development for khapra beetle DNA barcoding. The novel primers and their combinations need to be trial validated by replicated PCR to determine their functionality and performance with target khapra beetle, other *Trogoderma*, and non-target species.

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Acknowledgements

Drafts of this report were improved by Bernie Dominiak and anonymous reviewers.

Contact

Dr David Gopurenko
Wagga Wagga Agricultural Institute, Wagga Wagga
david.gopurenko@dpi.nsw.gov.au
02 6938 1946

Determining the soil moisture characteristic using commonly available water content and water potential sensors

Sam North and Don Griffin

NSW DPI, Deniliquin

Key findings

- The water retention and hydraulic conductivity characteristics of two soils used for tomato production were determined using simultaneous in-situ paired measurement of volumetric water content and matric potential.
- This field method of determining the soil moisture characteristic was a more convenient method than manual gravimetric sampling and could be used widely to assist optimisation of irrigation design.

Introduction

The Australian processing tomato industry has set a target to lift yields from the current average of 90 t/ha (ABS 2020) to 200 t/ha. The industry considers soil constraints to be a key area for improvement to meet this target. Low pH, high salinity, migration of clay away from drip emitters, and coalescence of continually wet soil have been identified as issues affecting soil structure and thus water and oxygen supply to plants (Barber et al. 2001; Lanyon and Kelly 2010). However, efforts to improve soil structure with liquid gypsum (Yong et al. 2015), and mitigate waterlogging with oxygenation in drip lines, have had no significant effect on yields (Brown 2016).

Soil water status was monitored under nine commercial tomato crops in the summer of 2019–20 (North 2020). All nine crops in the study were irrigated using drip tape placed at a depth of 20–25 cm with drippers spaced every 50 cm. Four crops had tape with 1.05 L/hr emitters, while the other five crops had tape with 1.6 L/hr emitters.

In the red brown earth (RBE) soils (chromosols; Isbell and National Committee on Soil and Terrain – NCST, 2016) in the study, poor matching of sub-surface drip irrigation application rates to soil type was identified as a potential yield limiting factor. In the uniform clays (vertosols; Isbell and NCST 2016) in the study, upward and lateral wetting by capillarity ('subbing') ensured the soil in the raised beds was relatively evenly wetted from the sub-surface drip lines (Figure 1, left). In contrast, the RBE soils have a coarser textured A horizon that does not 'sub'. This results in a smaller wetted zone around and below the tape; drier near-surface soil in the centre of the bed under the crop; and very dry zones on the shoulders of the beds (Figure 1, right). Given that similar amounts of water (≈8 ML/ha) and nitrogen (≈350 kg/ha N) were applied to the study crops, the lower yields in the RBE soils was attributed, in-part, to the loss of water and nitrogen in drainage below the root zone.

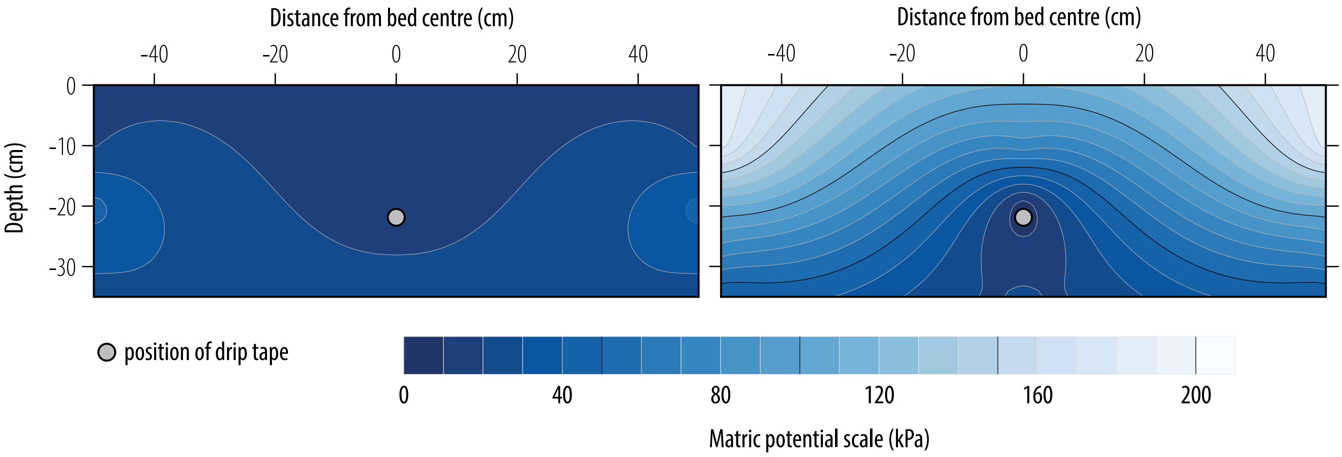

Figure 1 Average matric potential (kPa) during January 2020 in a cross-section through raised beds under tomatoes growing in a uniform clay (left) and a duplex RBE (right).

It was not possible to determine whether emitter flow rate had any effect on soil wetting patterns because there was no replication of the two flow rates within soil type and irrigation management (i.e. run times) was not consistent across all sites. Consequently, further investigation was warranted to determine the influence of tape design and irrigation management on wetting patterns and deep drainage losses. However, a field trial to determine optimum tape design for a range of soil types was considered too costly, given the number of different combinations of emitter rate, spacing, depth, and soil type that would need to be evaluated. Instead, a modelling approach was chosen because of the ease with which a large number of design permutations can be tested via simulation. Information from the modelling will inform a small number of theoretically optimum designs for field testing.

The HYDRUS model (https://www.pc-progress.com/en/Default.aspx?support-hydrus) is a Microsoft Windows based modelling environment for analysing water flow and solute transport in variably saturated porous media. HYDRUS has been used to evaluate sub-surface drip irrigation systems internationally (e.g. Simunek et al. 2012) and nationally (e.g. Cote et al. 2003). This requires knowledge of the relationship between soil water content and soil water (matric) potential (i.e. the soil moisture characteristic).

The data required to define the soil moisture characteristic is time consuming to obtain so is normally estimated from pedo-transfer functions driven by particle size analysis and soil dry bulk density data. However, the clay soils of the Riverine Plains are highly structured and the ideal pore size distributions assumed in pedo-transfer models do not necessarily correspond well with our field soils. Measuring soil water content and matric potential using commercially available sensors is now commonplace in the irrigation industry. This project assessed the use of such sensors to collect field information to determine the soil moisture characteristic of two major, contrasting, soil types used by the tomato industry (i.e. duplex RBEs and uniform clays) for use as input to the HYDRUS model.

Methods

Two sites were selected from the nine used in the 2019–20 study: a uniform clay (Rochester clay; Skene and Harford 1964) at Strathallen, Victoria; and a duplex RBE (Bunnaloo loam; Johnston 1952) at Bunnaloo, NSW. Soil sampled in December 2019 was used to obtain the particle size distribution and dry bulk density of the surface (0–5 cm) and the sub-soil at the level of the drip tape (20–25 cm). Saturated water content (θ_s) was estimated from water content readings when the soil was saturated. Saturated hydraulic conductivity (K_{sat}) at the depth of the drip tape was determined in May 2020 using constant-head well-permeameters (Amoozegar 1989). The values obtained are shown in Table 1.

Table 1 Particle size analysis of the two soils from December 2019 samples and saturated hydraulic conductivity (K_{sat} cm/day) from well permeameter measurements made in May 2020.

Soil type	Horizon	Clay (%)	Silt (%)	Sand (%)	Texture	K_{sat}
Duplex RBE (Chromosol)	0–5 cm	25	26	49	silty loam	–
	15–25 cm	34	26	41	clay loam	12
Uniform clay (Vertosol)	0–5 cm	46	15	40	medium clay	–
	15–25 cm	45	13	43	medium clay	46

The water content-matric potential relationships in the wet range (0–1800 cm water in the duplex RBE; 0–800 cm water in the uniform clay) for these two soils were determined from paired measurements at 10, 20, 30, 40 and 50 cm depths. Paired measurements of water content and matric potential were made using EnviroPro® capacitance sensors (https://enviroprosoilprobes.com) and Watermark™ sensors (https://www.irrometer.com) respectively, with loggers storing hourly readings.

Seven sets of paired sensors were installed in a uniform area of soil roughly 20 m by 10 m that represented the paddock. Each of the seven sets of five paired sensors was installed within a 60 cm diameter steel infiltration ring that was driven 10 cm into the soil surface. The capacitance sensor string was installed in the centre of the ring with the five matric potential sensors installed 20 cm from it and equidistant from each other.

Water was ponded in the rings to a constant head (5 cm) after sensor installation and 220 L of water was allowed to infiltrate the soil under each ring. Once all water had infiltrated, the soil in each ring was covered with straw for insulation, and then plastic sheeting to prevent evaporation.

Soil samples were collected across the range of measured water contents (to calibrate the capacitance water sensors) using a thin wall soil corer to extract cores (4.4 cm diameter, 10 cm high) from within the rings at depths of 5–15, 15–25, 25–35, 35–45 and 45–55 cm.

The soil moisture content and matric potential data was analysed using the program RETC (https://www.pc-progress.com/en/Default.aspx?retc) to determine the best-fit model for the soil water retention curve and the theoretical pore-size distribution for predicting the unsaturated hydraulic conductivity functions of the two soils. The specific mathematical form of the soil water retention function has no influence on the conductivity prediction as long as it describes the data accurately (Kosugi et al. 2002), so a range of functions were investigated in RETC to find the best fit model.

Results

Results are presented in Table 2 and Figure 2.

Table 2 Parameters describing the soil hydraulic properties of the two soils determined from least-squares fitting in RETC.

Parameter	Units	Duplex RBE		Uniform clay
		10 cm	20–50 cm	0–50 cm
θ_s	(m/m)	0.38	0.35	0.38
θ_r	(m/m)	0	0	0.09
α	(cm^{-1})	0.0105	0.0060	0.0086
n		2.354	2.204	1.121
K_{sat}	(cm/day)	76*	12	46
R^2		0.86	0.93	0.56

*This K_{sat} is a value modelled from particle size and bulk density data input to the Rosetta model.
θ_s is saturated water content, θ_r is residual water content and α and n are fitting parameters.
Soil water retention data was fitted to the van Genuchten model with $m = 1 - 2/n$.

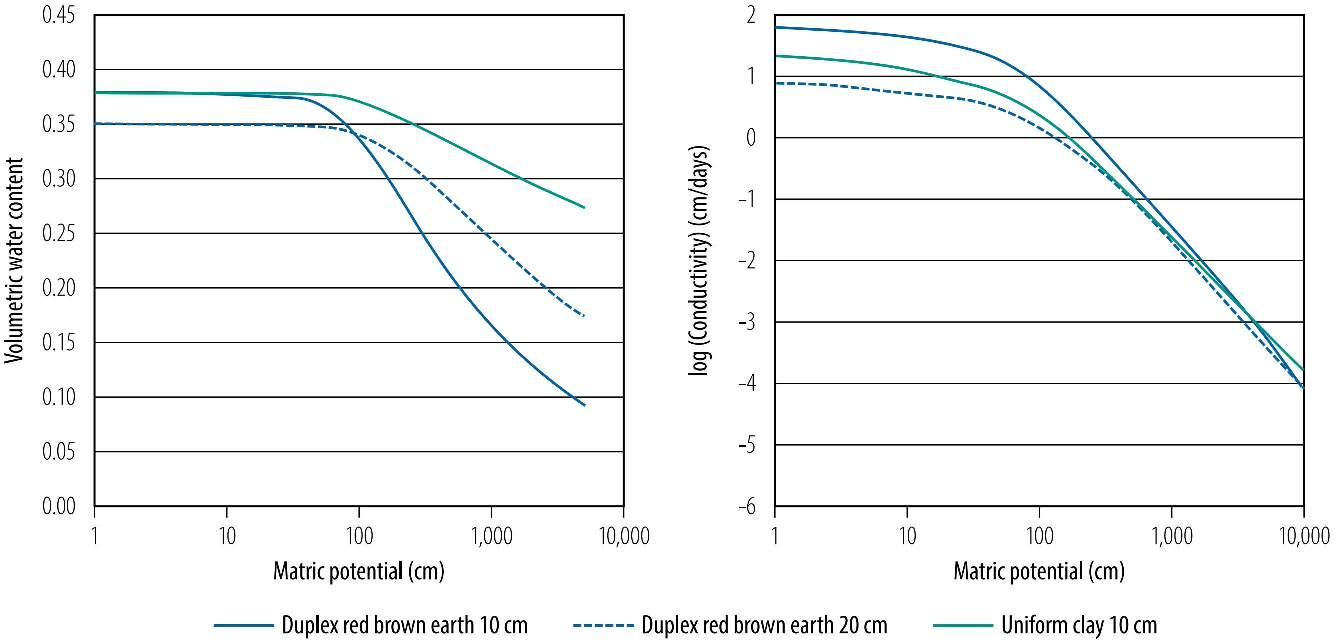

Figure 2 Soil water retention curves fitted to the volumetric water content and matric potential data from the duplex RBE and uniform clay (UC) (left) and the corresponding predicted unsaturated hydraulic conductivity functions obtained using RETC (right).

Discussion and conclusions

Using paired soil water content and matric potential sensors provides a convenient way to obtain in-situ data to determine the moisture characteristics of field soils. Lower R^2 values from the uniform clay reflect the smaller water potential range measured at that site, caused by very slow internal drainage. The lack of readings in drier soil introduces a level of uncertainty regarding the parameters found for the uniform clay. However, given that the hydraulic properties of the soils to be modelled will be at the wet end during irrigations, the outputs from this data will not be used outside the measured range. The parameters obtained from this analysis will be used as input into the investigation of optimised sub-surface drip design using HYDRUS. The model output from HYDRUS shows the one-dimensional water distribution within the soil profile around the drip-tape, and this will be compared to field measurements made in 2019–20 at the same sites to assess validity of the results.

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Acknowledgements

This experiment was part of the 'Consultancy to APTRC – 2020–21 season', December 2020–August 2021.

Thank you to Alex Shultz, who assisted with loggers, and to Darcy Kirchoffer (Kagome) and Bill and Jamie Weeks for their cooperation and access to the sites.

Contact

Sam North
NSW DPI, Deniliquin
samuel.north@dpi.nsw.gov.au
03 5881 9926

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