Department of
Primary Industries

Southern NSW research results 2020

RESEARCH & DEVELOPMENT – INDEPENDENT RESEARCH FOR INDUSTRY

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an initiative of Southern Cropping Systems

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Cover image: Maturing barley heads, Dr Felicity Harris, NSW DPI, Wagga Wagga.

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Foreword

NSW Department of Primary Industries (NSW DPI) welcomes you to the Southern NSW research results 2020. 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 in southern NSW.

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

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

NSW DPI's research program includes the areas of:

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

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

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

We acknowledge the many collaborators (growers, agribusiness and consultants) that make this research possible. We 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

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Scott Wallace, Seasonal Conditions Coordinator, NSW DPI Climate Branch

Climate summary

Condobolin Agricultural Research and Advisory Station

The average minimum temperatures at Condobolin were above the long-term average (LTA) for the majority of 2019 (Figure 1). June, August and September were exceptions when minimum temperatures were closer to average. The 2019 average maximum temperatures were also above the LTA throughout the year. Several months were very warm compared with the average maximum, however, January and December had the largest anomalies and were extremely hot. Both the average maximum and minimum temperatures were above the LTA during the growing season.

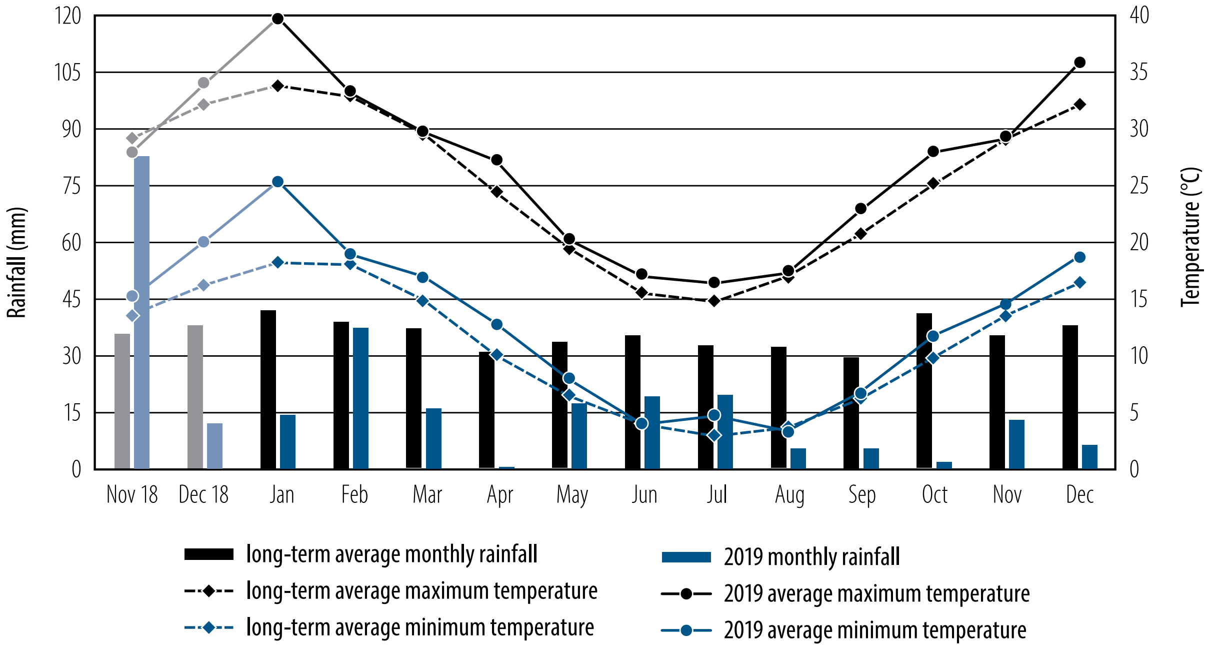


Figure 1 Monthly temperature and rainfall for Condobolin Agricultural Research and Advisory Station in 2019.

Rainfall was below average at Condobolin for all months during 2019 (Figure 1). This is the lowest recorded total (155.3 mm) at Condobolin Agricultural Research and Advisory Station since 1914 when records began. The previous lowest recorded rainfall was 166.9 mm in 1919. February was the only month when rain totals were near average. The soil moisture status was low at the start of the sowing period after a dry summer fallow period and autumn. Planting opportunities were rare and plant establishment was extremely challenging.

Yanco Agricultural Institute

The average minimum temperatures at Yanco were above the LTA for the majority of 2019 (Figure 2). The warmer April and May temperatures promoted rapid growth in the canola experiments and accelerated time to flowering in the early-maturing varieties. June and August were exceptions when minimum temperatures were closer to average. Low frost severity characterised the winter of 2019 with little to no frost damage seen in any of the winter crop experiments. The 2019 average maximum temperatures were also above the LTA during the year. All months were very warm compared with the average maximum, however, January and December had the largest anomalies and were extremely hot. Both the average maximum and minimum temperatures were above the LTA during the growing season. The above average temperature in early October provided excellent conditions for establishing the early cotton experiments at Yanco. Unfortunately, there was a cold snap in late October/early November that retarded crop growth and delayed the later sown cotton experiments.

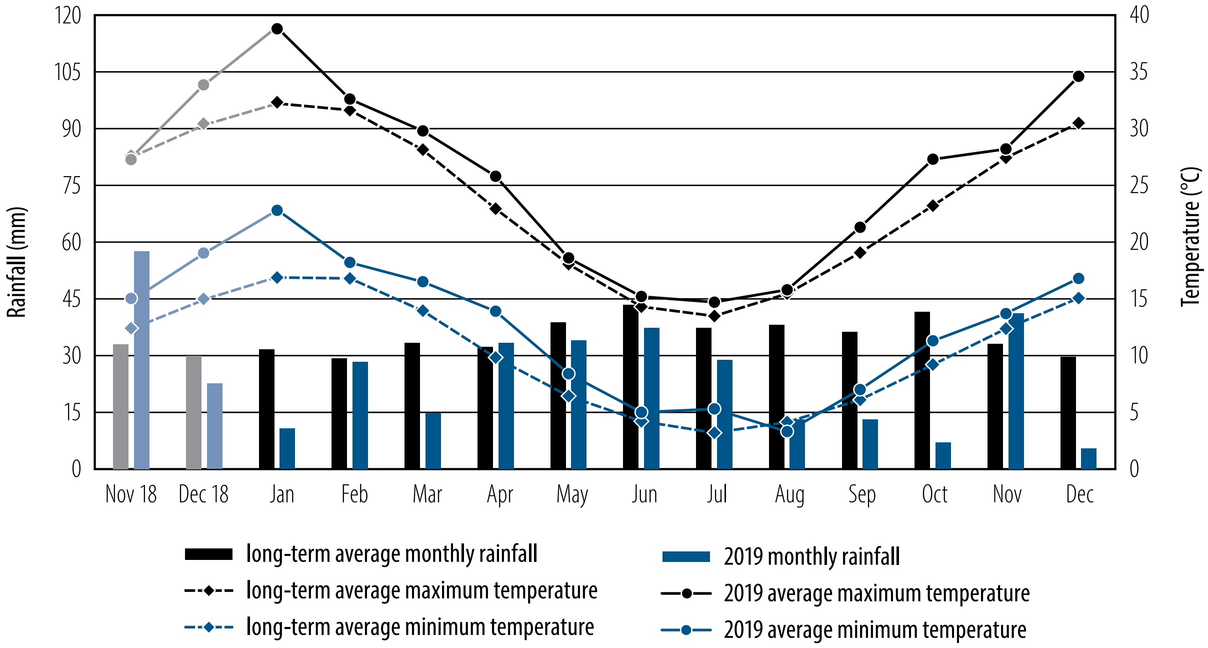


Figure 2 Monthly temperature and rainfall for Yanco Agricultural Institute in 2019.

Rainfall during 2019 was below average at Yanco for all months except April and November (Figure 2). The high rainfall in November was too late for the winter cropping experiments, but was useful for establishing the summer soybean experiments. Soil moisture levels were low to moderate at the start of the winter cropping sowing period, however, rain in the period between April and July assisted plant establishment and increased soil moisture levels in the early part of the growing season. Conditions turned dry in late winter and during most of spring when rainfall was well below average. Yield potential declined and was exacerbated by the warm conditions late in the growing season.

Wagga Wagga Agricultural Institute

The average minimum temperatures at Wagga Wagga were above the LTA between January and May 2019 (Figure 3). In contrast, the average minimum temperatures from June to December were below the LTA, except in July when the minimum average temperature was slightly above the average. The minimum temperature anomalies in August and September were cold and well below the LTA during this part of the growing season. The 2019 average maximum temperatures were above the LTA throughout the year. Several months were very warm compared with the average, however, January and December anomalies were substantial with extremely hot conditions.

Rainfall totals at Wagga Wagga were below average for all months during 2019 except May and November, while March was near average (Figure 3). Soil moisture levels were low to moderate during the sowing period, however, rain between May and July assisted plant establishment and increased soil moisture levels in the early part of the growing season. Conditions turned dry from mid winter to late spring when rainfall was well below average. This caused yield potential to decline rapidly during spring, which was exacerbated by the combination of colder than average minimum temperatures, and warmer than average maximum temperatures during this period.

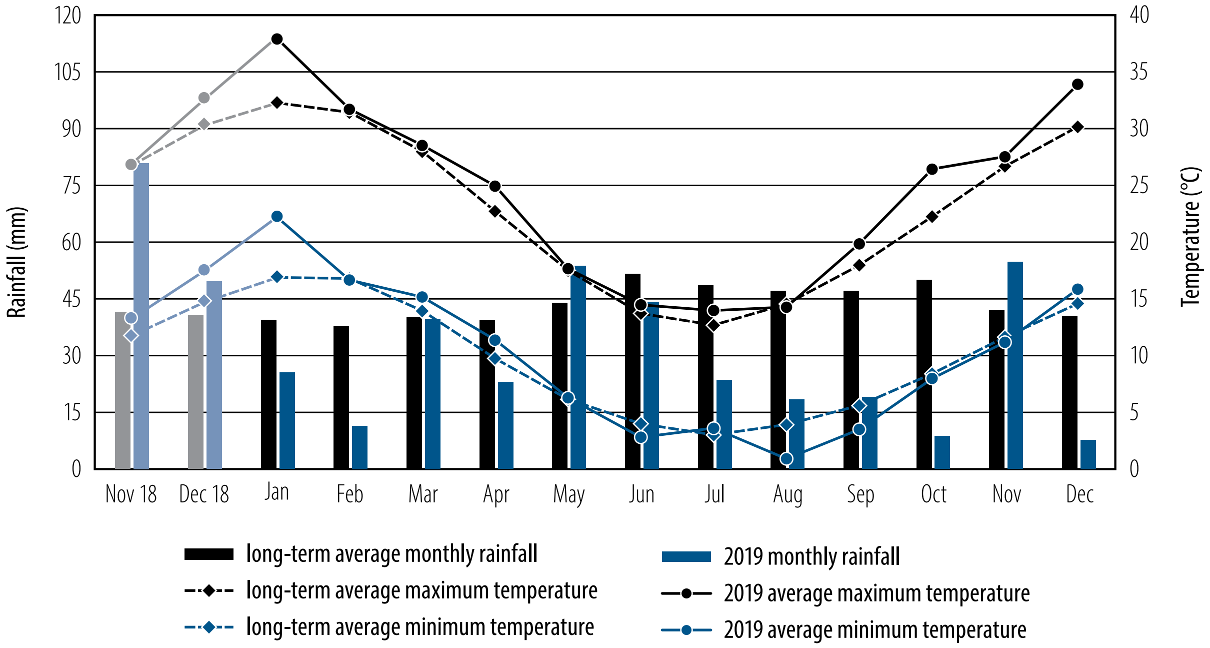


Figure 3 Monthly temperature and rainfall for Wagga Wagga Agricultural Institute in 2019.

Disease

Winter cereals

The extensive drought in the 2019 season in southern NSW affected sowing times and crop development in many regions. The 2019 GRDC northern region winter cereal disease survey results reflected these environmental influences with low levels of leaf diseases observed. Quantitative polymerase chain reaction (qPCR) analysis conducted on the survey samples highlighted that crown rot (*F. pseudograminearum*, *F. colmorum* and *F. graminearum*) were common and widespread across southern NSW reaching medium to high levels of pathogen load.

Diagnostic samples received at Wagga Wagga Agricultural Institute were predominately wheat followed by barley and oats. There was a significant increase in oats enquiries during 2019. Stripe rust of wheat and root disease complexes were the most common issues followed by septoria tritici blotch.

Disease surveys are important to stay abreast of developing issues within farming systems. The following key issues were identified in 2019:

- Fusarium crown rot and common root rot (*Bipolaris*) were widespread in cereal crops in 2019.
- The yellow spot fungus was detected in 52% of wheat crops surveyed and surprisingly also in 53% of the barley crops. This presumably highlights how effective the yellow spot fungus is as a weak pathogen or as saprophyte of dead barley tissue.
- The pathogen mix of wheat leaf blotch diseases in the GRDC northern region is more diverse than previous surveys have found. We detected widespread yellow leaf spot, septoria tritici blotch and stagnospora nodorum blotch co-infecting grower paddocks.
- The spot form of net-blotch was detected more frequently and at higher DNA concentrations in barley crops than the net-form of net blotch in 2019. Saprophytic colonisation of wheat as an alternative host appeared lower with net-blotch compared with the reciprocal situation with yellow spot.
- qPCR assays (PREDICTA® B platform) appear to be a valuable tool to rapidly quantify a wide range of fungal pathogens, nematode pests and beneficial fungi within wheat and barley crops.
- The most prevalent wheat stripe rust strain found across NSW was the pathotype 198 E16 A+ J+ T+ 17+ (characterised by the University of Sydney Rust Lab.). This pathotype was first detected near Wagga Wagga in 2018 and has now spread reaching into Victoria and Queensland. Wheat varieties affected by this pathotype are DS Bennett$^{\phi}$ and LongReach Trojan$^{\phi}$ and, to a lesser

extent, Devil$^{\phi}$, Illabo$^{\phi}$, DS Darwin$^{\phi}$, Emu Rock$^{\phi}$ and Hatchet CL Plus$^{\phi}$; several durum varieties (e.g. Bittaroi, DBA Artemis$^{\phi}$, DBA Bindaroi$^{\phi}$, DBA Lillaroi$^{\phi}$, DBA Spes$^{\phi}$, DBA Vittaroi$^{\phi}$ and EGA Bellaroi$^{\phi}$); and several triticale varieties (Astute$^{\phi}$, Joey$^{\phi}$ and Wonambi$^{\phi}$).

Winter pulse and oilseed

Dry seasonal conditions in 2019 resulted in reduced disease development in pulse and oilseed crops across the region, especially foliar diseases. Diagnostic samples received at Wagga Wagga Agricultural Institute included a range of minor diseases and confirmed various herbicide injury and frost injury symptoms.

A small outbreak of *Turnip yellows virus* (TuYV) was detected in canola crops north of Temora in late July. Crop sampling in the area found high populations of green peach aphid, which had aided the build-up and spread of the virus in winter. Dr Joop van Leur (NSW DPI, Tamworth) who identified the virus offered diagnostic support and offered free virus testing for crops suspected of having the disease.

Surveys of commercial pulse crops (lupin, chickpea, faba bean, lentil, field pea) across the region found lower than average levels of foliar disease compared with traditionally wetter seasons. But most common pathogens were still present in crops, despite the dry conditions.

- Despite dry conditions low levels of ascochyta blight were found in chickpea crops. This is a concern for producers planning to use that harvested seed for sowing crops in 2020.
- Low to medium levels of root disease were found in most pulse crops. Common root pathogens included Pythium, Rhizoctonia and *Didymella pinodes* (the fungus that causes blackspot of field pea). *Sclerotinia* spp. was also detected on the roots of several lupin crops, despite no above-ground symptoms.
- The detection of *Didymella pinodes* was particularly interesting. This fungus is recorded as an important pathogen of field pea, but was detected on roots of all pulse crops that were sampled.
- Other significant symptoms that were observed within the sampled crops included frost injury, especially those crops sown into cereal stubble and particularly faba bean crops, which had serious symptoms of frosting including stem twisting and deformed and aborted flowers.
- Several pulse crops also had symptoms of virus infection, which can result in reduced yields or build up of the virus in seed, depending on the virus present. The appearance of virus symptoms is also a reflection of the season and the aphid populations present.
- Whilst low levels of disease were detected in most crops, the survey demonstrated that dry conditions do not remove plant pathogens from paddocks and even low levels still survive and can pose a threat to crops in following years.

Acknowledgements

Thank you to contributors Ewan Leighton, Tony Napier, Andrew Carmichael, Dr Andrew Milgate and Dr Kurt Lindbeck, and Don McCaffery for review.

Wheat phenology and yield responses to sowing time – Marrar 2019

Dr Felicity Harris, Hugh Kanaley, Mary Matthews, Cameron Copeland, Dean Maccallum, Jess Simpson and Ian Menz (NSW DPI, Wagga Wagga)

Key findings

- Phenology and grain yield responses were significantly influenced by seasonal conditions in 2019.
- Severe heat stress and terminal drought conditions favoured faster developing spring genotypes, which achieved the highest grain yields in 2019.
- Grain yield responses varied in response to sowing date, and highest yields occurred when phenology was matched with recommended sowing windows.

Introduction

In 2019, field experiments were conducted across 10 sites in the northern grains region (NGR) to determine the influence of phenology on grain yield responses for a diverse set of wheat genotypes. This paper presents results from the Marrar site (southern NSW) 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	Takada, Marrar 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$_{Ca}$	5.3 (0–10 cm); 5.4 (10–30 cm)
Mineral nitrogen (N)	At sowing (1.5 m depth): 134.5 kg N/ha
Fertiliser	• 90 kg/ha mono-ammonium phosphate (MAP) (sowing). • 42 kg N/ha urea (28 June).
Weed control	Knockdown • Glyphosate (450 g/L) 2 L/ha. Pre-emergent • Sakura® 118 g/ha + Avadex Xtra 1.6 L/ha + Trifluralin (480 g/L) 0.8 L/ha. In-crop • Axial® 300 mL/ha + Precept® 2 L/ha (SD1 and SD2: 13 May). • LVE MCPA 570 600 mL/ha + Paradigm 25 g/ha (SD3 and SD4: 18 July). • Axial® 300 mL/ha (SD3 and SD4: 25 July).

Disease and pest management

Seed treatment

- Hombre® Ultra 200 mL/100 kg.
- Gaucho® 600 120 mL/100 kg.

Fertiliser treatment

- Flutriafol 250 g/L (400 mL/ha).

Foliar fungicide

- Prosaro® 300 mL/ha (SD1 and SD2: 4 June, SD3 and SD4: 28 August).

Rainfall

- In-crop (April–October): 194.5 mm
- In-crop long-term average: 293 mm

Severe temperature events

- Seven heat stress events (days >30 °C during October), including 31.1 °C (3 October) and 34.1 °C (6 October) (coinciding with critical flowering and early grain-filling stages, significantly influencing yield).
- 10 frost events (days <0 °C), no days recorded below –2 °C (minimal influence of frost in 2019).

Harvest date

- 14 November 2019 (SD1 and SD2).
- 27 November 2019 (SD3 and SD4).
- 11 December 2019 Manningᶲ (all SDs), RGT Accrocᶲ (all SDs) and DS Bennettᶲ (all SDs) due to delayed maturity.

Treatments

Thirty-six wheat genotypes (Table 1), varying in phenology responses were sown on four sowing dates in 2019:

- SD1: 5 April
- SD2:18 April*
- SD3: 6 May
- SD4: 20 May.

*SD2 was established with 10 mm supplementary watering via drippers.

Table 1 Expected phenology responses of the 2019 experiment genotypes.

Phenology type	Genotypes*
Winter (W)	Longswordᶲ (Fast), LongReach Kittyhawkᶲ (Mid), EGA Wedgetailᶲ (Mid), DS Bennettᶲ (Mid–slow), RGT Accrocᶲ (Slow), Manningᶲ (Slow)
Very slow (VS)	EGA Eaglehawkᶲ, RGT Zanzibarᶲ, **LongReach Nighthawk**ᶲ
Slow (S)	Cutlassᶲ, Sunlambᶲ, Sunmaxᶲ
Mid (M)	**Catapult**ᶲ, Coolahᶲ, DS Pascalᶲ, EGA Gregoryᶲ, LongReach Lancerᶲ, LongReach Trojanᶲ, Mitchᶲ
Mid-fast (MF)	Beckomᶲ, Janz, LongReach Reliantᶲ, Suntopᶲ, Sunvaleᶲ
Fast (F)	Corackᶲ, **LongReach Hellfire**ᶲ, LongReach Mustangᶲ, LongReach Spitfireᶲ, Maceᶲ, Scepterᶲ, Sunprimeᶲ
Very fast (VF)	Condoᶲ, LongReach Dartᶲ, H45, TenFourᶲ, Vixenᶲ

*New releases in **bold**.

Results

Phasic development

When considering variety options at sowing, growers should aim to synchronise crop development with seasonal patterns, so that flowering occurs at an optimal time. This period is a trade-off between increasing drought and heat threat, and declining frost risk.

Generally, the highest yields are achieved at Marrar when genotype and sowing date combinations flower in early to mid October. In 2019, the flowering window spanned from 18 August to 21 October, and was directly influenced by severe drought conditions, significant heat stress and mild frost conditions. The highest yields were achieved when flowering occurred early to mid September (2–3 weeks earlier than long-term data, see previous results in Harris et al., 2018; Harris et al., 2019). There was a significant decline in grain yield when flowering occurred after late September (Figure 1).

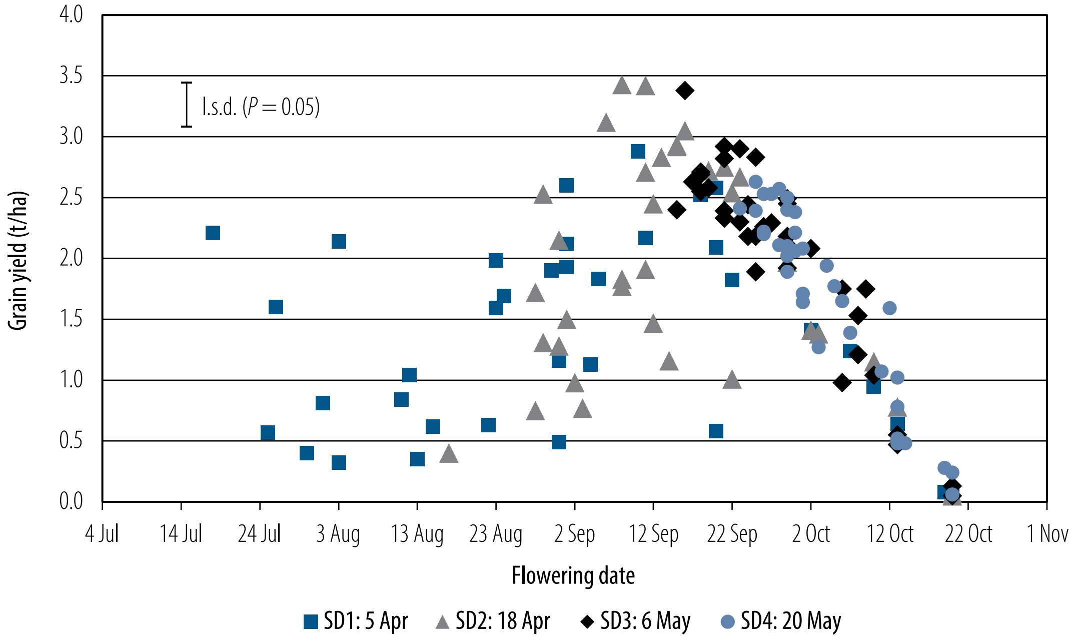
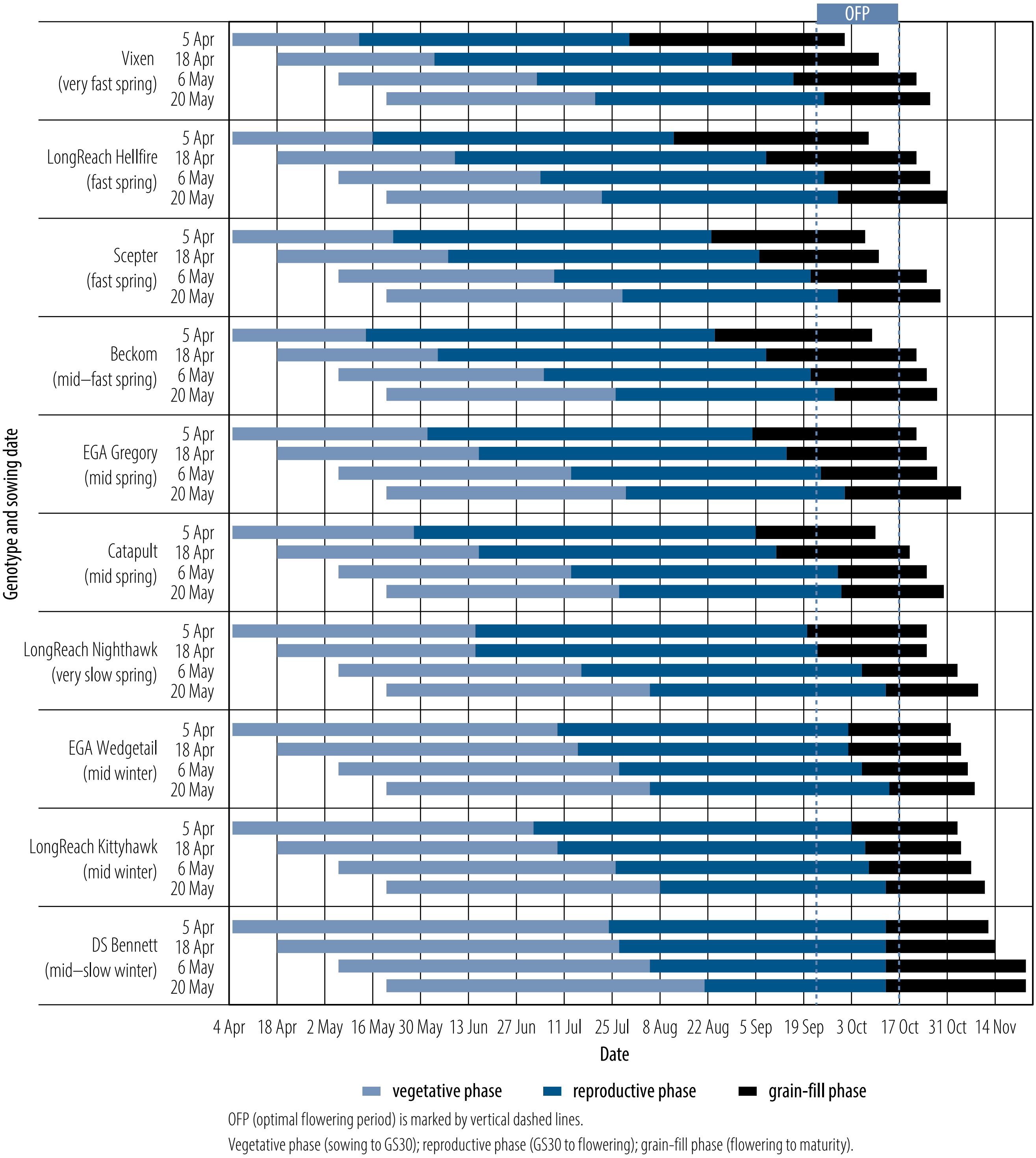


Figure 1 Relationship between flowering date and grain yield for 36 genotypes sown on four sowing dates at Marrar, 2019.

There are varied development responses to vernalisation and photoperiod among the genotypes tested, which resulted in phasic development varying significantly with respect to sowing date (Figure 2). This variation influenced the flowering grain yield responses shown in Figure 1. Faster developing spring types (with minimal response to vernalisation), when sown early (characterised by warmer temperatures and longer days), developed quickly and flowered earlier than the optimal flowering period (OFP). For example, new release Vixen$^{\phi}$, flowered on 30 July from SD1, which was two months earlier than the OFP yielding 0.40 t/ha. However, when sown on either SD3 or SD4 (May), Vixen$^{\phi}$ flowered on 16 September (SD3) and 25 September (SD4) and achieved the highest yield ranking (SD3: 3.38 t/ha and SD4: 2.63 t/ha, Table 2).

In contrast, the slower developing winter types had prolonged vegetative phases from earlier sowing dates (afforded by their vernalisation requirement) and had later, more stable flowering dates across sowing treatments. Whilst mid-winter types EGA Wedgetail$^{\phi}$ and LongReach Kittyhawk$^{\phi}$ recorded similar flowering dates, differences were observed in pre-flowering phases in response to sowing date, which has been reported previously (Harris et al., 2018; Harris et al., 2019). In 2019, LongReach Kittyhawk$^{\phi}$ reached GS30 6–7 days faster than EGA Wedgetail$^{\phi}$ for SD1 and SD2, while there was only 1–3 days difference for SD3 and SD4 (Figure 2). DS Bennett$^{\phi}$ was slower, reaching GS30 9–18 days later than EGA Wedgetail$^{\phi}$ across sowing dates (Figure 2). DS Bennett$^{\phi}$ has previously reported stable flowering dates afforded by a strong photoperiod response (Harris et al., 2018; Harris et al., 2019). However, in 2019 severe drought and heat stress conditions significantly delayed flowering (also observed in other slower developing genotypes) a result of spikes not progressing beyond the booting phase or emerging from the flag leaf and as such flowering was not observed on a large proportion of tillers.



OFP (optimal flowering period) is marked by vertical dashed lines.

Vegetative phase (sowing to GS30); reproductive phase (GS30 to flowering); grain-fill phase (flowering to maturity).

Figure 2 Influence of sowing date on phasic development of selected genotypes sown 5 April, 18 April, 6 May and 20 May at Marrar, 2019.

Grain yield

Grain yields and genotype rankings varied significantly across the sowing dates (early April to late May) (Table 2), which confirms that genotypes are not broadly adapted to sowing date. In 2019, mid–fast developing spring types sown in late April achieved the highest grain yields (e.g. Beckom$^{\Phi}$, LongReach Trojan$^{\Phi}$), and fast spring types in early May (Vixen$^{\Phi}$) (Table 2). While there were yield penalties when fast developing spring wheats were sown in early April, there was a 2–3 week shift in earlier OFP under severe heat and terminal drought conditions. But slow spring and winter genotypes flowered too late, and recorded the lowest grain yields for 2019 (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.

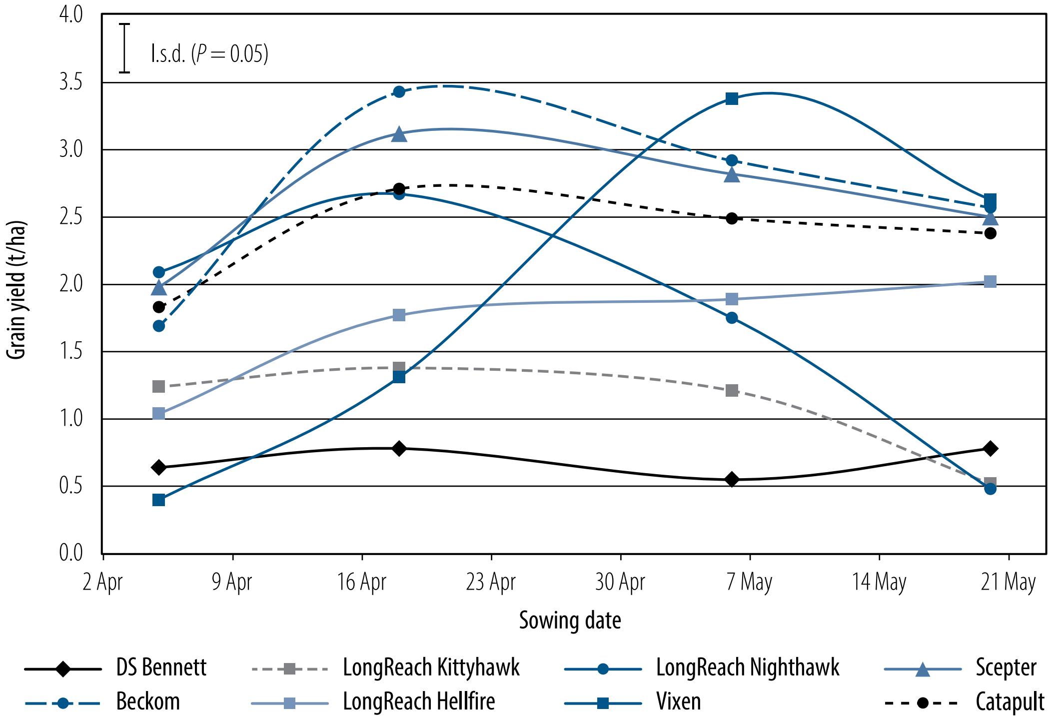


Figure 3 Grain yield of selected genotypes across four sowing dates: 5 April, 18 April, 6 May and 20 May at Marrar, 2019.

Grain quality

Despite significant differences within genotype, sowing date and the interaction between genotype and sowing date, seasonal conditions significantly influenced grain quality in 2019 (Table 3). Generally, grain protein and screenings were high and test weight low.

Table 2 Grain yield of genotypes across four sowing dates at Marrar in 2019.

Genotype	**Grain yield (t/ha)***							
	SD1: 5 April		**SD2: 18 April**		**SD3: 6 May**		**SD4: 20 May**	
Beckom	1.69	(15)	3.43	(1)	2.92	(2)	2.57	(2)
Catapult	1.83	(13)	2.71	(10)	2.49	(11)	2.38	(9)
Condo	2.14	(7)	2.15	(15)	2.69	(7)	2.20	(12)
Coolah	2.17	(6)	2.92	(6)	2.29	(18)	1.27	(26)
Corack	0.84	(24)	1.50	(21)	2.90	(3)	2.40	(7)
Cutlass	0.49	(31)	1.47	(22)	2.45	(12)	1.94	(18)
DS Bennett	0.64	(26)	0.78	(31)	0.55	(33)	0.78	(29)
DS Pascal	2.88	(1)	3.05	(4)	2.11	(23)	1.77	(20)
EGA Eaglehawk	1.82	(14)	1.97	(16)	1.04	(31)	0.50	(31)
EGA Gregory	1.13	(21)	1.16	(27)	2.18	(20)	1.71	(21)
EGA Wedgetail	1.41	(18)	1.41	(23)	0.98	(32)	0.48	(32)
H45	1.60	(16)	1.72	(20)	2.55	(10)	2.22	(10)
Janz	0.62	(28)	1.91	(17)	2.18	(21)	1.89	(19)
Longsword	0.58	(29)	1.01	(29)	1.92	(25)	1.64	(23)
LongReach Dart	0.57	(30)	0.40	(34)	2.40	(14)	2.41	(6)
LongReach Hellfire	1.04	(22)	1.77	(19)	1.89	(26)	2.02	(17)
LongReach Kittyhawk	1.24	(19)	1.38	(24)	1.21	(30)	0.52	(30)
LongReach Lancer	2.12	(8)	2.93	(5)	2.26	(19)	1.39	(25)
LongReach Mustang	0.32	(34)	1.28	(26)	2.58	(9)	2.10	(14)
LongReach Nighthawk	2.09	(9)	2.67	(11)	1.75	(27)	0.48	(33)
LongReach Reliant	1.16	(20)	1.83	(18)	2.30	(17)	2.11	(13)
LongReach Spitfire	0.35	(33)	0.77	(32)	2.39	(15)	2.21	(11)
LongReach Trojan	2.60	(2)	3.42	(2)	2.44	(13)	2.06	(16)
Mace	0.63	(27)	0.98	(30)	2.33	(16)	2.53	(3)
Manning	0.06	(36)	0.05	(36)	0.05	(36)	0.06	(36)
Mitch	1.90	(12)	2.45	(14)	2.18	(22)	1.59	(24)
RGT Accroc	0.08	(35)	0.07	(35)	0.13	(35)	0.28	(34)
RGT Zanzibar	2.58	(3)	2.75	(8)	1.53	(29)	1.02	(28)
Scepter	1.98	(10)	3.12	(3)	2.82	(5)	2.50	(5)
Sunlamb	0.95	(23)	1.15	(28)	0.47	(34)	0.24	(35)
Sunmax	2.52	(4)	2.54	(12)	1.75	(28)	1.07	(27)
Sunprime	2.21	(5)	2.53	(13)	2.71	(6)	2.39	(8)
Suntop	1.59	(17)	2.83	(7)	2.83	(4)	2.08	(15)
Sunvale	1.93	(11)	2.72	(9)	2.08	(24)	1.65	(22)
TenFour	0.81	(25)	0.75	(33)	2.63	(8)	2.53	(4)
Vixen	0.40	(32)	1.31	(25)	3.38	(1)	2.63	(1)
Mean	1.36		1.86		2.04		1.66	
l.s.d. ($P = 0.05$)								
Genotype	0.19							
SD	0.06							
Genotype × SD	0.38							

* Yield ranking according to sowing date treatment in parentheses.

Table 3 Grain protein (GP), screenings (SCRN) and test weight (TWT) of genotypes across four sowing dates at Marrar in 2019.

Genotype	SD1: 5 April			SD2: 18 April			SD3: 6 May			SD4: 20 May		
	GP (%)	SCRN (%)	TWT (%)	GP (%)	SCRN (%)	TWT (%)	GP (%)	SCRN (%)	TWT (%)	GP (%)	SCRN (%)	TWT (%)
Beckom	15.3	9.7	75.6	12.6	15.0	78.0	12.9	12.1	78.8	14.2	19.3	80.3
Catapult	14.9	12.0	76.1	14.0	15.0	79.8	14.3	9.6	81.6	15.1	11.4	81.3
Condo	15.5	12.6	72.7	14.7	12.9	71.1	13.4	19.3	78.3	15.8	21.9	78.9
Coolah	13.8	15.3	76.0	12.7	12.1	79.7	13.9	12.6	81.1	14.7	16.0	80.5
Corack	16.6	5.7	70.0	15.1	8.8	75.2	13.5	14.6	80.9	15.4	13.4	79.8
Cutlass	16.7	6.7	74.1	15.6	9.7	78.9	14.7	11.9	79.6	16.2	15.2	79.2
DS Bennett	14.8	14.3	75.1	14.8	15.2	76.3	16.0	11.7	76.0	16.1	14.0	77.8
DS Pascal	13.3	10.5	79.3	14.0	9.4	78.4	15.3	10.1	80.2	16.1	13.5	79.9
EGA Eaglehawk	15.6	8.4	78.6	15.1	8.1	80.8	15.8	13.4	79.9	16.5	10.4	73.6
EGA Gregory	15.2	12.2	72.1	15.4	12.3	77.4	15.1	10.2	81.3	15.3	11.1	81.3
EGA Wedgetail	15.6	9.5	75.4	15.7	10.9	75.5	15.5	17.8	75.3	16.1	9.1	69.9
H45	15.1	8.7	71.2	15.4	13.0	72.2	12.9	26.5	77.9	14.4	22.4	80.4
Janz	16.6	5.6	71.5	15.3	9.3	76.8	15.3	10.0	80.5	15.5	13.9	81.7
Longsword	17.2	3.2	73.1	16.4	5.3	76.8	15.5	6.7	80.0	15.7	7.0	80.1
LongReach Dart	16.1	12.4	62.9	17.7	6.0	70.9	14.9	13.7	79.8	15.4	20.1	80.0
LongReach Hellfire	18.8	7.0	71.2	17.0	10.8	77.3	16.3	11.2	80.8	17.3	13.8	81.6
LongReach Kittyhawk	15.7	6.1	80.7	15.4	5.5	81.7	15.5	7.9	82.0	16.0	7.6	79.1
LongReach Lancer	16.3	10.9	74.6	15.6	12.4	78.4	16.2	14.1	79.1	16.9	12.6	80.2
LongReach Mustang	15.2	12.9	63.7	15.5	10.7	75.0	14.9	14.7	79.6	15.9	12.7	81.2
LongReach Nighthawk	14.8	7.2	78.7	13.7	10.7	80.4	14.7	11.5	80.5	16.3	7.0	75.8
LongReach Reliant	15.7	14.9	72.6	15.2	10.5	74.9	14.7	15.6	79.5	16.0	18.8	84.0
LongReach Spitfire	17.8	6.3	70.6	17.6	5.1	73.5	15.9	13.8	80.1	16.2	17.7	80.9
LongReach Trojan	13.8	13.4	73.5	13.2	12.9	78.0	14.3	10.3	82.2	15.6	17.0	81.6
Mace	16.5	8.4	69.8	15.7	9.0	73.9	14.4	9.7	79.9	15.0	12.9	80.4
Manning	15.6	10.3	73.1	15.1	11.1	76.3	14.9	13.3	79.2	15.7	14.6	79.3
Mitch	13.7	12.6	70.6	13.6	16.2	74.2	14.6	18.5	77.2	15.7	23.9	77.8
RGT Accroc	16.9	7.0	69.5	16.4	7.8	72.7	16.2	11.7	75.2	17.1	9.4	75.9
RGT Zanzibar	14.2	19.1	77.3	13.8	16.0	78.8	14.6	13.7	79.2	15.6	15.6	77.7
Scepter	15.1	17.0	73.9	13.5	18.6	77.0	13.8	15.2	80.1	15.0	17.4	81.5
Sunlamb	16.0	6.7	74.4	15.2	7.7	76.0	16.1	7.1	73.7	15.9	15.0	74.8
Sunmax	15.0	12.8	78.8	15.3	8.5	80.4	16.0	7.6	81.9	16.8	9.5	79.9
Sunprime	15.3	11.6	69.4	14.4	15.7	71.5	14.2	22.2	76.1	15.7	23.8	77.6
Suntop	15.6	10.1	76.2	13.8	12.2	77.7	13.7	15.9	80.7	15.3	15.2	82.0
Sunvale	15.3	9.3	76.5	14.8	8.8	80.0	16.3	12.1	80.3	16.7	12.6	82.2
TenFour	15.6	12.1	66.9	16.4	12.9	69.6	14.8	16.9	76.4	14.4	17.3	77.6
Vixen	16.4	8.4	65.4	16.3	14.1	72.3	13.9	17.2	76.6	15.2	15.2	77.4
Mean	15.6	10.3	73.1	15.1	11.1	76.3	14.9	13.3	79.2	15.7	14.7	79.3
l.s.d. ($P = 0.05$)												
Genotype	0.4	2.0	1.4									
SD	0.1	0.7	0.5									
Genotype × SD	0.9	4.1	2.8									

Summary

Seasonal conditions significantly influenced phenology, yield and grain quality responses to sowing date in 2019. Severe drought and heat stress, combined with minimal frosts resulted in optimal flowering time for maximum grain yield shifting 2–3 weeks earlier than average. This favoured quicker developing spring genotypes sown earlier than their optimal sowing window based on previous data, and slow developing spring and winter genotypes suffered significant yield penalties. We observed differences in phenology and yield responses among genotypes with similar flowering dates, indicating the significant influence sowing date can have on pre-flowering and grain filling phases, which was amplified by extreme drought conditions. These results highlight the interaction between phasic development and yield formation, how this can be amplified under severe seasonal conditions, and the importance for growers to consider long-term responses when choosing cultivars and management through sowing date.

References

Harris F, Kanaley H, Copeland C, Maccallum D and Petty H, 2019. Sowing date influence on wheat phenology and grain yield – Wagga Wagga 2018. D Slinger, T Moore and C Martin (eds). *Southern NSW research results 2019*, NSW Department of Primary Industries.

Harris F, Kanaley H, McMahon G and Copeland C, 2018. Influence of sowing date on phenology and grain yield of wheat – Wagga Wagga, 2017; D Slinger, T Moore and C Martin (eds). *Southern NSW research results 2018*, NSW Department of Primary Industries.

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Early sowing options: wheat phenology and yield responses – Wallendbeen 2019

Dr Felicity Harris, Hugh Kanaley, Mary Matthews, Cameron Copeland, Dean Maccallum, Jess Simpson and Ian Menz (NSW DPI, Wagga Wagga)

Key findings

- Despite the significant effect of seasonal conditions in 2019, grain yields of >5.5 t/ha were achieved, highlighting the opportunity for early sown winter wheats in grain-only systems.
- Differences in phenology and yield responses across sowing dates suggest cultivar performance can be manipulated by sowing time and can vary across environments.
- New winter and long season spring types with consistent yield performance provide alternative early sowing options for growers in southern NSW.

Introduction

Recently, breeders have released a number of new winter wheat genotypes suited to early sowing. In 2019, field experiments were conducted at two sites: Wallendbeen (southern NSW) and Wongarbon (central NSW) to determine the influence of phenology on grain yield responses for a set of 16 commercial and newly released genotypes in response to sowing date (SD). This paper presents results from the Wallendbeen site.

Site details

Location	Braeside, Wallendbeen NSW
Soil type	Grey kandasol
Previous crop	Canola
Sowing	• Direct drilled with DBS tynes spaced at 250 mm using a GPS auto-steer system. • Target plant density: 140 plants/m^2. • SD1: 27 March; SD2: 10 April; SD3: 30 April.
Fertiliser	• 98 kg/ha mono-ammonium phosphate (MAP) (sowing). • Activist® Max (70% zinc) 1 L/ha + Easy N 20 L/ha (21 May, 6 June). • OmniGRO 4 L/ha (24 May). • 93 kg N/ha (applied as urea, 8 July).
Weed control	Knockdown • Glyphosate (450 g/L) 2.0 L/ha. Pre-emergent • Sakura® 118 g/ha (before SD1, incorporated by rain). • Avadex Xtra 1.6 L/ha + Trifluralin (480 g/L) 0.8 L/ha (pre-sowing). In-crop • LVE MCPA 570 600 mL/ha + Paradigm® Arylex® active 25 g/ha (SD1 and SD2 on 15 May, SD3 on 26 July).

- Axial® 300 mL/ha (SD3 on 26 July).

Disease and pest management

- Seed treatment: Hombre® Ultra 200 mL/100 kg and Gaucho® 600 120 mL/100 kg.
- Flutriafol-treated fertiliser 250 g/L (400 mL/ha).
- Prosaro® 300 mL/ha (SD1 and SD2: 6 June, all SDs on 19 July).

Rainfall

- In-crop rainfall (April–October): 192.5 mm
- In-crop long-term average: 420 mm
- 36 mm rain recorded on 3 November, which coincided with the early grain-filling stages of winter genotypes.

Severe temperature events

- Twelve heat stress events (days >30 °C until 28 November) including 32.7 °C (6 October) (coinciding with critical flowering and early grain-filling stages).
- Eight frosts (days <0 °C), one severe frost –2.2 °C (22 June).

Harvest dates

- 28 November
- 10 December: Manning$^{\phi}$ (all SDs) due to delayed maturity.

Treatments

Sixteen wheat genotypes varying in phenology responses (Table 1) were sown on three sowing dates: SD1: 27 March, SD2: 10 April and SD3: 30 April in 2019.

Table 1 Expected phenology responses of the 2019 experiment genotypes.

Phenology type	Genotypes*
Winter (W)	Longsword$^{\phi}$ (F), LongReach Kittyhawk$^{\phi}$ (M), EGA Wedgetail$^{\phi}$ (M), Illabo$^{\phi}$ (MF), DS Bennett$^{\phi}$ (MS), RGT Accroc (S), Manning$^{\phi}$ (S), ADV08.0008, ADV13.1292
Spring	Scepter$^{\phi}$ (F), LongReach Lancer$^{\phi}$ (M), Cutlass$^{\phi}$ (S), Sunmax$^{\phi}$ (S), Sunlamb$^{\phi}$ (S), RGT Zanzibar$^{\phi}$ (VS), **LongReach Nighthawk$^{\phi}$ (VS)**

New release in **bold**.
* Very slow (VS), Slow (S), M (Mid), MS (Mid–slow), MF (Mid–fast) and Fast (F).

Results

Phasic development

The optimal flowering period (OFP), whereby yield is maximised and risk of frost, heat and drought is minimised, is mid to late October at Wallendbeen. In 2019, the flowering window spanned from 31 August to 25 October and, despite below average in-crop rainfall and significant heat stress events, the highest yields were achieved when flowering coincided with the OFP (Figure 1). When sown early, faster developing spring types (with minimal response to vernalisation) flowered early and recorded significant yield penalties, even with mild frost conditions (Figure 1). For example, Scepter$^{\phi}$ sown on 30 April (SD3, closer to its recommended main season sowing window for its given phenology type), flowered on 6 October and recorded 5.01 t/ha. However, when sown early on 27 March (SD1), Scepter$^{\phi}$ flowered on 31 August, nearly two months earlier than the OFP and had a 70% yield penalty (1.48 t/ha) (figures 1 and 3).

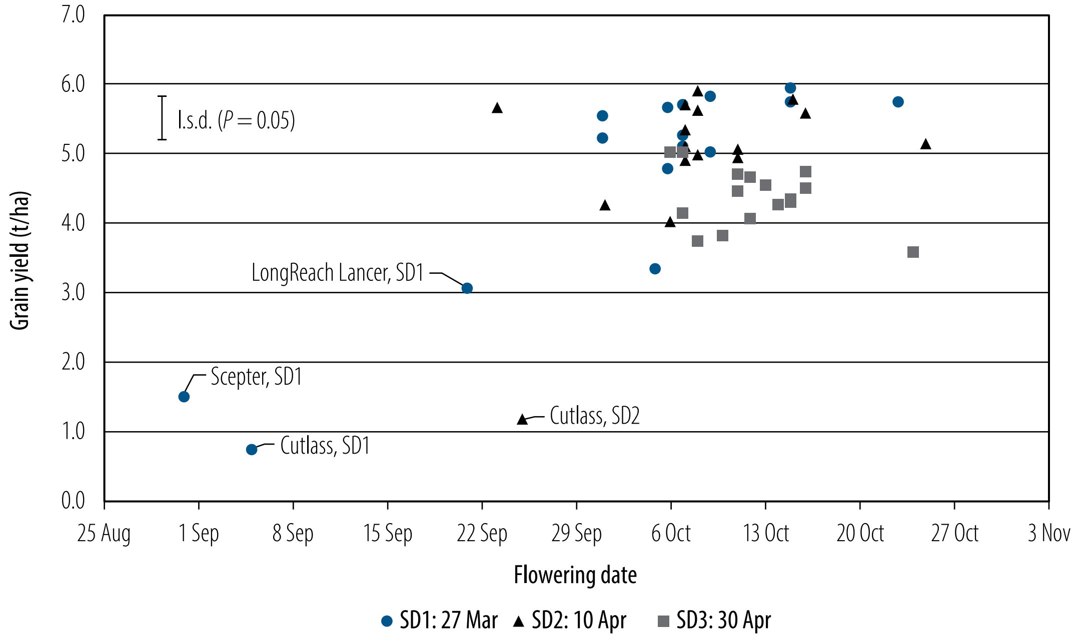


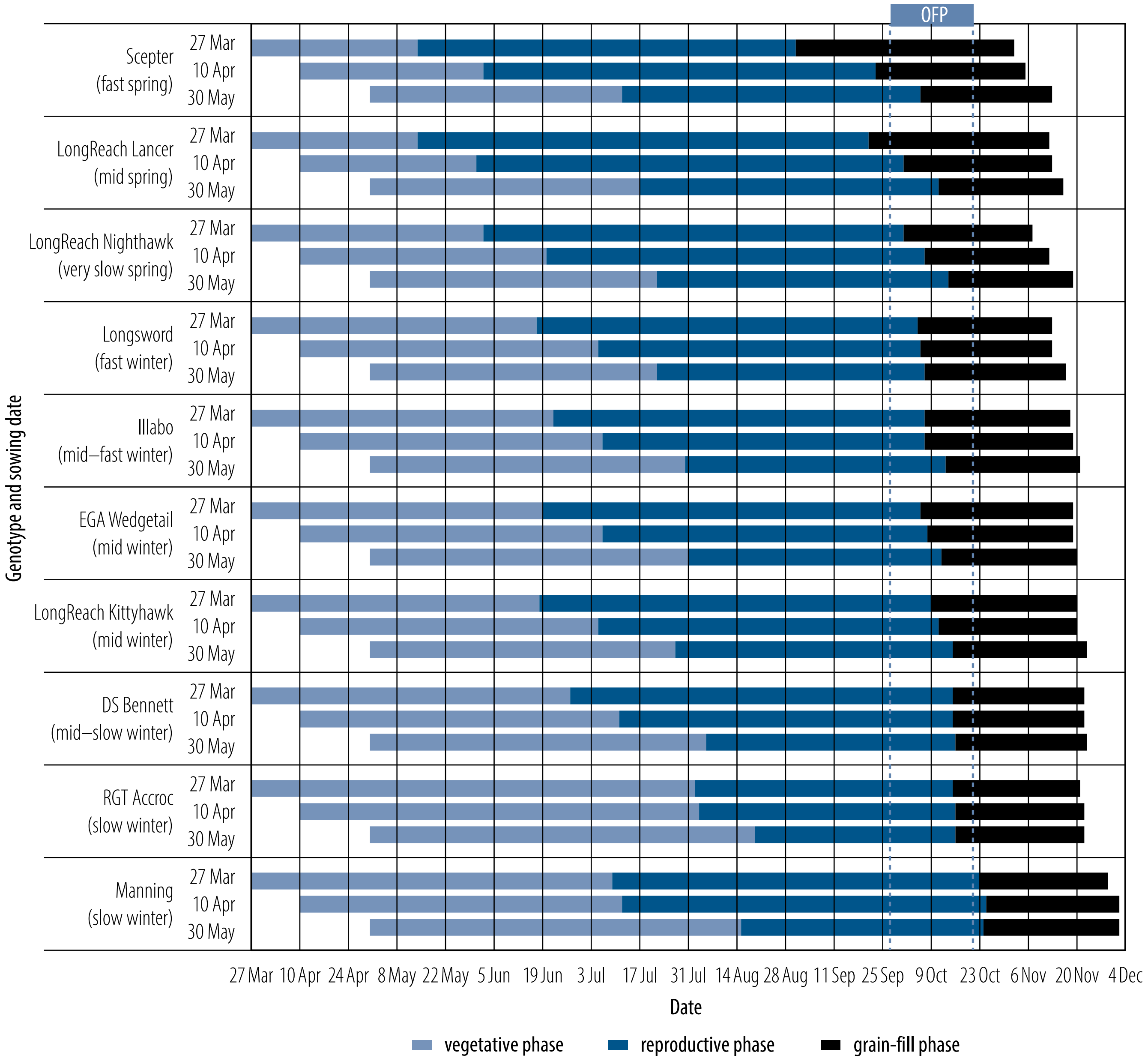
Figure 1 Relationship between flowering date and grain yield for 16 genotypes sown on 27 March (SD1), 10 April (SD2) and 30 April (SD3) at Wallendbeen, 2019.

While many of the slower developing spring and winter genotypes flowered within the OFP, we observed significant variation in phenology and grain yield responses (figures 1and 2).

The newly released LongReach Nighthawk⁽ᴰ⁾ showed a novel phenology response in 2017–19 field experiments. LongReach Nighthawk⁽ᴰ⁾, a very slow spring type, can progress quickly to stem elongation when sown early compared with more stable winter types (e.g. 17 days faster than EGA Wedgetail⁽ᴰ⁾ for SD1, 9 days faster for SD3). However, LongReach Nighthawk⁽ᴰ⁾ has shown a relatively stable flowering time across sowing dates (Figure 2), and grain yield responses to sowing date similar to mid winter types (Figure 3). This novel phenology response could provide an alternative early sowing option for growers in environments not suited to winter wheats.

In 2019, we observed similar phenology responses in mid winter types Illabo⁽ᴰ⁾, EGA Wedgetail⁽ᴰ⁾ and LongReach Kittyhawk⁽ᴰ⁾, with no significant difference in GS30 date (start of stem elongation) in response to sowing date. Previously, we have observed consistent differences in vegetative phase length among these types, whereby both Illabo⁽ᴰ⁾ and LongReach Kittyhawk⁽ᴰ⁾ were faster to GS30 when sown earlier than mid April, despite similar flowering responses (Harris et al., 2018, Harris et al., 2019). We did, however, observe LongReach Kittyhawk⁽ᴰ⁾ was 3–4 days later to flower across all sowing dates compared with Illabo⁽ᴰ⁾ and EGA Wedgetail⁽ᴰ⁾ (Figure 2). The fastest developing winter type, Longsword⁽ᴰ⁾, also had a similar phenology response to the mid winter types in SD1 and SD2, however, it was significantly faster to stem elongation and flowering than EGA Wedgetail⁽ᴰ⁾ (7–8 days) in SD3 (Figure 2).

The slow winter types DS Bennett⁽ᴰ⁾, Manning⁽ᴰ⁾ and RGT Accroc⁽ᴰ⁾ were significantly slower to GS30 and flowering than the other winter types. DS Bennett⁽ᴰ⁾ was consistently 5–8 days slower to stem elongation and flowering than EGA Wedgetail⁽ᴰ⁾, and had stable flowering dates across the three sowing dates, consistent with results in previous years (Harris et al., 2018; Harris et al., 2019). In 2019, we observed Manning⁽ᴰ⁾ to be 4–14 days faster to GS30 than RGT Accroc⁽ᴰ⁾, however, RGT Accroc⁽ᴰ⁾ flowered and reached physiological maturity 8–9 days quicker than Manning⁽ᴰ⁾ (Figure 2).



OFP (optimal flowering period) is marked by vertical dashed lines.

Vegetative phase (sowing to GS30); reproductive phase (GS30 to flowering); grain-fill phase (flowering to maturity).

Figure 2 Sowing date influence on phasic development of selected genotypes sown on 27 March (SD1), 10 April (SD2) and 30 April (SD3) at Wallendbeen, 2019.

Grain yield

Generally, winter genotypes achieved consistently high yields from the first two sowing dates, with a significant yield penalty for SD3 when grain-filling coincided with increased heat stress events. However, there were differences in yield responses among the winter types (Figure 3, Table 2), suggesting that there are opportunities for growers to use phenology and sowing date as a management strategy to optimise grain yield. For example, yield responses in the fast winter type Longsword⁽ᵈ⁾ is consistent with 2017 and 2018 results (Harris et al., 2018, Harris et al., 2019), that suggest optimal sowing dates from mid April onwards when ungrazed.

The accelerated development, and earlier flowering of faster spring types (e.g. Scepter⁽ᵈ⁾) and spring genotypes (LongReach Lancer⁽ᵈ⁾), resulted in yield penalties of up to 75% in SD1 and SD2 (Figure 3, Table 2). However, when spring types were sown closer to their recommended sowing window (SD3), they were capable of flowering at an optimal time and achieving comparable yields to winter types.

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 the growing environment.

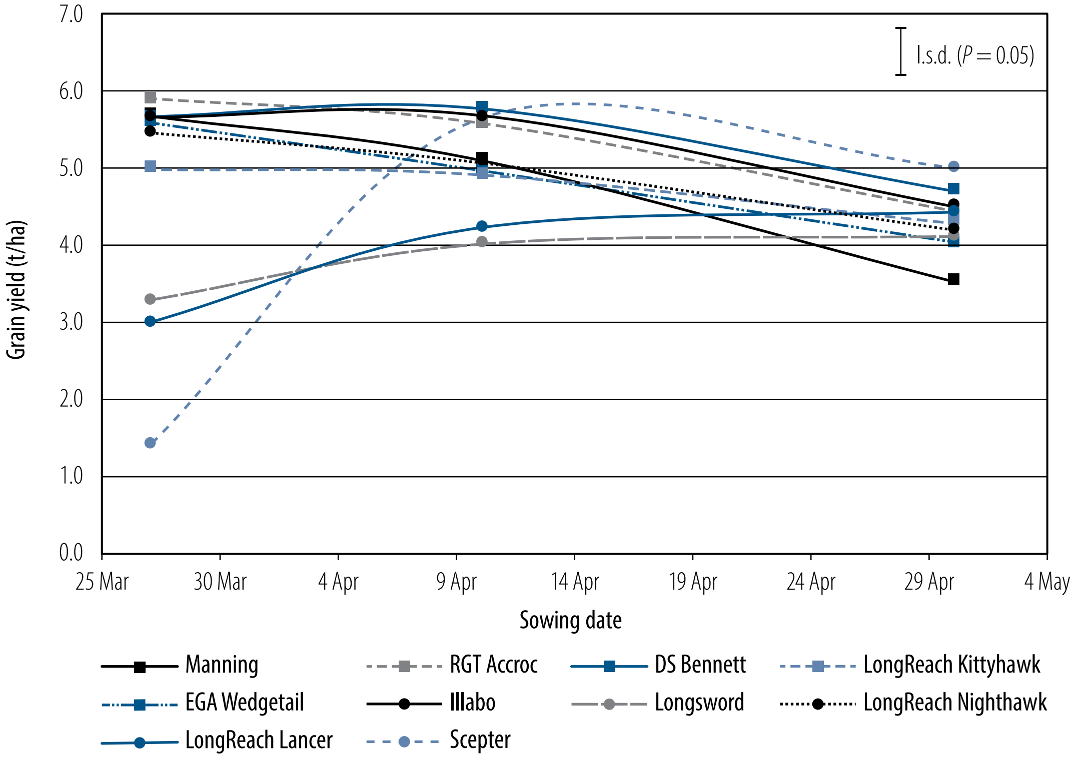


Figure 3 Grain yield responses across three sowing dates: 27 March (SD1), 10 April (SD2) and 30 April (SD3) at Wallendbeen, 2019.

Grain quality

Seasonal conditions had a significant influence on grain quality parameters in 2019 at Wallendbeen (Table 3). All genotypes achieved greater than 11.5% grain protein and, with the exception of Cutlass$^{\text{Ф}}$ and Scepter$^{\text{Ф}}$ (SD1), had test weights >76 kg/hL. All genotype × sowing date combinations recorded high screenings (>5%) (Table 3), which corresponds to a series of severe heat stress events during the grain-filling period (12 days >30 °C).

Table 2 Grain yield of genotypes across three sowing dates at Wallendbeen in 2019.

Genotype	**Grain yield (t/ha)**		
	SD1: 27 March	**SD2: 10 April**	**SD3: 30 April**
ADV08.0008	5.21	5.92	4.65
ADV13.1292	5.79	5.60	4.29
Cutlass	0.68	1.15	5.01
DS Bennett	5.69	5.79	4.72
EGA Wedgetail	5.61	4.98	4.04
Illabo	5.67	5.69	4.52
Longsword	3.30	4.03	4.13
LongReach Kittyhawk	4.99	4.92	4.30
LongReach Lancer	3.01	4.24	4.44
LongReach Nighthawk	5.48	5.09	4.22
Manning	5.70	5.12	3.54
RGT Accroc	5.91	5.59	4.46
RGT Zanzibar	5.07	5.33	4.66
Scepter	1.43	5.66	5.01
Sunlamb	4.72	5.05	3.72
Sunmax	5.18	4.88	3.79
Mean	4.59	4.94	4.34
Mean (Winter)	5.32	5.29	4.29
Mean (Spring)	3.65	4.49	4.41
l.s.d. ($P = 0.05$)			
Genotype	0.37		
SD	0.16		
Genotype × SD	0.63		

*Blue shading indicates genotype x SD are statistically similar and highest yielding.

Summary

While seasonal conditions significantly influenced phenology, grain yield and quality responses to sowing date in 2019, high grain yields were achieved from various genotype × sowing date combinations at Wallendbeen. Winter genotypes were generally stable in their flowering time, yet there were differences in phenology and grain yield responses across sowing dates from late March to late April, suggesting cultivar performance can be manipulated with management (sowing date) and can vary across growing environments.

The faster developing spring genotypes were not suited to very early sowing dates, and suffered severe yield penalties, however, some were able to achieve comparable grain yields when sown later (e.g. Scepter(b) on SD3). The recent release of new winter cultivars (e.g. Illabo(b)) and some novel slower developing spring cultivars (e.g. LongReach Nighthawk(b)) provide increased options for growers for early sowing. These results highlight the opportunity for early sown winter wheats in grain-only systems, as well as the importance of considering phenology when determining genotype and sowing date decisions to achieve flowering at an optimal time and optimum grain yields.

Table 3 Protein (%), screenings % (SCRN) and test weight (kg/hL) (TWT) of genotypes across three sowing dates at Wallendbeen in 2019.

Genotype	**SD1: 27 March**			**SD2: 10 April**			**SD3: 30 April**		
	Protein (%)	**TWT (kg/hL)**	**SCRN (%)**	**Protein (%)**	**TWT (kg/hL)**	**SCRN (%)**	**Protein (%)**	**TWT (kg/hL)**	**SCRN (%)**
ADV08.0008	13.7	81.9	8.5	14.4	81.2	15.6	14.7	79.6	12.4
ADV13.1292	13.4	83.6	11.1	13.7	84.1	14.4	13.9	81.4	13.0
Cutlass	14.9	73.2	10.2	16.5	75.2	11.5	13.8	80.1	16.3
DS Bennett	13.1	81.9	10.5	13.0	81.2	15.9	13.4	79.4	17.0
EGA Wedgetail	14.8	79.9	13.3	15.5	81.5	7.2	15.9	76.3	17.6
Illabo	14.0	81.3	9.9	14.5	86.0	14.2	15.3	77.3	10.8
Longsword	16.4	79.4	11.6	16.6	81.3	11.0	15.9	82.0	15.8
LongReach Kittyhawk	13.7	83.6	10.3	13.5	83.1	5.8	14.1	80.7	14.9
LongReach Lancer	16.2	81.1	11.0	15.5	83.8	11.6	14.5	80.1	8.1
LongReach Nighthawk	12.6	83.7	12.5	13.4	83.4	18.2	14.2	81.7	17.9
Manning	12.8	77.2	12.9	12.5	78.2	10.0	13.5	77.7	15.1
RGT Accroc	13.6	80.5	13.4	14.2	80.3	9.6	14.9	78.3	13.2
RGT Zanzibar	12.7	81.0	10.5	13.3	79.9	9.6	13.7	80.2	12.6
Scepter	15.3	74.5	11.7	12.6	82.9	8.7	14.0	79.1	18.7
Sunlamb	14.4	83.3	11.4	14.5	82.6	10.9	15.8	81.9	12.9
Sunmax	13.1	83.6	7.7	14.2	79.8	9.5	16.0	79.2	13.0
l.s.d. ($P = 0.05$)									
Genotype	0.6	8.0	ns						
SD	0.2	3.5	1.5						
Genotype × SD	1.0	13.8	5.9						

References

Harris F, Kanaley H, Copeland C, Maccallum D and Petty H, 2019. Early sowing options: sowing date influence on phenology and grain yield of long-season wheat genotypes – Wallendbeen, 2018; D Slinger, T Moore and C Martin (eds), *Southern NSW research results 2019*, pp. 11–16, NSW Department of Primary Industries.

Harris F, Kanaley H, McMahon G, Copeland C and Petty H, 2018. Early sowing options: sowing date influence on phenology and grain yield of long-season wheat genotypes – Wallendbeen, 2017; D Slinger, T Moore and C Martin (eds), *Southern NSW research results 2018*, pp. 49–53, NSW Department of Primary Industries.

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Sowing date effect on phasic development and yield of thirty-two wheat varieties – Condobolin 2019

David Burch and Nick Moody (NSW DPI, Condobolin); Dr Felicity Harris (NSW DPI, Wagga Wagga)

Key findings

- Seasonal conditions, characterised by low frost incidence combined with heat stress and terminal drought conditions, significantly affected grain yield and quality responses.
- The highest yields were associated with earlier flowering; there was a significant yield penalty associated with later flowering of slower developing genotypes or when sowing was delayed.

Introduction

In central western NSW, there is a high risk of early frost damage in combination with heat and moisture stress later in the season. It is therefore important to match variety phenology with sowing date so that flowering is synchronised with a period of least risk, known as the optimal flowering period (OFP), to maximise grain yield. This paper reports the findings of a field experiment conducted at Condobolin in 2019, where the phenology, yield and quality responses of 32 wheat varieties were evaluated across three sowing dates from late April to late May.

Site details

Location	Condobolin Agricultural Research and Advisory Station
Soil type	Red chromosol
Previous crop	2018 fallow (wheat stubble), 2017 wheat, 2016 (field peas).
Rainfall	• Fallow (November–March): 164 mm • Fallow long-term average (LTA): 147 mm • In-crop (April–October): 74 mm • In-crop LTA: 209 mm • An additional 180 mm of water was applied before sowing and periodically during the season in order to simulate a decile 6 season (60 mm 2–4 April; 30 mm 27 May; 30 mm 25 June; 20 mm 5 August; 30 mm 16 September).
Stress events (April to October)	• There were 36 nights with minimum temperatures below 2 °C, (LTA 45). Of these, 10 nights dropped below 0 °C, (LTA 16). • There were 39 days with maximum temperatures between 25 °C and 30 °C, (LTA 29) and 17 days with maximums over 30 °C, (LTA 10).
Soil nitrogen at sowing	• 0–10 cm: 44.2 kg/ha • 10–60 cm: 69.0 kg/ha • 60–100 cm: 120.0 kg/ha
Starter fertiliser	70 kg/ha mono-ammonium phosphate (MAP)

Treatments

Variety

Table 1 Putative phenology types of the experiment genotypes.

Phenology type	Varieties
Winter (W)	Longsword⌽ (Fast), LongReach Kittyhawk⌽ (Mid), EGA Wedgetail⌽ (Mid), DS Bennett⌽ (Mid–slow)
Very slow (VS)	EGA Eaglehawk⌽
Slow (S)	Cutlass⌽, Sunlamb⌽, Sunmax⌽
Mid (M)	Catapult⌽, Coolah⌽, DS Pascal⌽, EGA Gregory⌽, LongReach Lancer⌽, LongReach Trojan⌽, Mitch⌽
Mid–fast (MF)	Beckom⌽, Janz, LongReach Reliant⌽ Suntop⌽ Sunvale⌽
Fast (F)	Corack⌽, LongReach Hellfire⌽, LongReach Mustang⌽, LongReach Spitfire⌽, Mace⌽, Scepter⌽, Sunprime⌽
Very fast (VF)	Condo⌽, H45⌽, LongReach Dart⌽, TenFour⌽, Vixen⌽

Sowing date (SD)

SD1: 18 April
SD2: 6 May
SD3: 20 May

Results

Seasonal conditions

In 2019, Condobolin recorded the lowest rainfall since the research station was established in 1913. In order to successfully establish a field experiment and create seasonal differences from the 2017–18 experiments, the site received 180 mm of additional water via overhead lateral irrigator throughout the season (see site details above), targeting a decile 6 season. Despite the favourable moisture conditions, fewer than normal frosts during the growing season (12 days <0 °C; long-term average is 20 days), combined with severe heat stresses in early October, influenced the experiment results as they coincided with grain filling, and in some treatments, later flowering.

Phenology

Optimum grain yield is achieved when genotypes are matched with sowing date to ensure flowering time is appropriate. The OFP in central western NSW is typically in the second week of September to minimise frost risk during the vulnerable flowering period, and maximise grain filling time without heat and moisture stress halting grain development. The onset of stem elongation differed by six weeks between LongReach Dart⌽ (VF) sown SD1, compared with SD3, while winter variety EGA Wedgetail⌽ differed by four weeks between SD1 and SD3 (Figure 1). The time between the onset of stem elongation and ear emergence decreased significantly with later sowing dates for all varieties, as thermal time accumulated faster.

Anthesis occurred at SD1 in fast flowering varieties LongReach Dart⌽ and LongReach Spitfire⌽ on 6 August and 11 August respectively. As a result, both varieties encountered more frosts during anthesis (11 and seven nights below 2 °C respectively) than for SD2 (0 and two nights). While varieties flowering later did not encounter the same frost occurrences, increased temperatures decreased phasic duration, limiting anthesis and grain filling time. The grain filling time for LongReach Dart⌽, for example, decreased by two weeks between SD1 and SD3, while yield was highest from SD2, where frost and heat risk during grain fill was best balanced. The highest grain yields were generally achieved from SD1, which flowered in the first week of September (Figure 2). This is earlier than the long-term average, possibly due to lower than average frosts during reproductive development.

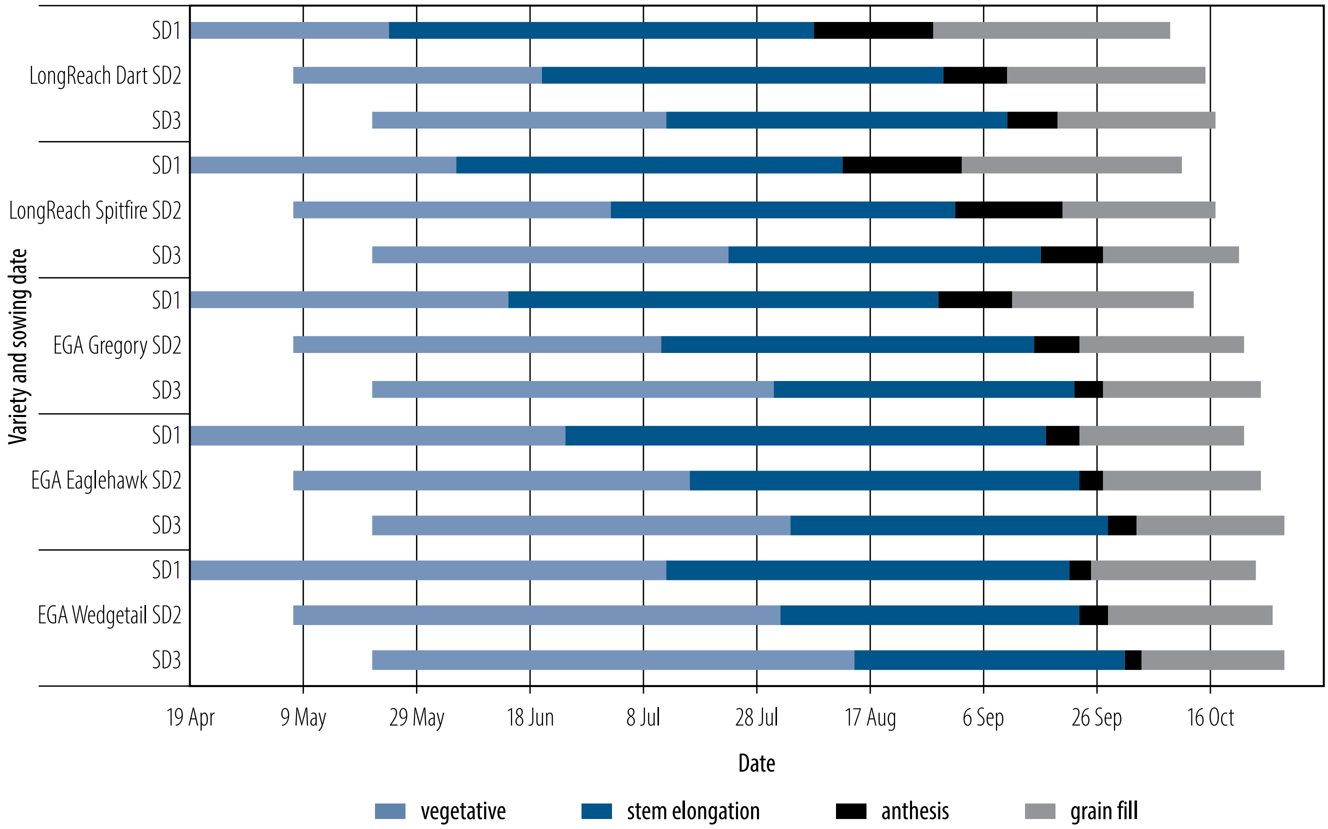

Figure 1 Phenology phases of LongReach Dart$^{\phi}$ (VF), LongReach Spitfire$^{\phi}$ (F), EGA Gregory$^{\phi}$ (M), EGA Eaglehawk$^{\phi}$ (VS) and EGA Wedgetail$^{\phi}$ (W, M) sown 18 April (SD1), 6 May (SD2) and 20 May (SD3), Condobolin, 2019.

Grain yield

There were significant differences in grain yield across sowing dates ($P = 0.04$) and within genotypes ($P<0.01$) with a significant interaction ($P<0.001$) (Table 2). The mid–fast spring cultivars sown early achieved the highest yields, with a general yield decline as sowing was delayed. The highest yielding treatment was Catapult$^{\phi}$ (SD1), which achieved 4.36 t/ha (74% above site mean of 2.17 t/ha), though it was able to maintain yield ranking across all sowing dates, indicating its potential flexibility. There were a number of genotypes that achieved statistically similar high yields from SD2 and SD3 (Table 2).

Table 2 Grain yield (t/ha) of wheat phenotypes across sowing dates at Condobolin, 2019.

Genotype	**Grain yield (t/ha)***					
	SD1: 18 April		**SD2: 6 May**		**SD3: 20 May**	
Beckom	3.11	(124)	2.59	(113)	1.60	(94)
Condo	3.02	(121)	2.43	(106)	1.85	(108)
Coolah	2.37	(95)	2.25	(98)	1.58	(94)
Corack	3.00	(129)	**2.78**	**(121)**	**2.19**	**(128)**
Cutlass	2.60	(104)	**3.01**	**(131)**	1.86	(109)
DS Bennett	1.33	(53)	0.90	(39)	0.96	(56)
DS Pascal	2.32	(93)	1.79	(78)	1.19	(70)
EGA Eaglehawk	2.07	(83)	1.69	(74)	1.59	(93)
EGA Gregory	3.08	(123)	2.24	(97)	1.31	(77)
EGA Wedgetail	1.63	(65)	2.25	(98)	0.98	(57)
H45	2.05	(82)	**2.76**	**(120)**	1.74	(102)
Janz	2.11	(84)	2.05	(89)	1.46	(85)
LongReach Dart	1.77	(71)	**2.96**	**(129)**	1.75	(102)
LongReach Kittyhawk	1.12	(45)	1.41	(62)	1.45	(85)
LongReach Lancer	3.01	(120)	2.32	(101)	1.63	(96)
LongReach Mustang	1.89	(76)	**2.98**	**(130)**	**2.20**	**(129)**
LongReach Reliant	2.84	(114)	2.26	(98)	1.69	(99)
Longreach Hellfire	2.76	(110)	2.24	(98)	**2.17**	**(127)**
LongReach Spitfire	1.82	(73)	2.50	(109)	1.68	(98)
LongReach Trojan	3.83	(153)	2.33	(102)	1.69	(99)
Longsword	1.88	(75)	1.72	(75)	1.76	(103)
Mace	2.45	(98)	2.26	(99)	1.89	(111)
Mitch	2.78	(111)	1.98	(86)	1.77	(104)
Catapult	**4.36**	**(174)**	**2.82**	**(123)**	**2.27**	**(133)**
Scepter	3.69	(148)	**2.77**	**(120)**	2.07	(121)
Sunlamb	1.45	(58)	1.41	(61)	1.12	(66)
Sunmax	2.15	(86)	1.88	(82)	1.56	(91)
Sunprime	2.51	(100)	2.70	(118)	2.11	(123)
Suntop	2.88	(115)	2.44	(106)	1.42	(83)
Sunvale	2.07	(83)	1.87	(82)	1.53	(89)
TenFour	2.43	(97)	**2.85**	**(124)**	2.06	(120)
Vixen	3.43	(137)	**3.01**	**(131)**	**2.52**	**(147)**
Mean	2.50	(100)	2.30	(100)	1.71	(100)
l.s.d. (*P*<0.05)						
SD	0.57					
Variety	0.39					
SD × Variety	0.80					

* Yield expressed as a percentage of the mean yield in parentheses.
Figures in **bold** indicate highest yielding genotype(s) for each SD.

Effect of flowering date on yield

Generally, at Condobolin the OFP to maximise grain yields is mid–late September. However, in 2019, in the absence of severe frost, the highest yields came from earlier flowering in late August to early September (Figure 2); increased heat stress and terminal drought conditions caused a significant yield penalty when flowering was delayed.

The spread in flowering dates across SD1 spanned 32 days from 20 August to 5 October, illustrating the range in phenology responses among the genotypes evaluated. The flowering spread was condensed when sowing was delayed to 17 days (SD2) and 15 days (SD3) (Table 3).

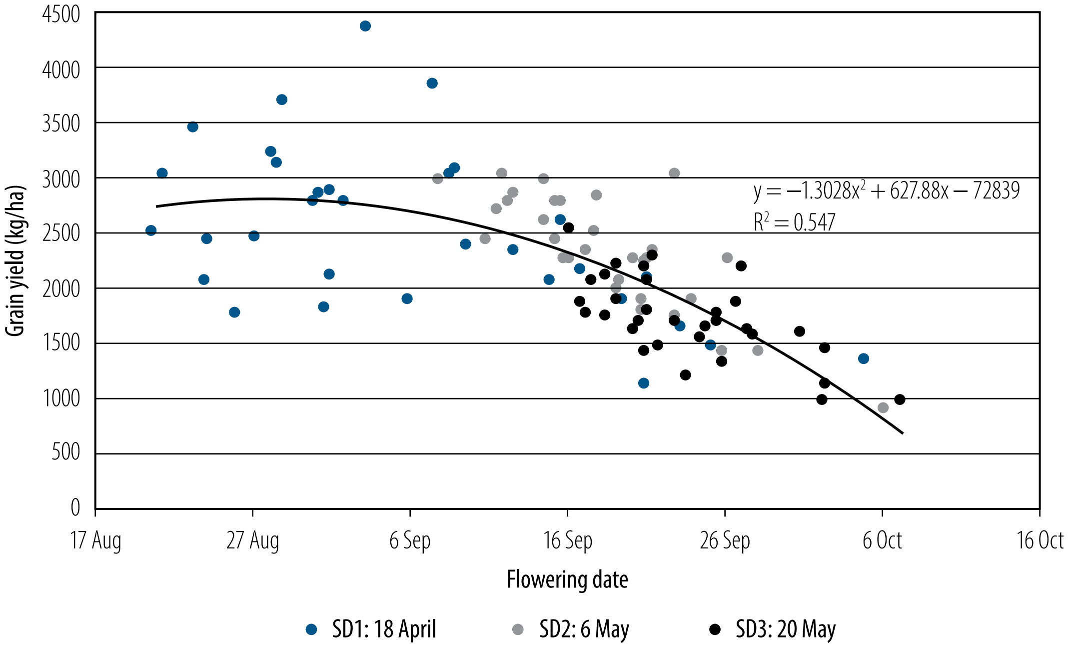

Figure 2 The relationship between grain yield and flowering date of 32 wheat varieties sown on three dates at Condobolin, 2019.

Early season frosts were lower compared with the long-term average. In previous years, early season frost has affected very fast varieties such as Condo$^{\Phi}$ and LongReach Dart$^{\Phi}$ inducing sterility and stem frost. Very slow and winter varieties were relatively low yielding compared with faster varieties for all sowing dates, with none yielding significantly above the mean for any sowing date (Table 2).

Grain quality

There were significant genotypic differences in grain protein, test weight and screenings ($P<0.05$), although there was no significant sowing date effect or interaction between the two (Table 3). LongReach Spitfire$^{\Phi}$ had the highest grain protein concentration at 15.5% (SD1).

Slower developing genotypes with later flowering including DS Pascal$^{\Phi}$, DS Bennett$^{\Phi}$, LongReach Kittyhawk$^{\Phi}$, EGA Wedgetail$^{\Phi}$, EGA Gregory$^{\Phi}$ and Sunlamb$^{\Phi}$ all had high screenings, probably from exposure to heat and moisture stress during the grain-filling period. Across all sowing dates, faster developing genotypes (which flowered earlier) had lower screenings, with Catapult$^{\Phi}$ and Vixen$^{\Phi}$ demonstrating consistently low screenings across all three sowing dates.

Table 3 Grain quality characteristics of 32 wheat varieties sown on three dates at Condobolin, 2019.

Variety	SD1: 18 Apr			SD2: 6 May			SD3: 20 May		
	Protein (%)	Test weight (kg/hL)	Screenings (% <2.2 mm)	Protein (%)	Test weight (kg/hL)	Screenings (% <2.2 mm)	Protein (%)	Test weight (kg/hL)	Screenings (% <2.2 mm)
Beckom	11.9	82.1	2.5	11.4	80.7	2.6	12.2	81.2	4.1
Catapult	10.6	83.2	1.9	11.4	81.1	2.6	11.7	82.5	3.0
Condo	12.2	82.5	3.1	11.1	81.1	3.2	12.5	80.5	4.2
Coolah	11.0	81.6	3.6	10.3	81.7	3.7	11.5	81.4	4.8
Corack	12.7	82.5	2.5	11.6	82.5	2.5	11.3	81.6	3.0
Cutlass	12.3	83.2	3.5	11.1	82.8	2.6	12.5	81.8	3.9
DS Bennett	12.7	81.4	7.5	12.6	79.4	7.5	12.9	53.7	5.3
DS Pascal	12.1	79.7	3.0	12.1	77.9	3.9	13.1	79.1	8.4
EGA Eaglehawk	12.6	81.2	4.1	11.8	81.7	5.1	12.5	82.6	4.6
EGA Gregory	11.4	82.1	3.1	11.2	80.5	4.0	12.5	81.0	7.6
EGA Wedgetail	14.1	76.7	5.0	11.7	78.8	3.2	13.8	52.7	5.6
H45	13.4	81.5	4.0	11.2	80.9	2.8	11.8	81.6	5.0
Hellfire	14.1	84.0	3.1	13.6	81.7	3.2	13.8	84.3	3.4
Janz	13.1	82.2	3.8	12.8	81.3	3.5	13.5	80.9	4.3
LongReach Dart	14.4	82.5	4.2	10.9	82.5	2.6	12.5	81.4	3.8
LongReach Kittyhawk	14.9	81.7	7.4	12.2	82.7	5.5	12.0	82.4	5.8
LongReach Lancer	12.1	82.3	2.5	12.7	81.9	2.9	13.2	82.7	3.7
LongReach Mustang	13.4	82.5	4.1	10.8	82.5	2.3	11.6	83.0	3.0
LongReach Reliant	11.0	83.1	3.2	11.9	80.6	3.7	11.7	80.9	4.6
LongReach Spitfire	15.5	83.3	4.3	13.2	83.7	3.0	14.1	83.5	4.7
LongReach Trojan	11.3	84.1	2.2	11.7	82.5	2.9	12.8	83.5	4.4
Longsword	14.8	79.6	4.2	13.3	80.4	4.3	13.2	82.4	3.7
Mace	12.5	82.1	3.3	11.7	81.2	2.9	12.2	80.9	3.7
Mitch	11.7	79.2	3.1	11.4	78.9	3.6	11.7	78.8	4.1
Scepter	10.9	82.8	2.3	10.9	82.1	2.5	12.0	82.2	3.2
Sunlamb	14.0	80.2	5.1	14.0	80.2	5.4	13.8	81.1	7.7
Sunmax	12.8	81.4	3.5	12.7	81.2	4.1	12.3	82.3	6.2
Sunprime	13.1	81.3	3.5	11.4	79.8	2.9	12.0	81.5	3.7
Suntop	11.7	83.0	2.8	11.8	80.8	3.3	12.6	82.5	5.3
Sunvale	13.1	81.9	3.8	11.7	82.3	3.6	13.3	83.2	4.6
TenFour	13.5	79.4	3.3	11.8	78.8	2.5	12.5	79.0	3.0
Vixen	12.3	81.5	2.0	11.2	80.0	2.0	11.5	79.5	2.4
l.s.d. (*P*<0.05)									
SD	0.9	6.1	1.3						
Variety	0.7	5.2	1.7						
Variety × SD	1.3	11.1	2.5						

Summary

In 2019, seasonal conditions significantly influenced phenology, grain yield and quality responses to sowing date at Condobolin. Grain yield is maximised when flowering occurs at a time when the likelihood of stress from frost, heat and moisture is minimised. Longer term trends and modelling have indicated the OFP, where these risks are minimised and yield is maximised, is mid to late September at Condobolin. Previous data has reported severe yield penalties in seasons with a high incidence of frost (e.g. Burch et al., 2018). While highest yields were achieved when flowering occurred in late August to early September in 2019, long-term data and on-farm risk should be considered when making sowing decisions.

Reference

Burch D, Moody N, Harris F and Brangwin B, 2018. Effect of sowing date on the phenology and grain yield of thirty-two wheat varieties – Condobolin 2017; D Slinger, T Moore and C Martin (eds), *Southern NSW research results 2018*, pp. 31–36, NSW Department of Primary Industries.

Acknowledgements

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Sowing date effect on twelve barley varieties – Condobolin 2019

David Burch and Nick Moody (NSW DPI, Condobolin); Dr Felicity Harris (NSW DPI, Wagga Wagga)

Key findings

- Seasonal conditions significantly affected phenology and yield responses to sowing date among barley varieties in 2019.
- Phenology significantly influenced yield and quality responses, whereby later flowering incurred severe yield and quality penalties, affecting overall profitability.

Introduction

In order to maximise grain yield in cereal crops, flowering date must be timed to minimise frost damage risk, while providing sufficient time for grain filling without heat or moisture stress. Currently there is a number of barley varieties available on the Australian market, with differing phenologies and morphologies giving growers the ability to manipulate both variety and sowing date to maximise yield in their growing environment. This paper reports the results from a field experiment conducted at Condobolin in 2019 that evaluated the influence of three sowing dates on phenology and grain yield of 12 barley varieties.

Site details

Location	Condobolin Agricultural Research and Advisory Station (Condobolin ARAS)
Soil type	Red chromosol
Previous crop	2018 fallow (wheat stubble), 2017 wheat, 2016 (field peas)
Rainfall	• Fallow (November–March): 164 mm • Fallow long-term average (LTA): 147 mm • In-crop (April–October): 74 mm • In-crop LTA: 209 mm • An additional 180 mm of water was applied before sowing and periodically during the season in order to simulate a decile 6 season (60 mm 2–4 April; 30 mm 27 May; 30 mm 25 June; 20 mm 5 August; 30 mm 16 September).
Stress events (April to October)	• There were 36 nights with minimum temperatures below 2 °C, (LTA = 45). Of these, 10 nights dropped below 0 °C, (LTA = 16). • There were 39 days with maximum temperatures between 25 °C and 30 °C, (LTA = 29) and 17 days with maximums over 30 °C, (LTA = 10).
Soil nitrogen at sowing	• 0–10 cm: 44.2 kg/ha • 10–60 cm: 69.0 kg/ha • 60–110 cm: 120.0 kg/ha
Starter fertiliser	70 kg/ha mono-ammonium phosphate (MAP)

Treatments

Variety

Varieties have been designated to phenology types: Fast (F), Medium (M), Slow (S) and Winter (W).

Banks$^{\Phi}$ (S), Biere$^{\Phi}$ (F), Cassiopee$^{\Phi}$ (W), Commander$^{\Phi}$ (M), Compass$^{\Phi}$ (F), Fathom$^{\Phi}$ (F), La Trobe$^{\Phi}$ (F), RGT Planet$^{\Phi}$ (F), Rosalind$^{\Phi}$ (F), Spartacus CL$^{\Phi}$ (F), Traveler$^{\Phi}$ (S), Urambie$^{\Phi}$ (W).

Sowing date (SD)

SD1: 18 April
SD2: 9 May
SD3: 1 June

Results

Varietal and sowing effects on phasic development

Time to maturity significantly decreased with later sowing dates (Figure 1), however, vegetative phase length significantly increased between SD1 and SD3 as development rates decreased with lower temperatures. Stem elongation, anthesis and grain fill duration decreased with later sowing dates as thermal time accrued faster in later sowings.

A critical growth stage is the onset of anthesis and grain fill, which can be affected by frost induced sterility, or heat stress that limits grain fill.

Early sown fast varieties La Trobe$^{\Phi}$ and RGT Planet$^{\Phi}$ reached GS49 on 3 August and 8 August, with main season sowings reaching GS49 at the end of the month. There was an average of seven frosts below 2 °C in the final two weeks of August making early sown and flowering varieties at risk of frost effects during anthesis. Varieties flowering at the beginning of September would expose a crop to an average of 3.5 frosts. While frost risk is decreased for later flowering varieties, heat events increase later in the season. La Trobe$^{\Phi}$ and RGT Planet$^{\Phi}$ were not exposed to heat events >30 °C during grain fill from SD1 and SD2, however, there were two heat events in SD3, potentially disrupting grain fill. Grain fill duration decreased by over 50% from SD1 to SD3 in all varieties except Urambie$^{\Phi}$ as daily thermal time increased.

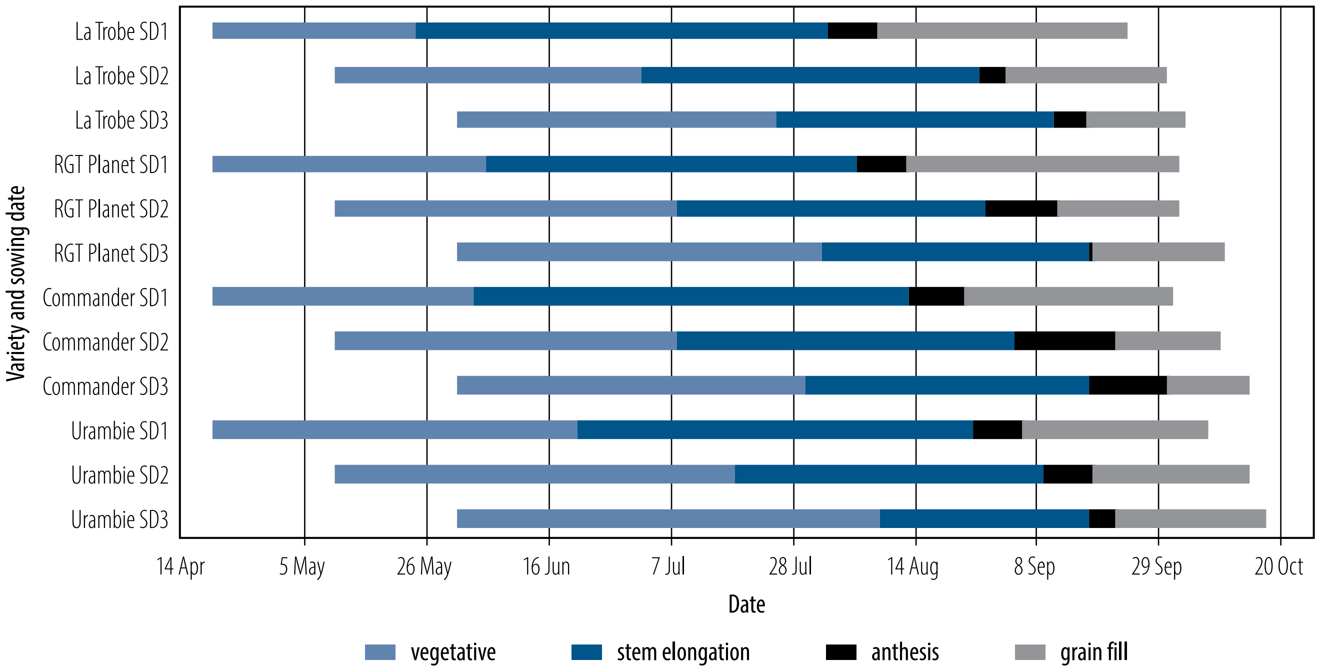


Figure 1 Phasic development of four representative barley varieties sown on 18 April (SD1), 9 May (SD2) and 1 June (SD3) at Condobolin, 2019.

Flowering date effect on yield

The yield declined in all varieties when flowering started after the beginning of September, showing the importance of the relationship between flowering and yield (Figure 2). The central west of NSW often has short growing seasons due to heat and moisture stress at grain fill. These stresses often interrupt the grain filling period of later flowering varieties, reducing grain size and yield. In a year characterised by low frost incidence, fast maturing varieties, when sown in April, perform as well as slower maturing varieties due to the absence of frost damage. However, it is reasonable to expect fast varieties such as Spartacus CL$^{\phi}$ would more likely be affected if a more typical frost pattern occurred.

While all varieties had a yield penalty with delayed sowing, there were differences among varieties in their responses to sowing date. Fast spring type Spartacus CL$^{\phi}$ reported the most consistent yields across the three sowing dates. In comparison, despite similar yields from SD1, RGT Planet$^{\phi}$ and Commander$^{\phi}$ had significantly lower yields from SD2 and SD3 compared with Spartacus CL$^{\phi}$ (Table 1), probably due to slower development rates and increased exposure to heat stresses during grain filling. In contrast, the slow winter type Cassiopee$^{\phi}$ flowered consistently later than all other genotypes and had lower grain yields from all sowing dates (figures 2 and 3).

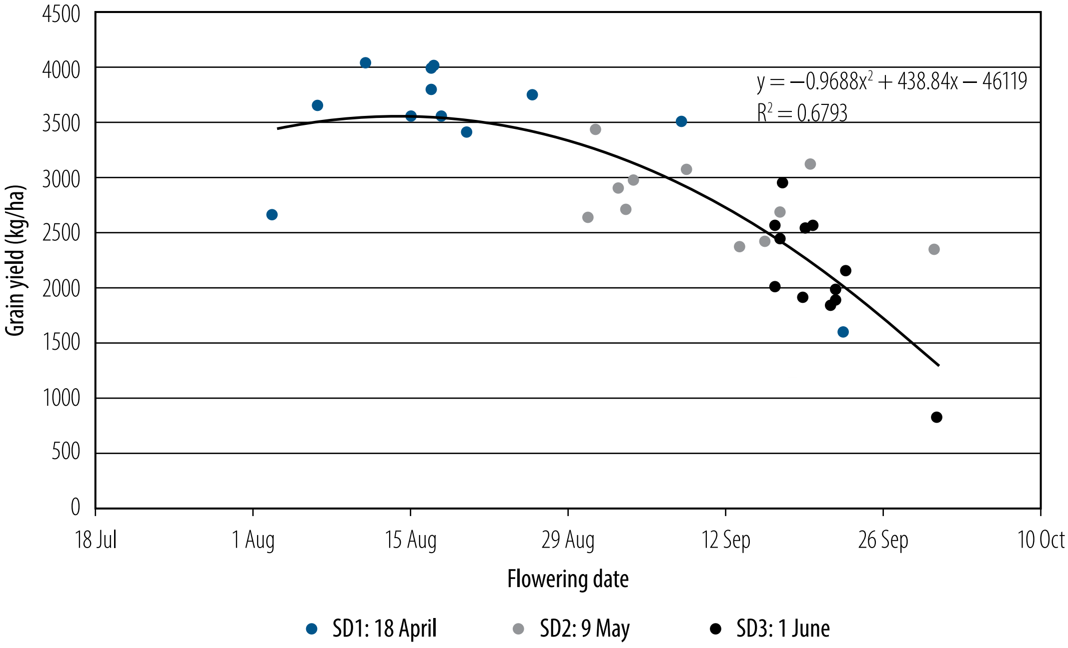


Figure 2 Relationship between grain yield and flowering date for 12 barley varieties sown on three sowing dates at Condobolin, 2019.

Grain yield

Significant differences were recorded between sowing dates ($P = 0.026$) and genotypes ($P<0.001$). In 2019, despite favourable moisture conditions, fewer frosts in conjunction with severe heat stress events influenced results in early October, coinciding with flowering and early grain filling phases in slower developing varieties or when sowing was delayed (Figure 2). The highest yields were achieved by mid–fast developing spring barley types in SD1, with all varieties incurring a significant yield penalty in SD2 and SD3 with the exception of Rosalind$^{\phi}$ (Table 1). There was no significant difference among the highest yielding treatments from SD1: La Trobe$^{\phi}$, RGT Planet$^{\phi}$, Compass$^{\phi}$, Commander$^{\phi}$ and Rosalind$^{\phi}$ (Table 1).

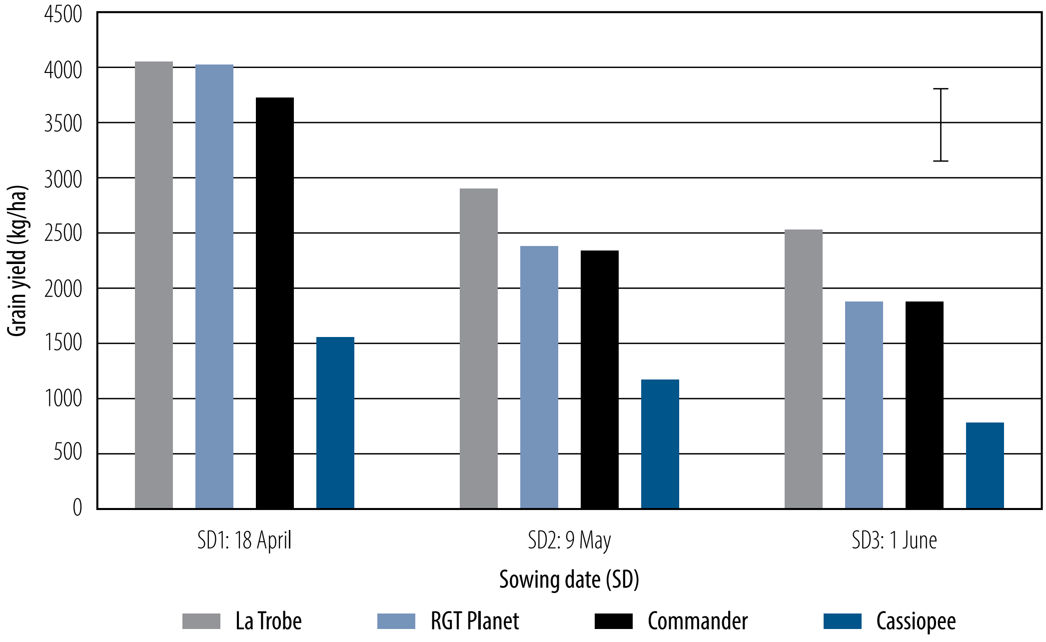
Grain quality

Barley grain quality is an important factor in determining market value, with the highest quality grain attracting a malt premium. There were significant sowing date, varietal and interaction effects for screenings, retention and grain weight. While there were significant varietal differences in protein concentration, there was no sowing date effect. The reduction in retention and subsequent increase in screenings could be attributed to increased exposure to heat and moisture stress later in the season, resulting in smaller grain.

Table 1 Grain yield (t/ha) of wheat phenotypes across sowing dates.

Genotype	Grain yield (t/ha)*					
	SD1: 18 April		SD2: 9 May		SD3: 1 June	
Banks	3.54	(102)	3.13	(118)	2.14	(101)
Biere	2.64	(76)	2.65	(100)	2.00	(94)
Cassiopee	1.59	(46)	1.17	(44)	0.79	(37)
Commander	3.73	(108)	2.35	(89)	1.86	(88)
Compass	4.00	(116)	2.99	(113)	2.56	(120)
Fathom	3.80	(110)	3.07	(116)	2.54	(120)
La Trobe	4.05	(117)	2.90	(110)	2.54	(120)
RGT Planet	4.02	(116)	2.38	(90)	1.90	(89)
Rosalind	3.54	(102)	2.71	(102)	2.90	(138)
Spartacus CL	3.64	(105)	3.44	(130)	2.42	(114)
Traveler	3.41	(99)	2.69	(102)	1.83	(86)
Urambie	3.49	(101)	2.41	(91)	1.96	(93)
Mean	3.45	(100)	2.66	(100)	2.12	(100)
l.s.d. (*P*<0.05)						
SD	0.82					
Variety	0.45					
SD × Variety	1.01					

* Yield expressed as a percentage of mean in parentheses.



Vertical bar indicates least significant difference (*P*<0.05).

Figure 3 Grain yield for four representative barley varieties sown on three dates at Condobolin, 2019: Spartacus CL[⊕] (Fast), RGT Planet[⊕] (Fast), Commander[⊕] (Medium), and Cassiopee[⊕] (Winter).

Table 2 Protein, screenings, retention, 1000 grain weight and test weight of 12 barley varieties sown on three dates at Condobolin, 2019.

Variety	Protein (%)			Screenings (% <2.2 mm)			Retention (% >2.5 mm)			1000 grain weight (g)			Test weight (kg/hL)		
	SD1	SD2	SD3	SD1	SD2	SD3	SD1	SD2	SD3	SD1	SD2	SD3	SD1	SD2	SD3
Banks	12.5	13.0	14.0	1.7	8.5	3.9	80.5	39.0	64.7	39.4	34.2	35.0	80.5	84.0	79.1
Biere	13.0	12.0	13.5	6.4	6.1	3.0	65.1	47.5	60.2	37.2	36.6	37.0	81.0	82.3	83.9
Cassiopee	15.7	15.7	13.9	35.9	52.3	40.4	22.3	14.1	18.9	28.6	26.8	28.8	71.2	71.3	69.9
Commander	11.5	12.3	13.7	2.0	4.1	5.7	88.4	72.3	68.9	40.7	35.6	33.6	83.6	80.7	76.1
Compass	11.9	11.5	13.3	2.1	2.6	2.2	87.9	83.1	82.0	42.2	38.7	36.6	82.1	79.9	78.2
Fathom	12.4	12.4	13.3	1.7	1.8	2.1	89.2	80.9	78.1	45.7	42.7	41.7	81.5	81.8	79.1
La Trobe	12.9	13.2	13.2	3.7	4.8	3.2	73.4	52.7	64.1	35.6	34.3	35.9	76.5	85.2	83.3
RGT Planet	11.6	12.9	13.1	2.8	5.7	7.4	83.9	60.7	60.3	42.1	36.5	34.9	82.8	81.0	77.1
Rosalind	12.5	12.2	12.4	3.5	4.5	2.8	73.1	59.7	65.5	36.8	34.2	36.2	84.1	75.7	82.3
Spartacus CL	12.8	12.4	14.2	2.5	4.3	1.9	83.1	65.7	71.3	36.3	34.8	36.0	81.3	84.2	84.4
Traveler	12.3	12.9	13.6	5.0	3.3	4.6	84.9	72.2	74.4	41.4	37.9	34.7	80.3	80.2	74.4
Urambie	13.0	12.2	13.6	9.2	24.5	27.6	32.3	14.2	22.1	37.9	35.0	34.1	81.4	76.4	75.0
Mean	12.7	12.7	13.5	6.4	10.2	8.7	72.0	72.0	55.2	38.6	35.6	35.4	80.5	80.2	78.6
l.s.d. (*P*<0.05)															
SD		1.0			3.4			5.6			1.9			2.6	
Variety		0.6			2.3			5.4			1.0			3.6	
SD × Variety		1.3			5.1			11.1			2.2			6.3	

While there was no significant sowing date effect on grain protein concentration, there was a negative linear relationship between thousand grain weight and grain protein. Heat and moisture stress can cause small grain size, which is evident in the reduced retention from SD1 to SD3. La Trobe$^{\phi}$, Spartacus CL$^{\phi}$ and RGT Planet$^{\phi}$ all had increased screenings as sowing was delayed, resulting in overall quality downgrades (e.g. RGT Planet$^{\phi}$ from Malt 1 (SD1) to Malt 2 (SD2, SD3)). In contrast, both Compass$^{\phi}$ and Commander$^{\phi}$, which have characteristically larger grains, were able to maintain grain size across sowing dates (Table 2). Slow developing winter types Cassiopee$^{\phi}$ and Urambie$^{\phi}$ had very high screenings across all sowing dates, indicating that grain filling coincided with later heat stress conditions in the season.

Yield components

Grain yield is derived from the combination of grain size, number of grains per head and the number of heads per square metre. There were significant varietal and sowing date differences for all three yield components, as well as total number of grains per square metre. Figures 4, 5, 6 and 7 illustrate how different varieties respond to these various components to achieve yield and how they respond to different sowing dates. For example, for SD1, Fathom$^{\phi}$ produced the highest number of grains per head and thousand grain weight from the lowest number of heads per square metre. In contrast, La Trobe$^{\phi}$ had fewer grains per head and a lower grain weight, but produced the highest number of grains per square metre due to more tillers. This is reflected somewhat in Fathom$^{\phi}$ maintaining high retention rates (percentage of grain by weight retained above a 2.5 mm screen) at SD2 and SD3, while retention rates for La Trobe$^{\phi}$ decreased from malt to Bar 1 (feed) standard.

Yield components differed significantly across sowing dates and varieties. For example, there was no significant difference in yield between RGT Planet$^{\phi}$ and La Trobe$^{\phi}$ from SD1, with tiller numbers driving yield for La Trobe$^{\phi}$, and grains per tiller and grain weight for RGT Planet$^{\phi}$. La Trobe$^{\phi}$ out-yielded RGT Planet$^{\phi}$ in SD2 and SD3, while both varieties had decreased heads per square metre, La Trobe$^{\phi}$

could compensate for this somewhat by increasing grains per head and grain weight. While La Trobe^(^ had no significant decrease in grain weight, RGT Planet^(^ had a 17.2% decrease in grain weight between SD1 and SD3.

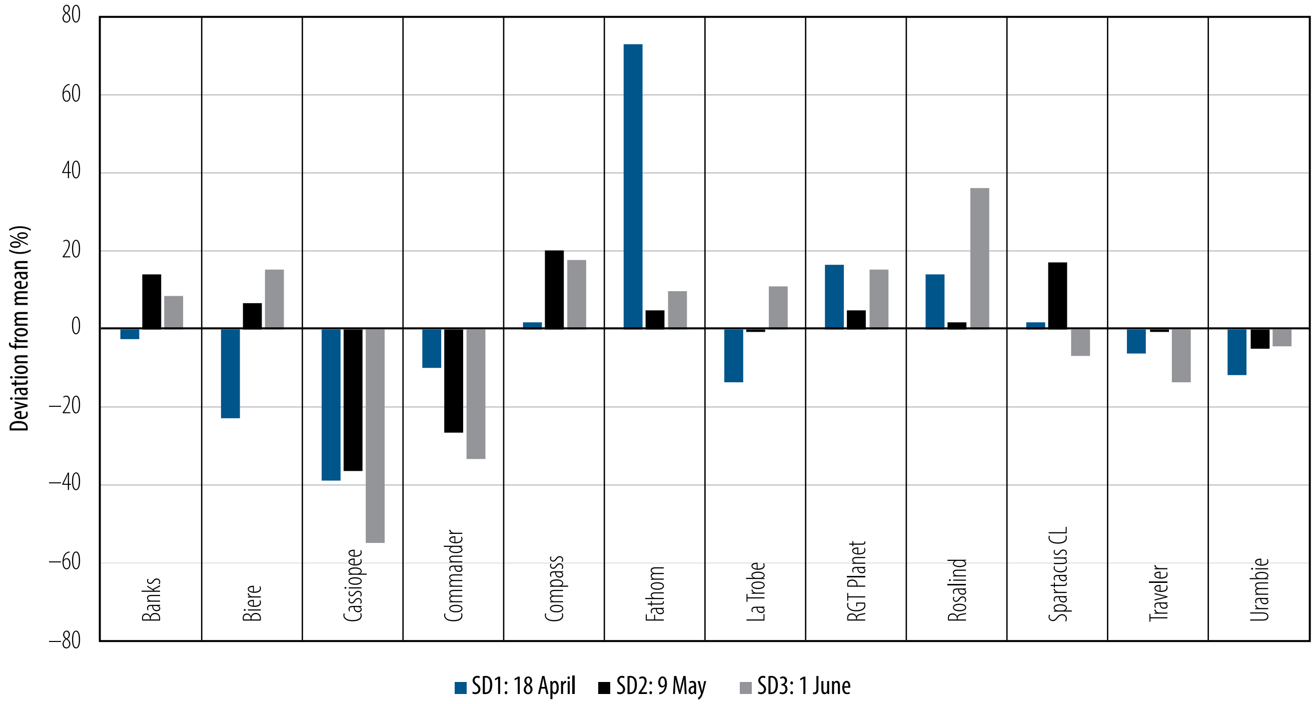


Figure 4 Grain number per head expressed as deviation from mean (%) of 12 barley varieties sown on three different dates at Condobolin, 2019.

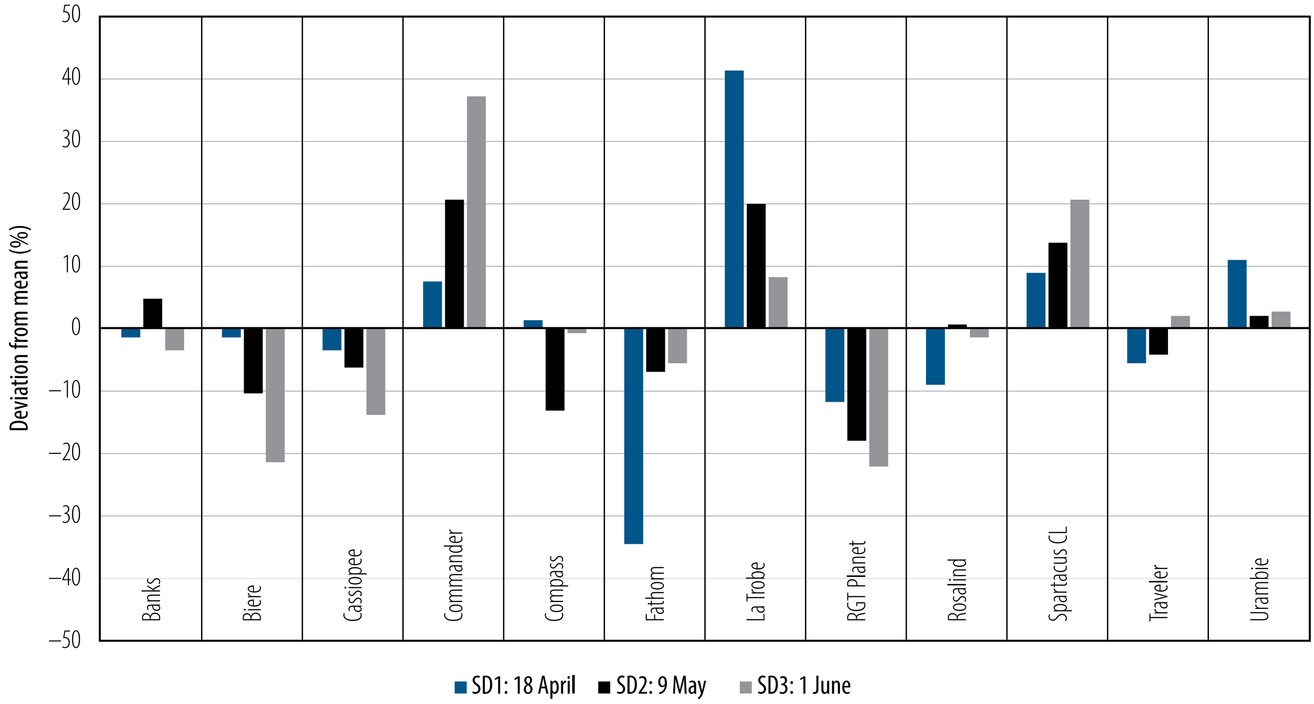


Figure 5 Head number (heads/m^2) expressed as deviation from mean (%) of 12 barley varieties sown on three different dates at Condobolin, 2019.

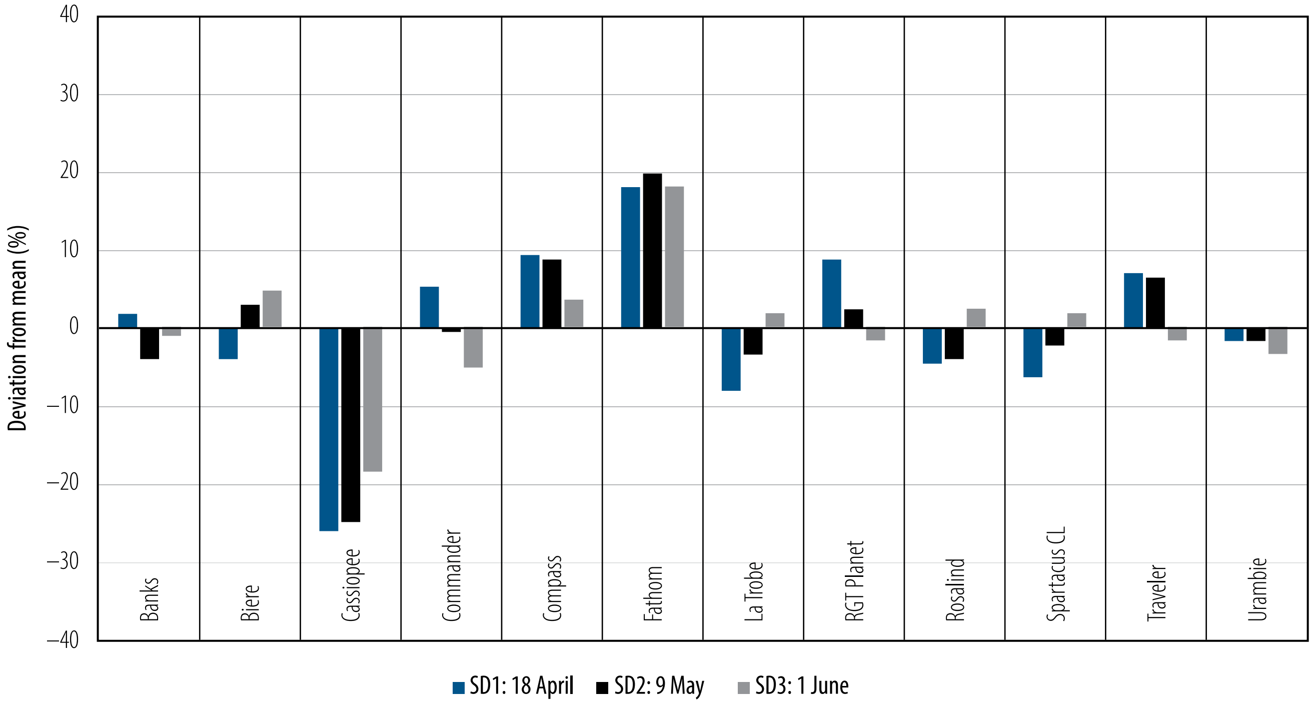


Figure 6 1000 grain weight (g) expressed as deviation from mean (%) of 12 barley varieties sown on three different dates at Condobolin, 2019.

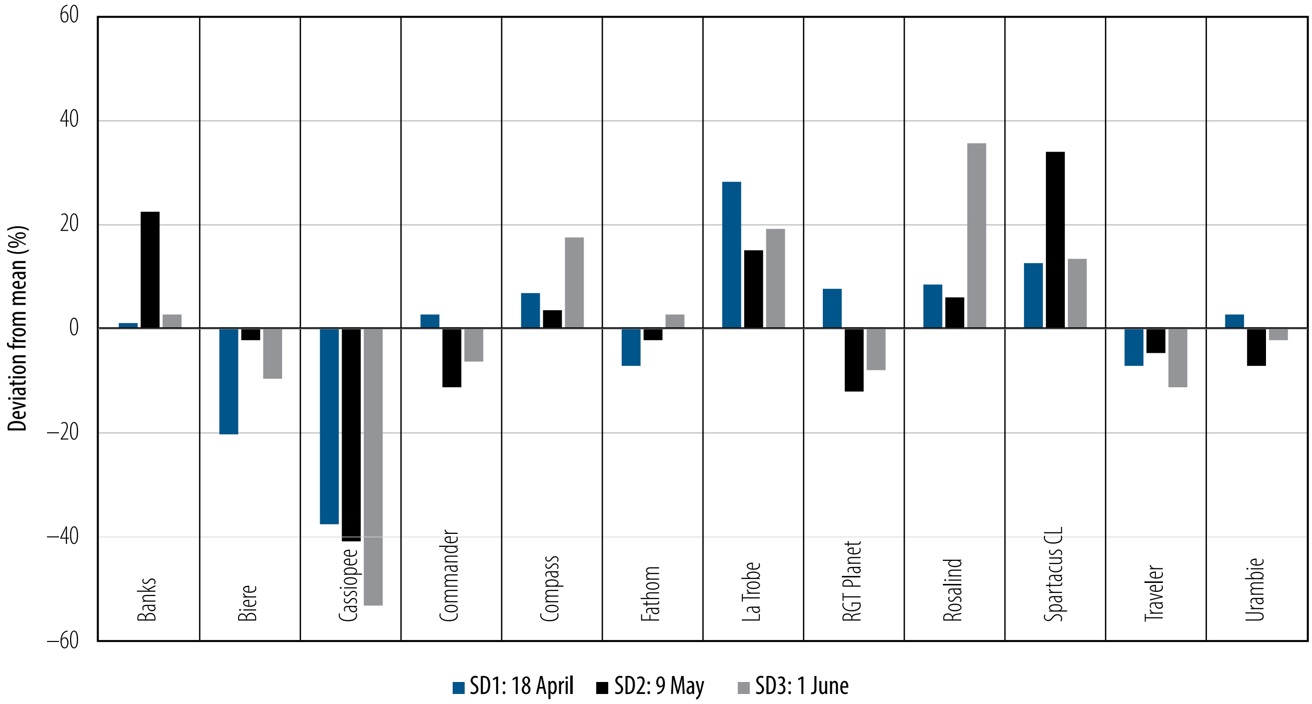


Figure 7 Grain number (grains/m^2) expressed as deviation from mean (%) of 12 barley varieties sown on three different dates at Condobolin, 2019.

Summary

In order to optimise grain yield, a variety must be selected as appropriate for the environment and sown in order to flower at a time that minimises the risk of frost damage at flowering, and heat and moisture stress during grain fill. The growing season in the central west of NSW is one that often has frost, heat and moisture stress in close proximity, with a short optimal flowering window to maximise grain yield. Conditions in 2019 favoured early flowering, whereby fast developing varieties, sown early were able to achieve the highest yields in the absence of significant frost stress and able to maximise grain filling time. This was illustrated by a general yield decline when varieties flowered after the beginning of September. Slower developing spring or winter types were not able to achieve comparable yields to faster spring types under 2019 conditions. However, previous data has shown yield penalties in seasons with high frost incidence (Burch et al., 2018), so long-term data and on-farm risk should be considered with determining variety and sowing decisions.

Reference

Burch D, Moody N and Brangwin B, 2018. Effect of sowing date on the phenology and grain yield of sixteen barley varieties – Condobolin 2017; D Slinger, T Moore and C Martin (eds), *Southern NSW research results 2018*, pp. 21–30, NSW Department of Primary Industries.

Acknowledgements

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

Thanks to the technical assistance of Condobolin ARAS NSW DPI staff, Daryl Reardon, Braden Donnelly and Karen Brangwin.

The effect of stored water and sowing date on flowering and grain yield of hybrid and open-pollinated canola in the low rainfall zone of central west NSW

Ewan Leighton and Daryl Reardon (NSW DPI, Condobolin)

Key findings

- Sowing canola early (6 April) on 200 mm applied water reduced the time to the start of flowering by up to two weeks, compared with a later sowing (7 May).
- Significant yield increases were recorded across all varieties (for both sowing dates) where 200 mm water was applied pre-sowing, compared with 70 mm and 0 mm.
- The highest yield resulted from sowing a mid season hybrid (Pioneer® 45Y91 (CL)) early on 200 mm applied water.
- Sowing canola early on 200 mm applied water yielded around 900 kg/ha more than sowing later with the same amount of applied water, averaged across all varieties.

Introduction

Matching variety phenology and sowing times to optimise yield is an important factor in ensuring profitable outcomes. However, in the New South Wales central west, variable seasonal conditions often make canola an opportunistic crop. This experiment was designed to determine the response of six canola varieties with diverse phenology and breeding (hybrid or open-pollinated (OP)) to varying stored soil water levels across two sowing dates.

Site details

Location	Condobolin Agricultural Research and Advisory Station (Condobolin ARAS)
Soil type	Brown chromosol, pH_{Ca} 4.5 (0–10 cm)
Previous crops	Wheat 2015, field peas 2016, wheat 2017, fallow 2018
Fertiliser	• 100 kg/ha mono-ammonium phosphate (MAP) at sowing + Jubilee (flutriafol 500 g/L) at 580 mL/100 kg MAP (fungicide on fertiliser). • 150 kg/ha urea broadcast pre-sowing.
Soil nitrogen (N)	138.6 kg/ha (0–120 cm) soil test conducted in April 2019
Rainfall	• Fallow (1 November 2018–31 March 2019): 169.6 mm • Growing season (1 April 2019–30 September 2019): 65.4 mm
Harvest date	Harvested by hand as varieties reached maturity

Treatments

Variety	Pioneer® 45Y91 (CL)	Mid–slow spring, hybrid Clearfield® (CLF)
	SF Ignite TT	Mid–slow spring, hybrid triazine tolerant (TT)
	ATR Wahoo$^{\Phi}$	Slow spring, open-pollinated (OP) TT
	Nuseed Diamond	Fast spring, hybrid conventional herbicide
	ATR Stingray$^{\Phi}$	Fast spring, OP TT
	Hyola® 350TT	Fast spring, hybrid TT

Sowing date (SD)	SD1: 6 April SD2: 7 May
Water applied	• 0 mm (no water applied) • 70 mm (water applied by dripper pipe pre-sowing) • 200 mm (water applied by dripper pipe pre-sowing)

Results

Seasonal conditions

For the second consecutive year, growing season and pre-season fallow rainfall were both below average for the region. The total growing season rainfall of 65.4 mm (1 April 2019 to 30 September 2019) was the lowest ever recorded for the region and followed the seventh driest year on record in 2018. The long-term average (LTA) growing season rainfall is 227.5 mm. Rainfall was below the LTA for all growing season months.

Monthly minimum temperatures were consistently above average, with temperatures only dropping below the LTA for a short period in late May. There were 12 days below 0 °C, with one major frost during the growing season, –3.7 °C (20 June).

Watering

Two water treatments (high and low) and one nil treatment were established across the site to simulate three levels of stored water from fallow rainfall. All plots received 12.5 mm water by dripper pipe post-sowing to assist germination and emergence. The nil treatment received no further water. Both the low and high water treatments received 70 mm of water on 23 March, 14 days before the first sowing date. The high water treatment received an additional 130 mm of water on 28 March, for a total of 200 mm applied water. Soil water was recorded for each water treatment at five depths to 110 cm.

Figure 1 shows increased soil water content for the 70 mm and 200 mm treatments moving down the profile to around 60 cm depth. Below 60 cm there was a sharp decrease in water content for the 70 mm treatment, while the 200 mm treatment maintained a higher water content to 110 cm.

Start and duration of flowering

From SD1, all varieties had delays to the start of flowering when sown into 0 mm compared with 70 mm and 200 mm applied water, but there was minimal delay between 70 mm and 200 mm (Figure 2). Start of flowering was delayed by 17 days for Pioneer® 45Y91 (CL) sown into 0 mm compared with 200 mm. This delay was shortened to three days between the 70 mm and 200 mm treatments. For both SF Ignite TT and ATR Wahoo$^{\phi}$ start of flowering was reduced by 13 days in the 0 mm treatment compared with the 200 mm treatment.

Mid–slow hybrid varieties Pioneer® 45Y91 (CL) and SF Ignite TT flowered for seven days less when sown into 0 mm applied water compared with both the 70 mm and 200 mm treatments, while the slow developing OP variety ATR Wahoo$^{\phi}$ flowered for 10 days less under the same conditions. There was no significant difference in flowering duration between the 70 mm and 200 mm treatments across all varieties.

Pioneer® 45Y91 (CL) sown into 200 mm and 70 mm applied water started flowering between three and nine days earlier than SF Ignite TT and ATR Wahoo$^{\phi}$. SF Ignite TT started flowering up to six days earlier than ATR Wahoo$^{\phi}$ when sown into 200 mm applied water, reducing to one day when sown into 70 mm applied water.

Plants sown into 0 mm applied water were exposed to moisture and heat stress and were not able to compensate in a shortened flowering period – regular flower abortion was observed. Plants with adequate soil water reserves were able to produce and maintain flowers for longer.

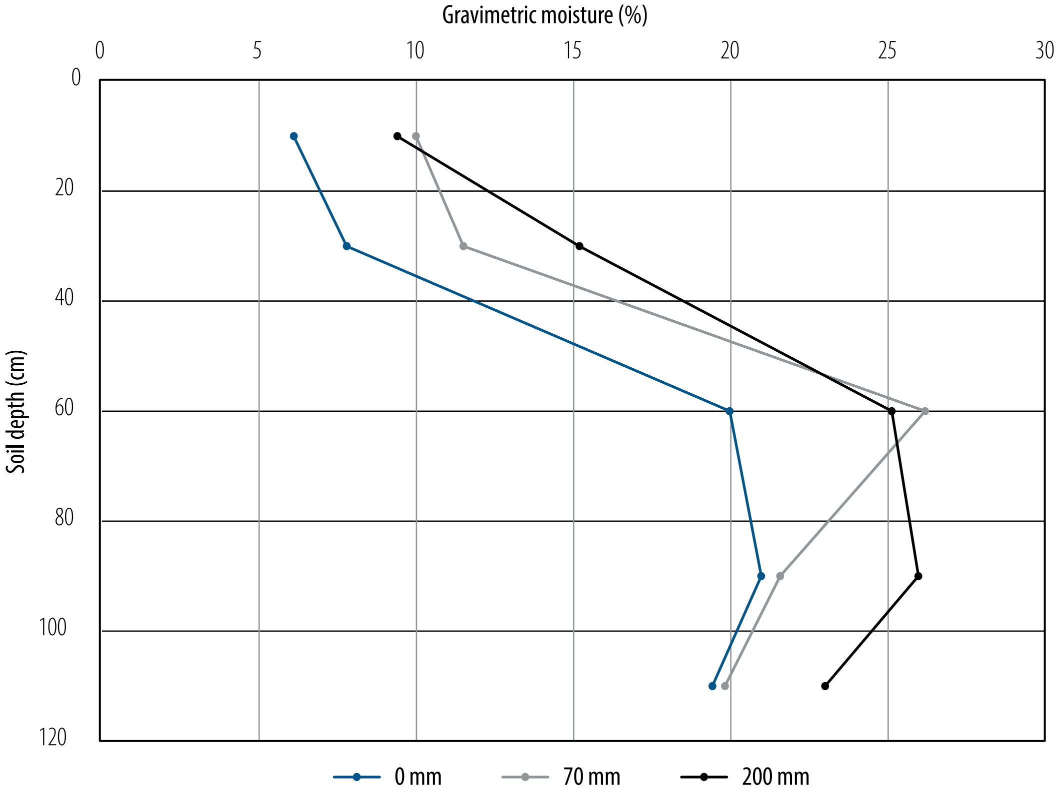


Figure 1 Site average gravimetric soil water content at five depths (10, 30, 60, 90 and 110 cm) for 0 mm, 70 mm and 200 mm applied water treatments, recorded pre-sowing at Condobolin, 2019.

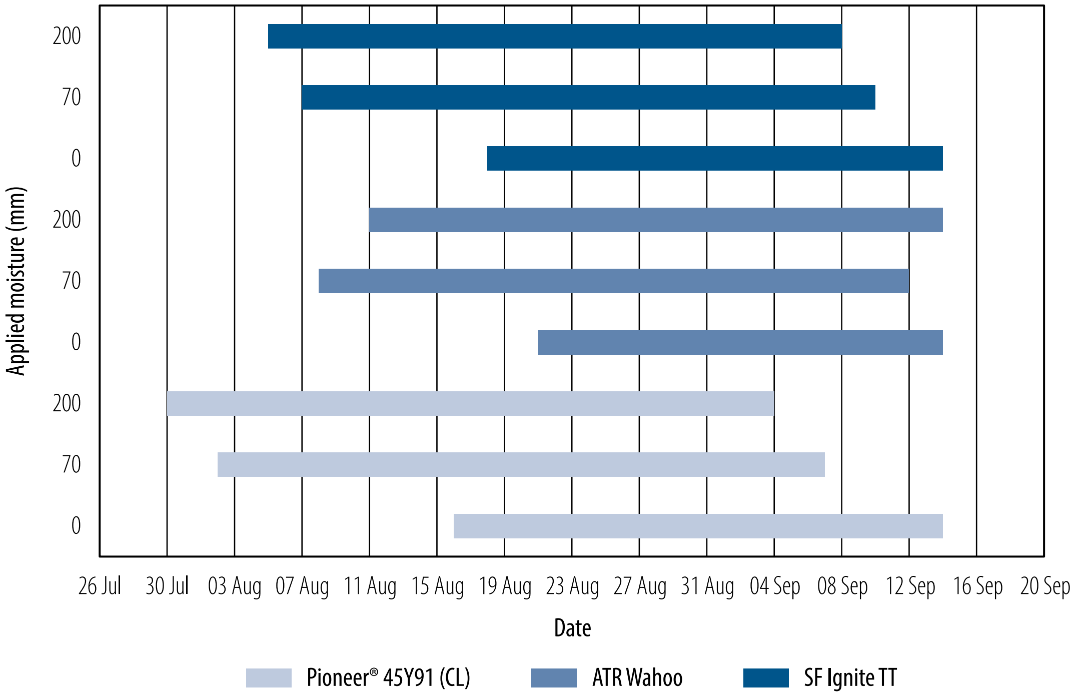


Figure 2 Start (50% of plants with at least one open flower) and duration of flowering for three mid–late developing canola varieties sown on 6 April at Condobolin 2019, under 0 mm, 70 mm and 200 mm applied water before sowing.

Within SD2, the hybrid varieties Nuseed Diamond and Hyola® 350TT started flowering 11 days earlier on average than the OP variety ATR Stingray$^{\Phi}$ when sown into 200 mm compared with the 0 mm stored soil water, and seven days earlier when sown into 70 mm stored soil water.

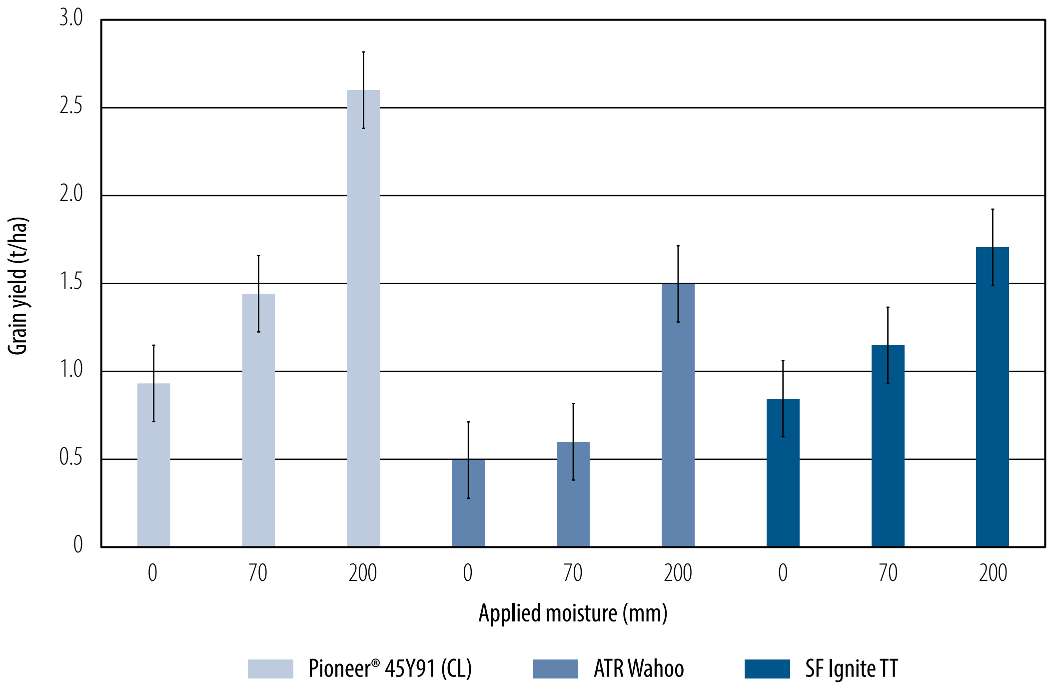
There was no significant difference in flowering start date or duration for Nuseed Diamond and Hyola® 350TT across any applied water treatment, including 0 mm applied water. ATR Stingray$^{\phi}$ flowered five days later and for three days less duration when sown into 0 mm applied water compared with 200 mm.

Grain yield

For SD1, Pioneer® 45Y91 (CL) yielded significantly higher than ATR Wahoo$^{\phi}$ across all water treatments and significantly higher than SF Ignite TT when sown on 200 mm applied water (Figure 3). Pioneer® 45Y91 (CL) was also the only variety to show significant yield increases as applied water increased.

Yields of both ATR Wahoo$^{\phi}$ and SF Ignite TT were not significantly better in the 70 mm treatment compared with the 0 mm treatment. However, applying 200 mm water pre-sowing increased yield up to 900 kg/ha in ATR Wahoo$^{\phi}$ and 560 kg/ha in SF Ignite TT compared with the 0 mm treatment.

The varieties sown on SD1 were able to use the increased moisture at depth in the 200 mm treatment. The prolonged growth period of the early sown varieties allowed plant roots to extract water to a greater depth, especially in the 200 mm treatment.



l.s.d. ($P = 0.03$) = 0.69 t/ha.

Figure 3 Grain yield of three mid–late developing canola varieties at 0 mm, 70 mm and 200 mm applied water treatment, sown 6 April at Condobolin, 2019.

All varieties sown on SD2 responded to the increased soil water from 0 mm to 70 mm applied water, but did not fully use the higher 200 mm treatment (Figure 4).

Nuseed Diamond yielded up to 810 kg/ha higher – a 224% increase – when sown into 70 mm and 200 mm applied water, compared with the 0 mm treatment.

ATR Stingray$^{\phi}$ yielded up to 510 kg/ha higher – a 230% increase – in the 70 mm and 200 mm applied water treatments compared with 0 mm.

There was no significant difference in yield for the hybrid variety Hyola® 350TT across any soil water treatment, however, yields were not significantly lower than the OP variety ATR Stingray$^{\phi}$ at the 70 mm and 200 mm treatments.

Varieties sown into the 0 mm treatment were exposed to significant moisture stress during flowering, which led to aborted flowers and pods, and an inability to recover due to the terminal drought conditions.

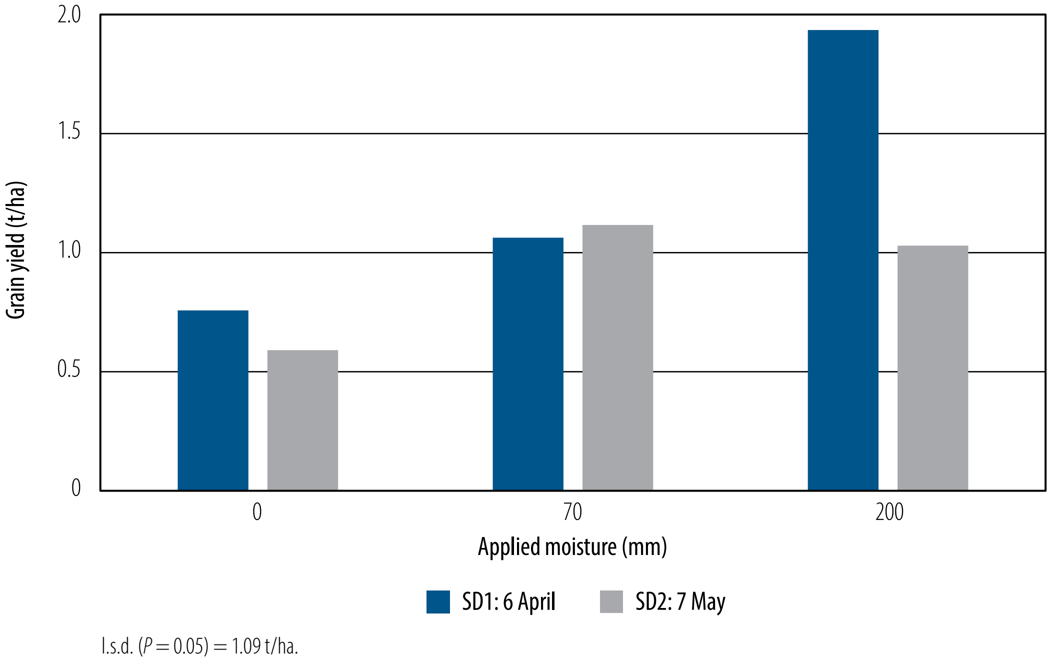


Figure 4 Grain yield of six canola varieties averaged across two sowing dates (6 April and 7 May) at 0 mm, 70 mm and 200 mm applied water before sowing at Condobolin, 2019.

Conclusion

Sowing slower developing varieties early allowed plants to use more soil moisture deeper in the soil profile leading to an earlier and prolonged flowering duration as plants were able to continue to develop flowers and set pods.

Where the profile was dry (0 mm applied water) an early sowing date resulted in delayed flowering and a shorter flowering period, where plants failed to compensate for drought-related flower losses.

Yields were highest with increased soil water levels and varieties were sown early. Faster developing varieties sown at a later date did not have sufficient time to use soil water within the profile. This meant plants were stressed during their reproductive growth stage regardless of starting soil water, probably because plants with a shallow root system were unable to extract the deeper water. Start and duration of flowering were not affected by soil water, and grain yields were significantly reduced for the later sowing date.

The outcomes from this experiment reinforce the importance of implementing effective agronomic practices to achieve viable yields in low rainfall canola production areas. These practices are outlined in the GRDC publication 20 tips for profitable canola – central & southern NSW (Brill, 2019). Ensuring adequate stored soil water through strict fallow weed control, and matching variety phenology with sowing date, will allow plants to use resources and minimise environmental stresses during critical growth periods. Sowing slower developing varieties early allowed plants more time to establish the root biomass needed to fully access soil moisture. This led to increased yield potential and the ability to recover from the effects of environmental stresses such as heat, drought and frost, during the sensitive flowering and podding growth stages.

Reference

Brill R (ed.), 2019. *20 tips for profitable canola – central & southern NSW*. Grains Research and Development Corporation. Available at https://grdc.com.au/20-tips-for-profitable-canola-central-and-southern-nsw. Downloaded 2 June 2020.

Acknowledgements

This experiment was a joint investment between GRDC and NSW DPI as part of the collaborative project 'Optimised canola profitability', CSP00187; 2014–19, a partnership also including the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the South Australian Research and Development Institute (SARDI).

Thanks to the operational staff at Condobolin ARAS for assistance throughout this experiment.

Phenology of commercial and new release canola varieties

Danielle Malcolm (NSW DPI, Wagga Wagga), Rohan Brill (formerly NSW DPI, Wagga Wagga) and Warren Bartlett (NSW DPI, Wagga Wagga); Don McCaffery (NSW DPI, Orange)

Key findings

- Canola varieties varied markedly in the time it took from sowing to the start of flowering.
- Eighteen of 31 varieties started flowering before the optimum start of flowering date for the Wagga Wagga region when sown early on 28 March 2019.
- Thirteen varieties started flowering after the optimum start of flowering date when sown on 26 April 2019.

Introduction

An important management strategy to maximise yield potential for canola is to sow varieties within the correct sowing window that will allow the variety to flower 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 potential.

The optimum start of flowering (determined to be when 50% of the plants have one open flower) differs for each location; for Wagga Wagga it is between 31 July and 23 August, the optimum being around 14 August. To start flowering within this window, a variety's phenology needs to be established so growers can sow varieties in the correct window to achieve flowering during this optimum time.

This experiment examined the phenology of 31 commercial varieties and newly released lines sown on two sowing dates at Wagga Wagga, NSW in 2019.

Site details

Location	Wagga Wagga Agricultural Institute
Soil type	Red dermosol
Previous crop	Wheat
Rainfall	• Fallow (November 2018–March 2019): 259 mm • In-crop (April 2019–October 2019): 126 mm • In-crop long-term average: 330 mm
Soil nitrogen (N)	159 kg N/ha (0–180 cm, 27 March)

Treatments

Variety	Table 1 lists the details of the varieties examined in this experiment.
Sowing date (SD)	SD1: 28 March SD2: 26 April

Table 1 Details of the varieties examined in the experiment at Wagga Wagga in 2019.

Variety	Phenology	Maturity	Herbicide tolerance*	Plant type
Archer	Slow	Late	CLF	Hybrid
ATR Bonito$^{\phi}$	Mid–fast	Early	TT	Open pollinated (OP)
ATR Stingray$^{\phi}$	Fast	Early	TT	OP
ATR Wahoo$^{\phi}$	Mid–slow	Mid	TT	OP
DG670TT	Mid	Mid	RR	Hybrid
GT-53	Mid	Mid	RR	Hybrid
Hyola 350TT	Fast	Early	TT	Hybrid
Hyola 410XX	Mid–fast	Early–mid	Truflex® RR	Hybrid
Hyola 530XT	Mid–fast	Mid	Truflex® RR/TT	Hybrid
Hyola 550TT	Mid–fast	Mid	TT	Hybrid
Hyola 580CT	Fast	Mid	CLF/TT	Hybrid
HyTTec Trident	Mid–fast	Early	TT	Hybrid
HyTTec Trophy	Mid	Mid	TT	Hybrid
InVigor R 4022P	Mid–fast	Early–mid	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
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® 45T03 (TT)	Mid–fast	Mid	TT	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 Raptor	Mid–fast	Early–mid	Truflex® RR	Hybrid

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

Results

Seasonal conditions

There was below average rainfall throughout 2019 at Wagga Wagga, with 126 mm falling in the growing season, well below the 330 mm average. Due to the dry conditions towards the end of the season and bird damage, yield data will not be presented here.

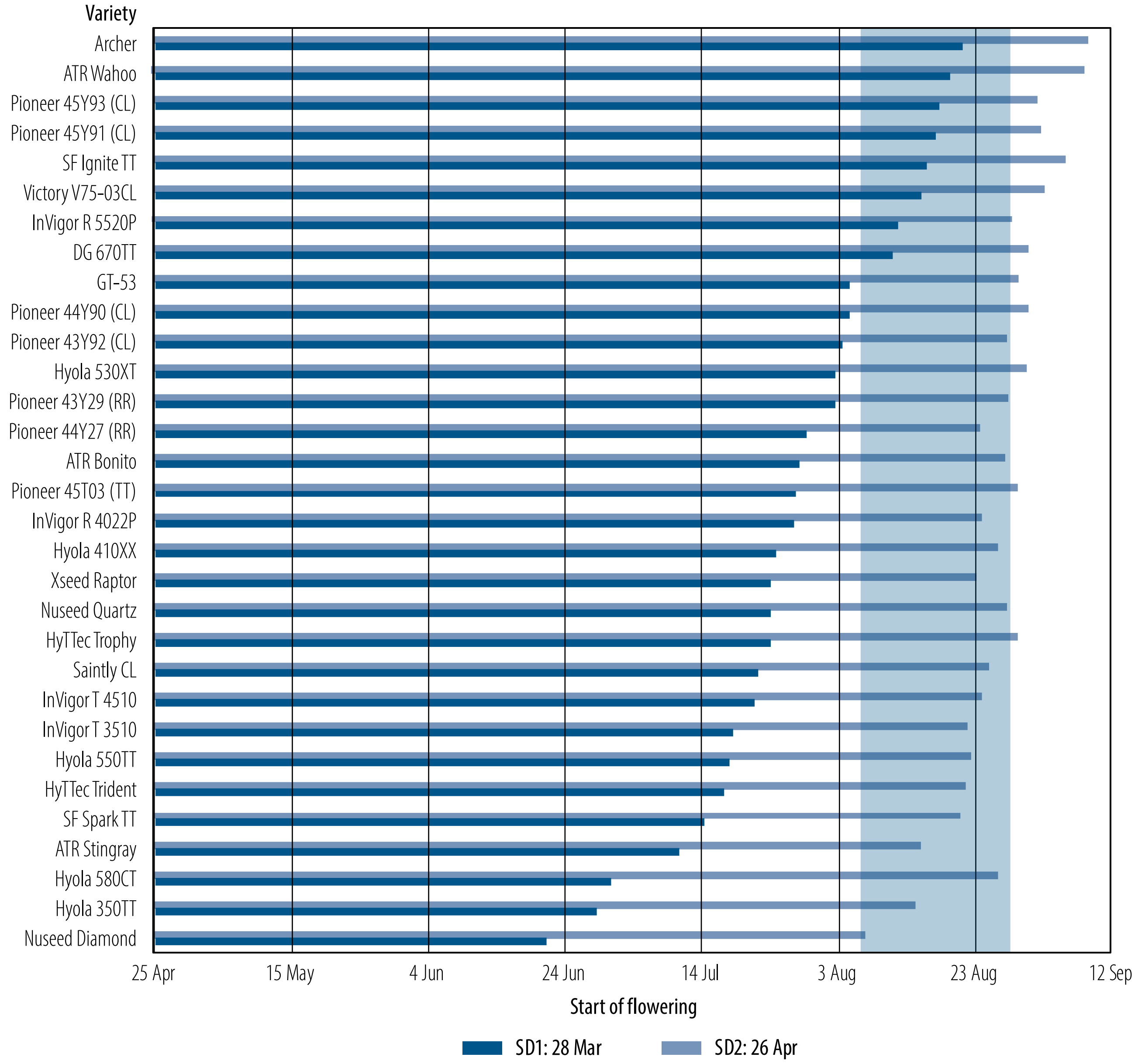
Frost was not a major issue at Wagga Wagga in 2019, with 33 days below 0 °C recorded between June and September from a weather station in the paddock: the lowest recorded temperature was –2.8 °C. While 33 days of below 0 °C is nearly double the long-term average of 18 days for Wagga Wagga (recorded at the Wagga Wagga Agricultural Institute weather station) (CliMate, 2020), the minimum temperatures were warmer than those seen in 2017 and 2018, which did cause significant damage to early flowering canola (temperatures below –4 °C). More work will be conducted in 2020 to determine minimum temperature thresholds for canola.

Phenology

Nuseed Diamond, Hyola® 350TT and Hyola® 580CT were the fastest to flower from SD1 with flowering starting in mid July, over a month earlier than the optimum start of flowering for the Wagga Wagga region – the second week in August (shaded area in Figure 1). These varieties flowered up to 58 days earlier from SD1 than SD2. 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 (Figure 1).

Varieties such as Pioneer® 43Y29 (CL) and InVigor R 5520P showed a greater level of flexibility in their flowering dates (Figure 1), falling within the optimum flowering period for both sowing dates.

Longer season varieties ATR Wahoo⦷, Pioneer® 45Y93 (CL), Pioneer® 45Y91 (CL), Victory V75-03CL and SF Ignite TT sown in late March started flowering in the optimum window (Figure 1). However, from the more traditional sowing date of 26 April (SD2), they flowered outside this window, increasing the risk of heat and/or moisture stress during their critical growth period (around 350 degree days following start of flowering date) (Kirkegaard et al., 2018).



Optimum start of flowering period for Wagga Wagga is shown as the blue shaded area.

Figure 1 Start of flowering date for each variety sown on two sowing dates at Wagga Wagga, 2019.

Conclusion

Canola varieties differ in their flowering times depending on when they are sown. Sowing a variety too early can lead to flowering when the risks of frost and disease are high; sowing a variety too late can lead to heat or moisture stress.

Matching a variety's phenology to its sowing time is critical for flowering to start during the optimum flowering period for that region, which is when environmental and disease risks are balanced for the highest yield potential. More information on sowing windows to suit variety phenology can be found in the DPI's *Winter crop variety sowing guide 2020*.

Previous research has shown that the time from sowing to the start of flowering could be different in any one year in response to temperature and solar radiation.

This phenology experiment will be repeated in 2020 with a slightly different variety set, including a number of unreleased lines that are also in the National Variety Trials (NVT).

References

Kirkegaard JA, Lilley JM, Brill RD, Ware AH and Walela CK, 2018. The critical period for yield and quality determination in Canola (*Brassica napus* L.). *Field Crops Research*, vol. 222, pp. 180–188.

CliMate Weather Data https://climateapp.net.au, accessed 19 May 2020.

Acknowledgements

This experiment was part of the 'Optimised canola profitability' project, CSP00187, 2014–19. The project is a collaborative partnership between GRDC, NSW DPI, Commonwealth Scientific and Industrial Research Organisation (CSIRO) and South Australian Research and Development Institute (SARDI).

Sowing date effect on flowering and grain yield of eight canola varieties – Leeton 2019

Tony Napier and Daniel Johnston (NSW DPI, Yanco); Rohan Brill (formerly NSW DPI, Wagga Wagga)

Key findings

- In a season characterised by low frost severity, Nuseed Diamond was the highest yielding variety for all three sowing dates.
- In a low frost severity season, earlier sowing on 27 March and 11 April achieved a higher grain yield compared with the later sowing on 30 April.
- Triazine tolerant varieties were generally lower yielding compared with other varieties with a similar phenology.
- Winter type canola yield and oil performance were comparable with spring types when sown before mid April and could be worth considering as a dual-purpose crop due to the additional value generated from grazing.

Introduction

This experiment was designed to increase the understanding of:

- canola yield potential in the high yielding irrigated zone of southern NSW
- the effect of climatic stress at different canola growth stages.

Improved understanding of variety-specific sowing date effects will enable growers to select a variety with the appropriate plant maturity type and sowing date to minimise environmental stresses and ensure that the critical growth periods coincide with the most favourable growing conditions.

Eight canola varieties with differing phenologies were evaluated for three sowing dates from late March to the end of April.

Site details

Location	NSW DPI – Leeton Field Station
Soil type	A grey clay soil, pH_{Ca} 6.4
Previous crop	Barley (irrigated)
In-crop rainfall	• 177 mm (April 2019–October 2019) (equivalent to 1.8 ML/ha). • April: 52 mm; May: 36 mm; June: 37 mm; July: 22 mm; August: 13 mm; September: 10 mm and October: 7 mm.
Irrigation schedule	• Flood irrigated on 12 March, before the first sowing date (SD1), with an estimated 220 mm (2.2 ML/ha). • Immediately after the first and second sowing date (SD1 and SD2), 10 mm was applied with dripper tubes; SD3 germinated on moisture. • Three flood irrigations with an estimated 80 mm per irrigation or 2.4 ML (15 August, 18 September and 11 October). • Total moisture supply approximately 6.4 ML.

Soil test	Mineral nitrogen (N) of 78.8 kg N/ha (90 cm) and phosphorus (P) (Colwell) of 53 mg/kg (10 cm).
Base fertiliser	• Mono-ammonium phosphate (MAP) at 200 kg/ha (20 kg N/ha and 44 kg P/ha). • Gran-Am at 200 kg/ha (41 kg N/ha and 48 kg sulfur (S)/ha). • Urea at 240 kg/ha (110 kg N/ha).
Topdressing fertiliser	• When plots were at 8-leaf stage – urea at 141 kg/ha (65 kg N/ha). • When plots were at visible bud stage – urea at 141 kg/ha (65 kg N/ha).

Treatments

Variety

Eight varieties described in Table 1.

Table 1 Eight canola varieties included in the experiment at Leeton, 2019.

Variety	Type	Description
Nuseed Diamond	Spring	Fast developing, conventional hybrid variety
ATR Bonito(D)	Spring	Mid–fast developing, triazine tolerant (TT) open pollinated (OP) variety
Pioneer® 44Y90 (CL)	Spring	Mid–fast developing, Clearfield® (CLF) hybrid variety
Pioneer® 45Y91 (CL)	Spring	Mid developing, CLF hybrid variety
Archer	Spring	Mid–slow developing, CLF hybrid variety
ATR Wahoo(D)	Spring	Mid–slow developing, TT OP variety
SF Edimax CL	Winter	Very slow developing, CLF variety
Hyola® 970CL	Winter	Very slow developing, CLF variety

Sowing date (SD)

SD1: 27 March 2019

SD2: 11 April 2019

SD3: 30 April 2019

Results

Phenology

Nuseed Diamond was the fastest developing spring variety from SD1 with flowering starting on 1 June, 66 days after sowing (Figure 1). Temperature primarily drives Nuseed Diamond's development (no vernalisation requirement), therefore warmer temperatures hastened development.

Hyola® 970CL was the slowest winter variety to start flowering from SD1, taking 184 days from sowing. This is a winter variety and has a strong vernalisation requirement, therefore it will not start flowering until after winter finishes.

ATR Wahoo(D) was the slowest spring variety to start flowering from SD1, taking 127 days from sowing to flowering.

Slower developing spring varieties have a response to both thermal time and vernalisation. Most spring varieties only have a small response to vernalisation, but this will still delay the start of flowering when conditions are warm (i.e. when sown early). The stronger the vernalisation influence, the greater the delay to flowering.

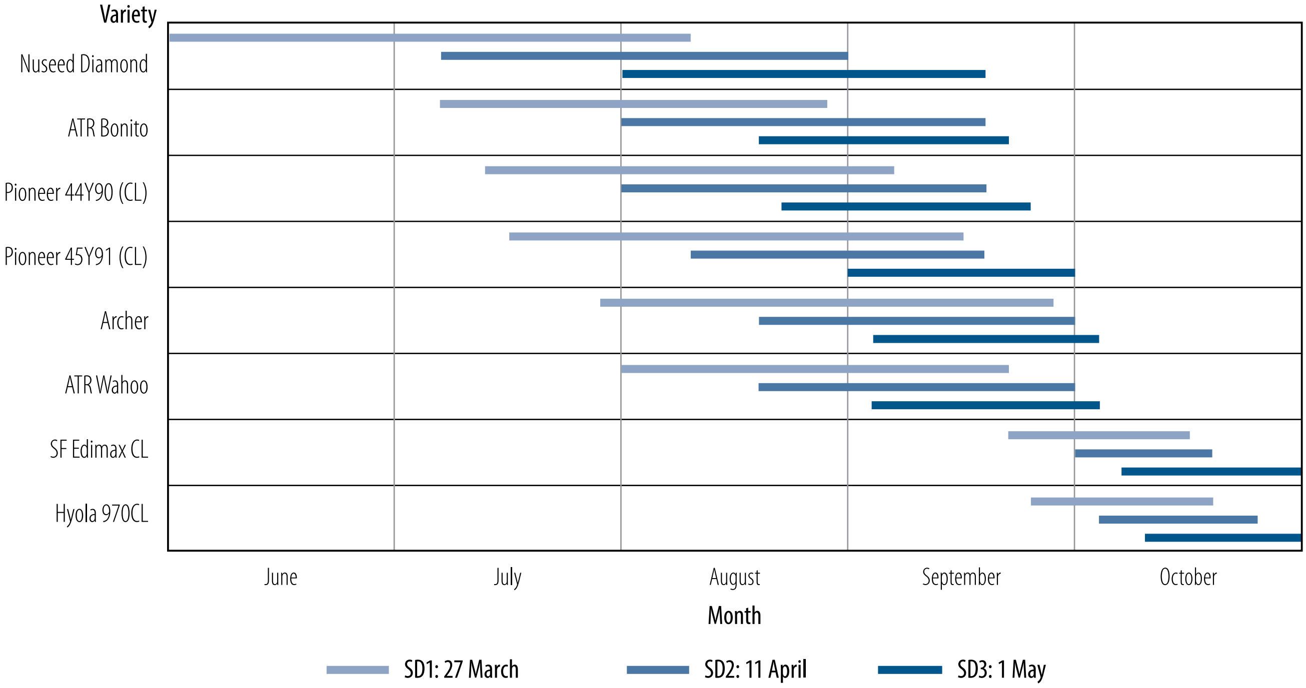


Figure 1 Flowering period of eight canola varieties sown on three sowing dates at Leeton, 2019.

Seasonal conditions

Only a few major frosts were recorded early in the 2019 season. No significant frost occurred after 23 June 2019 (Figure 2). This differed from the previous two seasons where multiple major frosts occurred during the flowering and podding periods up until mid September. Higher than average maximum temperatures were recorded during September and October in the 2019 season, but no extremes above 35 °C were recorded until 6 October 2019 when all spring types had finished flowering.

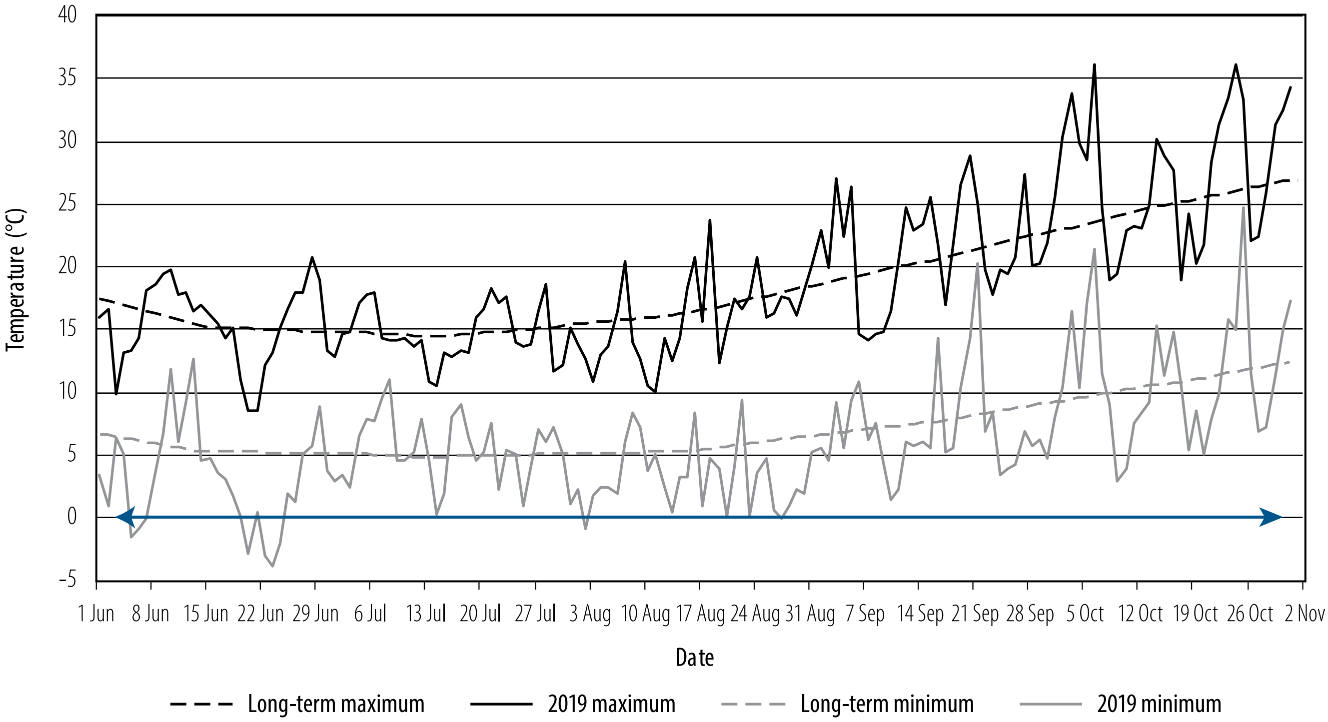


Figure 2 Maximum and minimum temperatures at Leeton during canola flowering period, 2019.

Grain yield

Nuseed Diamond (spring variety) had the highest grain yield with an average of 3.96 t/ha across all sowing dates and was significantly higher yielding than all other varieties (Table 3). The second sowing date of Nuseed Diamond had the highest grain yield at 4.15 t/ha and was statistically similar for both SD1 and SD3.

Pioneer® 45Y91 (CL) (SD1) was the second highest yielding spring type with a grain yield of 2.97 t/ha and was statistically similar for SD2, the spring varieties ATR Bonito$^{\phi}$ (all SDs), Pioneer® 44Y90 (CL) (SD1 and SD2) and Archer (all sowing dates).

Hyola® 970CL (SD1) was the highest yielding winter variety with 3.29 t/ha and was statistically similar for SD2 and SF Edimax CL (SD1 and SD2).

ATR Bonito$^{\phi}$ (SD2) was the highest yielding TT variety at 2.82 t/ha and was significantly higher yielding than the other TT variety, ATR Wahoo$^{\phi}$, for all sowing dates.

Sowing date had a significant effect on yield. Both SD1 and SD2 yielded significantly higher than SD3 (Table 2). SD1 had the highest grain yield with an average of 2.97 t/ha; SD2 had 2.89 t/ha; SD3 had the lowest average yield at 2.28 t/ha.

Not all varieties showed a response to sowing date. The spring varieties Nuseed Diamond, ATR Bonito$^{\phi}$ and ATR Wahoo$^{\phi}$ had statistically similar grain yields for all sowing dates. All other varieties had a significantly higher yield in SD1 compared with SD3.

Table 2 Grain yield (t/ha) and oil content (%) averaged across eight canola varieties sown on three sowing dates at Leeton, 2019.

Sowing date	Grain yield (t/ha)	Oil content (%)
SD1: 27 March	2.97	41.59
SD2: 11 April	2.89	42.00
SD3: 30 April	2.28	41.19
l.s.d. ($P<0.05$)	0.201	0.496

Oil content

The spring variety ATR Bonito$^{\phi}$ had the highest oil concentration, averaging 43.52% for all sowing dates, significantly higher than all other varieties (Table 3). ATR Wahoo$^{\phi}$ had the lowest oil concentration averaging 40.45% for all sowing dates and was statistically similar to Archer and Pioneer® 45Y91 (CL), all spring varieties.

Sowing date significantly affected oil content, with SD2 having an average oil concentration of 42.0% – significantly higher than SD3 which averaged 41.19% (Table 2).

There was a significant interaction between variety oil content and sowing date for ATR Bonito$^{\phi}$, which had a significantly higher oil concentration in SD2 and SD3 compared with SD1. This result was unexpected as delayed sowing is usually associated with reduced oil content. Both winter varieties (SF Edimax CL and Hyola® 970CL) had a significantly reduced oil concentration for the delayed sowing dates.

Table 3 Grain yield (t/ha) and oil content (%) of eight canola varieties sown on three sowing dates at Leeton, 2019.

Variety	Grain yield (t/ha)				Oil content (%)			
	SD1: 27 March	SD2: 11 April	SD3: 30 April	Average	SD1: 27 March	SD2: 11 April	SD3: 30 April	Average
Nuseed Diamond	3.91	**4.15**	3.82	**3.96**	40.54	42.16	41.24	41.31
ATR Bonito	2.68	2.82	2.53	2.67	42.49	**44.17**	43.89	**43.52**
Pioneer 44Y90 (CL)	2.87	2.36	2.09	2.44	41.89	41.14	40.79	41.27
Pioneer 45Y91 (CL)	2.97	2.38	2.08	2.48	40.42	41.81	41.26	41.16
Archer	2.81	2.87	2.69	2.79	40.41	41.19	41.46	41.02
ATR Wahoo	2.17	2.22	1.66	2.02	40.69	40.77	39.88	40.45
SF Edimax CL	3.10	3.17	1.80	2.69	42.42	42.00	40.24	41.55
Hyola 970CL	3.29	3.12	1.57	2.66	43.89	42.75	40.74	42.46
l.s.d. (*P*<0.05)	0.568			0.328	1.404			0.811

Bolded values indicate the highest value and underlined numbers indicate the lowest value for each group.

Conclusion

The 2019 experiment demonstrated that sowing on 27 March and 11 April (SD1 and SD2) gave the highest grain yield with a significant yield reduction when the sowing date was delayed to 30 April (SD3). The high yield in SD1 for 2019 was due to a warmer than average winter and no significant frosts during flowering or podding. In previous years, significant frosts during winter adversely affected the early sown (SD1) spring varieties, which resulted in lower grain yields.

Nuseed Diamond (a fast-developing conventional spring type hybrid) was the highest yielding variety for all sowing dates in 2019. The variety has also been the highest yielding variety over the past two seasons, but only for the later sowing dates. In most years, the faster developing varieties have performed poorly at SD1 due to frost damage.

In this year's experiment, ATR Wahoo$^{\text{⚘}}$ (an OP TT spring type) was the lowest yielding variety for SD1 and SD2, and the second lowest yielding variety at SD3. Triazine tolerant varieties (TT) have consistently yielded least over the past three seasons. Growers will need to consider using TT varieties where specific weed control is required, but in doing so, could incur a yield penalty. In situations where conventional herbicides can control weeds, Nuseed Diamond should be considered for a late April sowing time to achieve maximum yields while avoiding frost damage.

The two winter varieties (SF Edimax CL and Hyola® 970CL) also benefited from an earlier sowing date (SD1 and SD2) with grain yield and oil concentration significantly declining when the sowing date was delayed to 30 April (SD3). The overall performance of the winter varieties was comparable with most spring varieties for yield and oil concentration and could have a potential fit as a dual-purpose crop (grain and forage) in the irrigated production areas of southern NSW. Results from previous seasons have shown mixed results for winter types, demonstrating that not every season would produce a favourable result.

If considering growing a winter type as a dual-purpose crop, don't delay sowing past 11 April.

Acknowledgements

This experiment is part of the 'High yielding canola' project, BLG107, 2017–20, with joint investment by GRDC and NSW DPI.

Thank you to Michael Hately and Danielle Malcolm for their technical support.

Effect of sowing date on flowering and grain yield of ten canola varieties in a high yielding environment – Wallendbeen 2019

Danielle Malcolm (NSW DPI, Wagga Wagga), Rohan Brill (formerly NSW DPI, Wagga Wagga) and Warren Bartlett (NSW DPI, Wagga Wagga)

Key findings

- In 2019, the highest yields came from sowing in late March due to the dry spring conditions and only mild frosts at Wallendbeen.
- Nuseed Diamond was the highest yielding variety from all sowing dates. The highest yield was from the late March sowing date.
- The winter varieties were lower yielding than the spring types, with yields declining from later sowing dates.
- Open pollinated triazine tolerant varieties were generally lower yielding than the hybrid Clearfield® varieties with similar phenology.

Introduction

This experiment was conducted at Wallendbeen, typically a high rainfall area in the South West Slopes, to assess canola's yield potential across different sowing dates in a high yielding environment. Varieties were chosen to represent a diverse range of canola types to compare the different phenologies (including winter types), the breeding type (OP – open pollinated vs hybrid) and herbicide tolerance (TT vs non-TT – triazine tolerant) on three sowing dates: late March, mid April and late April.

This experiment was also conducted at Wallendbeen in 2017 and 2018.

Site details

Location	Wallendbeen (530 m ASL), 15 km north-east of Cootamundra
Soil type	Red ferrosol
Previous crop	Wheat
Rainfall	• Fallow (November 2018–February 2019): 272 mm • In-crop (March 2019–October 2019): 288 mm • In-crop (long-term average): 470 mm
Soil nitrogen	186 kg N/ha (0–180 cm, 27 March)

Treatments

Variety	Nuseed Diamond	Fast spring hybrid conventional herbicide
	Pioneer® 44Y90 (CL)	Mid–fast spring hybrid Clearfield® (CLF)
	ATR Bonito$^{(\Phi)}$	Mid–fast spring OP TT
	Nuseed Quartz	Mid spring hybrid conventional herbicide
	HyTTec Trophy	Mid spring hybrid TT
	Pioneer® 45Y91 (CL)	Mid–slow spring hybrid CLF
	ATR Wahoo$^{(\Phi)}$	Slow spring OP TT
	Archer	Slow spring hybrid CLF
	SF Edimax CL	Winter hybrid CLF
	Hyola® 970CL	Winter hybrid CLF

Sowing date (SD)	SD1: 28 March SD2: 11 April SD3: 30 April

Results

Seasonal conditions

Wallendbeen had below average rainfall throughout the 2019 growing season, with 288 mm recorded; the long-term average is 470 mm. Frost was not a major issue at Wallendbeen in 2019.

Phenology

Nuseed Diamond was the fastest variety to flower from all three sowing dates; SD3 started flowering close to the optimum date. Nuseed Diamond sown on SD1, flowered in early June, and was at risk of frost damage or upper canopy blackleg disease.

From SD2, HyTTec Trophy, ATR Bonito$^{\text{Ⓟ}}$, Nuseed Quartz, Pioneer® 44Y90 (CL), Archer and Pioneer® 45Y91 (CL) all flowered close to or at the optimum start of flowering date.

ATR Wahoo$^{\text{Ⓟ}}$ was better suited to SD1, flowering just before the optimum start of flowering date for Wallendbeen.

The winter varieties, SF Edimax CL and Hyola® 970CL, flowered about the same time from each sowing date, reaching the start of flowering well after the optimum start of flower date, exposing them to potentially a higher risk of heat and moisture stress through the critical growth period (Figure 1).

Grain yield

Due to the dry seasonal conditions in 2019 at Wallendbeen, yields were lower than in the project's previous years, e.g. in 2018, Nuseed Diamond sown on 28 March yielded 4.6 t/ha, whereas from the same sowing date in 2019 yielded 3.7 t/ha.

Nuseed Diamond was the highest yielding variety across all sowing dates, despite it being sown at a time (late March/early April) that would normally put it at high risk from frost or disease damage. Nuseed Diamond was also the highest yielding variety from SD2, with 3.3 t/ha. (Table 1).

Nuseed Quartz was the next highest yielding variety, with a yield of 3.4 t/ha from SD1.

Due to the late flowering window for the winter varieties and the dry conditions throughout the year, they were the lowest yielding overall from each sowing date: Hyola® 970CL yielding 1.1 t/ha from SD1 and 0.6 t/ha from SD3. SF Edimax CL was significantly higher yielding at 1.7 t/ha from SD1, but had a similar yield (0.8 t/ha) to Hyola® 970CL from SD3 (Table 1).

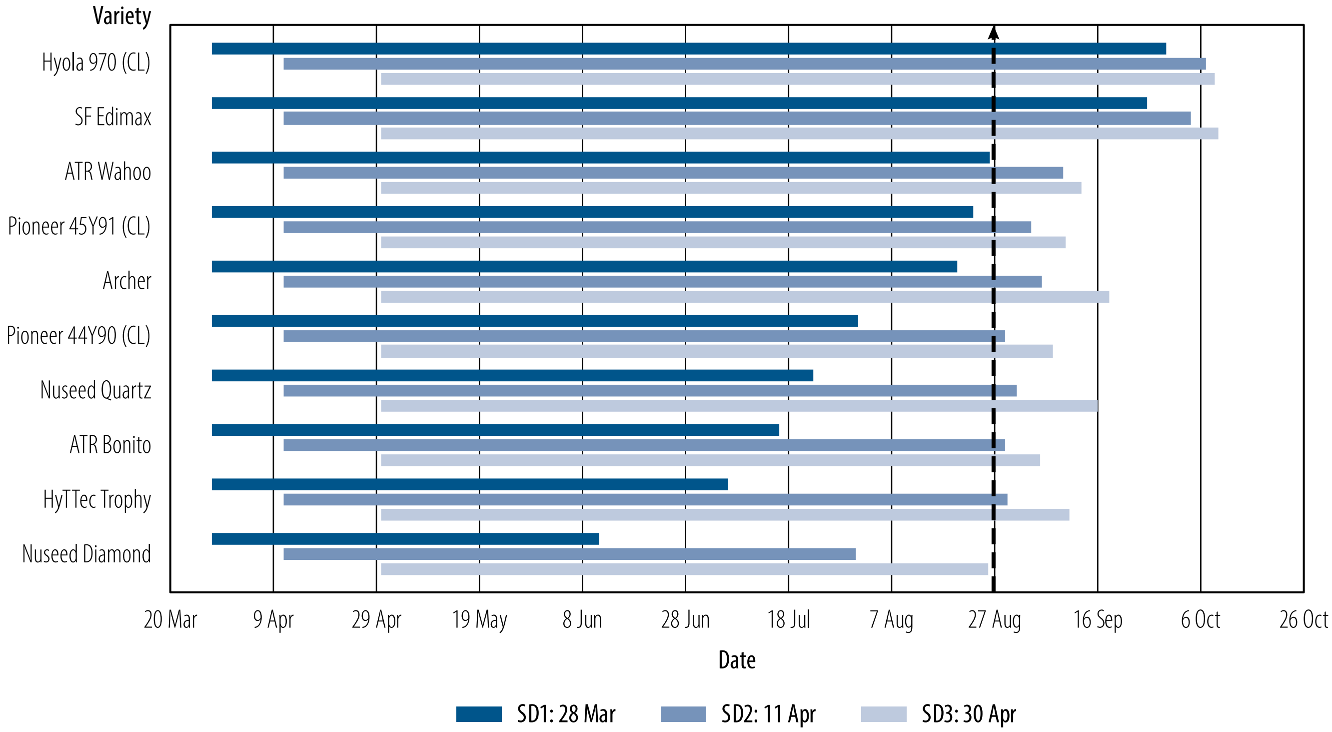
Oil concentration

Nuseed Diamond had the highest oil concentration at 41.8% from SD1. Oil concentrations were very similar within each sowing date between varieties, SD1 yielding the lowest oil concentration for the winter varieties. For the later sowings, oil concentration was reduced for all varieties. The lowest oil concentration was from Nuseed Diamond from SD3 with 36.7% (Table 1).

Table 1 Grain yield (t/ha) and oil concentration (%) of 10 canola varieties sown on three sowing dates at Wallendbeen, 2019.

Variety	Grain yield (t/ha)			Oil concentration (%)*		
	SD1: 28 Mar	SD2: 11 Apr	SD3: 30 Apr	SD1: 28 Mar	SD2: 11 Apr	SD3: 30 Apr
Nuseed Diamond	**3.7**	3.3	2.4	**41.8**	39.5	36.7
HyTTec Trophy	3.2	2.7	2.1	41.0	38.5	37.5
ATR Bonito	2.7	2.2	1.6	41.3	38.8	38.1
Nuseed Quartz	3.4	3.1	2.2	41.2	39.6	36.8
Pioneer 44Y90 (CL)	3.0	2.5	1.7	41.2	40.3	39.1
Archer	2.8	2.7	1.5	41.2	39.8	38.6
Pioneer 45Y91 (CL)	3.3	2.7	1.5	41.7	40.9	39.3
ATR Wahoo	2.4	1.9	1.5	40.7	39.4	39.1
SF Edimax CL	1.7	1.3	0.8	39.6	38.3	37.4
Hyola 970CL	1.1	0.9	0.6	39.2	38.1	37.9
l.s.d. ($P<0.05$)	0.43			1.03		

Values in **bold** indicate the highest value and underlined indicate the lowest for each group.
* Oil concentration is expressed at 6% moisture content.



Dotted line indicates the optimum start of flowering date for Young, NSW.

Figure 1 The start of flowering dates for 10 canola varieties sown on three sowing dates at Wallendbeen, 2019.

Conclusion

Due to the dry season in 2019 and minimal frosts, early flowering favoured higher yields at Wallendbeen. The fast spring variety, Nuseed Diamond was able to achieve the highest yield from SD1, where in a more typical season it would be better suited to a later sowing date. Its high yield in 2019 from SD1 compared with the later sowing dates is in contrast to what has been seen in previous years of this experiment, in particular when the season has a higher incidence of frost as occurred in 2017 when early sown Nuseed Diamond (sown late March) yielded 1.1 t/ha less than the Nuseed Diamond sown on 1 May.

Winter types were not able to reach the same yields as any of the spring types from all sowing dates, which could be due to flowering later than the optimum flowering period. Although the winter varieties did not match the grain yields of the spring varieties, it is important to remember that they are highly profitable as dual-purpose grain and graze varieties.

Acknowledgements

This project was part of the 'High yielding canola' project, BLG107, 2017–20, with joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

Thank you to Cameron and Sarah Hazlett (Wallendbeen) for cooperation with this experiment.

Effect of heat stress on canola yield and quality

Dr Rajneet Kaur Uppal (NSW DPI, Wagga Wagga), Rohan Brill (formerly NSW DPI, Wagga Wagga) and John Bromfield (NSW DPI, Wagga Wagga)

Key findings

- Heat stress during the reproductive development phase significantly reduced grain yield, harvest index and oil percentage.
- Varieties respond differently to heat stress: Nuseed Diamond had the highest reduction in grain yield and oil percentage under heat stress, whereas ATR Stingray$^{\Phi}$ had the lowest reduction in grain yield.
- Under heat stress, seed formation is more severely affected than pod formation.
- Canola pods that appear healthy can produce less, or even no, seed, and therefore do not achieve yield potential under heat stress.

Introduction

Canola (*Brassica napus* L.) is an economically important oilseed globally and the third most valuable crop in Australia, contributing $2.67b to gross domestic product (GDP) annually.

Abiotic stresses such as elevated temperature and moisture shortage, especially during reproductive development, result in significant yield loss in canola. Recent climate change predictions emphasise that extreme climatic event frequency is expected to increase, which poses serious concerns for winter crop productivity. By the end of the 21st century, global mean surface temperature is predicted to increase by 0.3 °C to 4.8 °C, which could lead to significant economic loss for canola growers.

Canola is particularly susceptible to heat stress during reproductive development. In particular, supra-optimal temperatures above 30 °C result in reduced seed set, grain yield and oil content. This experiment developed a novel method for assessing heat tolerance under field conditions using portable heat chambers to allow assessments at the plot scale without confounding by other environmental factors. It is paramount to not only breed for heat tolerant germplasm, but also to test the crop's heat tolerance in reliable field-based experiments for commercial adoption of varieties. Therefore, the aim of this experiment was to understand canola variety heat stress responses and their capacity to adapt to warmer future climates.

Site details	**Location**	Wagga Wagga Agricultural Institute (35º7′2.1900″S latitude and 147º21′23.4792″E longitude)	
	Soil type	Red–brown chromosol	
	Soil nitrogen	75 kg/ha at the time of sowing	
	Watering	To avoid any confounding effects from drought, the experiment was watered six times with a total 240 mm supplied using drip lines during the growing season.	
Treatments	**Variety**	Nuseed Diamond	Fast spring, hybrid conventional herbicide
		ATR Stingray$^{\Phi}$	Fast spring, open-pollinated triazine tolerant (OP TT)
		Pioneer® 43Y23 (RR)	Fast spring, hybrid roundup ready
		Hyola 350TT	Fast spring, hybrid triazine tolerant

Heat chambers	Eight chambers (2.5L × 1.8W × 1.2H m) were constructed with Suntuf Sunlite twin wall polycarbonate clear sheets fitted to a metal frame (Figure 1). Heating was provided by two standard 1200W fan heaters in each chamber, with the a 6KVA generator supplying power in the field. The heaters drew fresh air from outside the plots and a ceiling fan was used to distribute heat evenly throughout the chambers. A commercially available thermostat was used with extended thermocouples to control the heaters. Temperature and humidity inside the box were monitored at one-minute intervals using a TinyTag Plus2 temperature and humidity logger placed inside a small radiation screen.

Figure 1 Heat chambers for assessing heat stress in canola plots at Wagga Wagga Agricultural Institute.

Experiment design and heat treatments

A randomised complete block design with two heat treatments (control vs heat stress at 35 °C), three heat stress measurements (start of flowering, mid flowering and end of flowering), and four replications were used. Each chamber enclosed six 2.5 m long rows of canola plants covering an area of 4.5 square metres. Heat treatments were applied for eight days over two weeks to simulate the effect of a heat wave. The chambers were placed on the plots at 11.30 am and the heaters were switched on at 12.00 pm. The chambers were then heated to 35 °C. The time taken to achieve this temperature depended on ambient conditions on the day. The heaters were turned off at 4.30 pm and heat chambers removed at 5.00 pm.

Measurements

Plot yield, biomass, thousand seed weight and harvest index (HI) were assessed from 1.5 m^2 samples for each plot. The experiment was hand-harvested on 2 November 2019.

Results

Heat stress effect on grain yield

Heat stress had a significant effect on grain yield, biomass and HI, however, the interaction between heat and variety was not significant (Table 1). Nuseed Diamond was the highest yielding variety under non-stressed (control) conditions, followed by Hyola 350TT, Pioneer® 43Y23 (RR) and ATR Stingray⁽ᶦ⁾.

When heat stress was imposed at mid flowering, Nuseed Diamond had the maximum yield reduction (66%). ATR Stingray$^{(\Phi)}$ had a yield reduction of 44%, although HI was maintained under heat stress (17%). Nuseed Diamond HI, however, was reduced to 9% under heat stress.

Although Nuseed Diamond was the highest yielding variety, it also incurred the maximum yield penalty under heat stress due to reduced seed numbers per metre square: although pods were well developed, seeds did not form. Figure 2 shows developed Nuseed Diamond pods that failed to produce seed under heat stress. There were also varietal differences for reduced seed numbers under heat stress (Figure 3). For example, Nuseed Diamond seed numbers were significantly reduced as heat stress increased; however, ATR Stingray$^{(\Phi)}$ maintained seed numbers under the same heat stress conditions.

Table 1 Effect of heat stress on biomass yield, grain yield and harvest index in canola at reproductive development.

Variety	**Biomass yield (t/ha)**		**Seed yield (t/ha)**		**Harvest index**	
	Control	**Heat stress**	**Control**	**Heat stress**	**Control**	**Heat stress**
Pioneer® 43Y23 (RR)	10.60	8.90	2.30	0.88	0.22	0.09
ATR Stingray	8.50	6.50	2.12	1.18	0.25	0.17
Nuseed Diamond	12.20	11.30	3.15	1.07	0.26	0.09
Hyola 350TT	11.50	9.80	2.73	1.25	0.24	0.12
P (variety)	<.001		0.007		0.156	
P (heat)	<.001		<.001		<.001	
P (interaction)	0.178		0.382		0.859	
l.s.d.	0.68		0.38		0.038	

l.s.d., least significant difference.

Figure 2 Effect of heat stress on Nuseed Diamond seed pods at mid flowering stage.

Heat stress effect on oil percentage

Heat stress and variety individually had a significant effect on oil and protein percentage, however, the interaction between heat and variety was not significant (Table 2). Oil percentage was significantly reduced under heat stress in all varieties, with the maximum reduction of 6% in Nuseed Diamond. There is a trade-off between oil percentage and protein percentage, with protein percentage increasing under heat stress.

Table 2 Heat stress effect on oil percentage and protein in canola at reproductive development.

	Oil %		Protein %	
Variety	**Control**	**Heat stress**	**Control**	**Heat stress**
Pioneer® 43Y23 (RR)	41.95	39.98	22.43	23.57
ATR Stingray	43.88	41.67	22.28	24.55
Nuseed Diamond	44.32	41.38	20.00	23.33
Hyola 350TT	42.97	40.79	22.23	24.49
P (variety)	0.077		0.004	
P (heat)	<.001		<.001	
P (interaction)	0.767		0.664	
l.s.d.	1.666		1.230	

l.s.d., least significant difference.

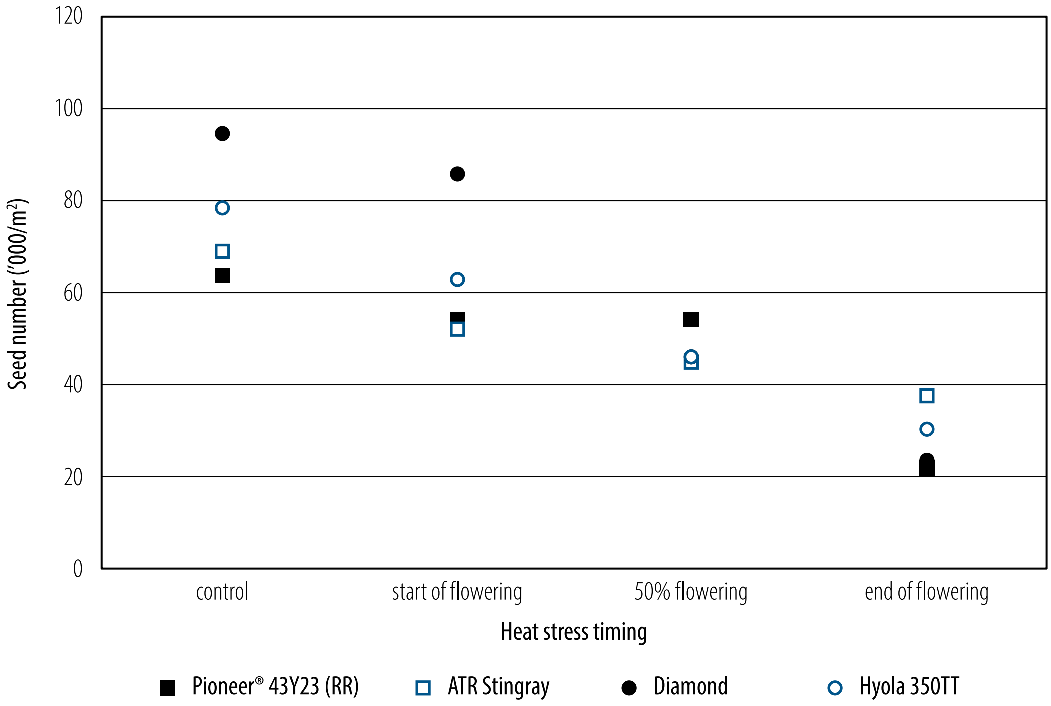


Figure 3 Effect from heat stress timing and variety on seed number/m^2 in canola.

Conclusions

The implications of this research are that heat stress has a significant effect on canola crops. Healthy canola pods heat stressed during the reproductive phase can have reduced seed and oil and therefore do not achieve yield and quality potential. Our field-based portable heat chamber system has increased the reliability of heat tolerance research and will allow the effect of heat stress on canola cultivars to be assessed for breeding programs.

Acknowledgements

This experiment was part of the 'Effect of heat stress on canola – protocol and hypothesis development' pilot project, BLG108, 2017–19, a joint investment between GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP)

Thanks to technical support from Warren Bartlett, Danielle Malcolm and Sophie Brill.

Determining canola physiological maturity with remote sensing

Joshua Hart, Brian Dunn and Chris Dawe (NSW DPI, Yanco); Rohan Brill (formerly NSW DPI, Wagga Wagga); Danielle Malcolm (NSW DPI, Wagga Wagga)

Key findings

- Relationships between remote sensing data and hand harvest data were identified for some varieties and sowing dates, suggesting remotely sensed data might be useful for determining canola maturity.
- Both variety and sowing date alter the relationship between remotely sensed data and hand harvested data.

Introduction

Physiological maturity is the stage at which canola is windrowed or treated with desiccants to aid harvesting. Currently, physiological maturity is determined by hand sampling and subjectively measuring seed colour change. It can be difficult to pinpoint the correct timing for optimum yield due to the speed at which seed colour can change, particularly on a commercial scale across paddocks with variable soil types, aspect and topography.

This project conducted a preliminary investigation to determine whether an objective remote sensing method could be a feasible alternative to hand sampling, and to guide further research.

Treatments

Treatments were selected out of a large variety × sowing date experiment to source a range of varieties and maturity dates to test.

Variety

Nuseed Diamond	Fast spring hybrid, conventional herbicide
Pioneer® 44Y90 (CL)	Mid–fast spring hybrid, Clearfield (CLF)
ATR Bonito⊕	Mid–fast spring open pollinated, triazine tolerant
Archer	Slow spring hybrid, CLF

Sowing date (SD)

SD1: 27 March 2019

SD2: 14 April 2019

SD3: 30 April 2019

Methodology

Grain sampling

Peak flowering date and visual assessment were used to determine when to begin sampling each treatment before physiological maturity. The aim was to capture data before and beyond physiological maturity to accurately pinpoint the date each variety reached maturity.

Sampling consisted of cutting whole plants from an area of 30 cm × 6 rows. Samples were air dried and stored until processed to determine thousand seed weight (TSW) and harvest index (HI). These measurements were used to identify the date of physiological maturity (Graham et al., 2017). Sampling took place three times each week, subject to field conditions.

Remote sensing

On each sampling date, remote sensing data was collected with a Micasense RedEdge multispectral sensor mounted on a DJI Matrice 100 drone. Imagery was collected at the same time each day (11 am), flight height (50 m), speed (5 m/s), overlap 80% and standardised with a reflectance panel. The Pix4D software package was used to process the imagery data. Normalised difference vegetation index (NDVI) maps were developed and individual plot data extracted using QGIS software. Over the two-month sampling period, 30 images were collected.

Results

Figure 1 shows the relationship between TSW and HI and how physiological maturity or windrowing date can be determined from them. As grain matures, it increases in size to a maximum seed size before it plateaus and can even decline. Increases in HI as the crop reaches physiological maturity can indicate an increase in grain size. The point at which HI starts to decline can indicate losses from pods shattering due to the crop becoming over ripe. This relationship indicates the optimum window for windrowing. In Figure 1, for Archer sown on 30 April, the optimum time for windrowing was between 6 November and 11 November.

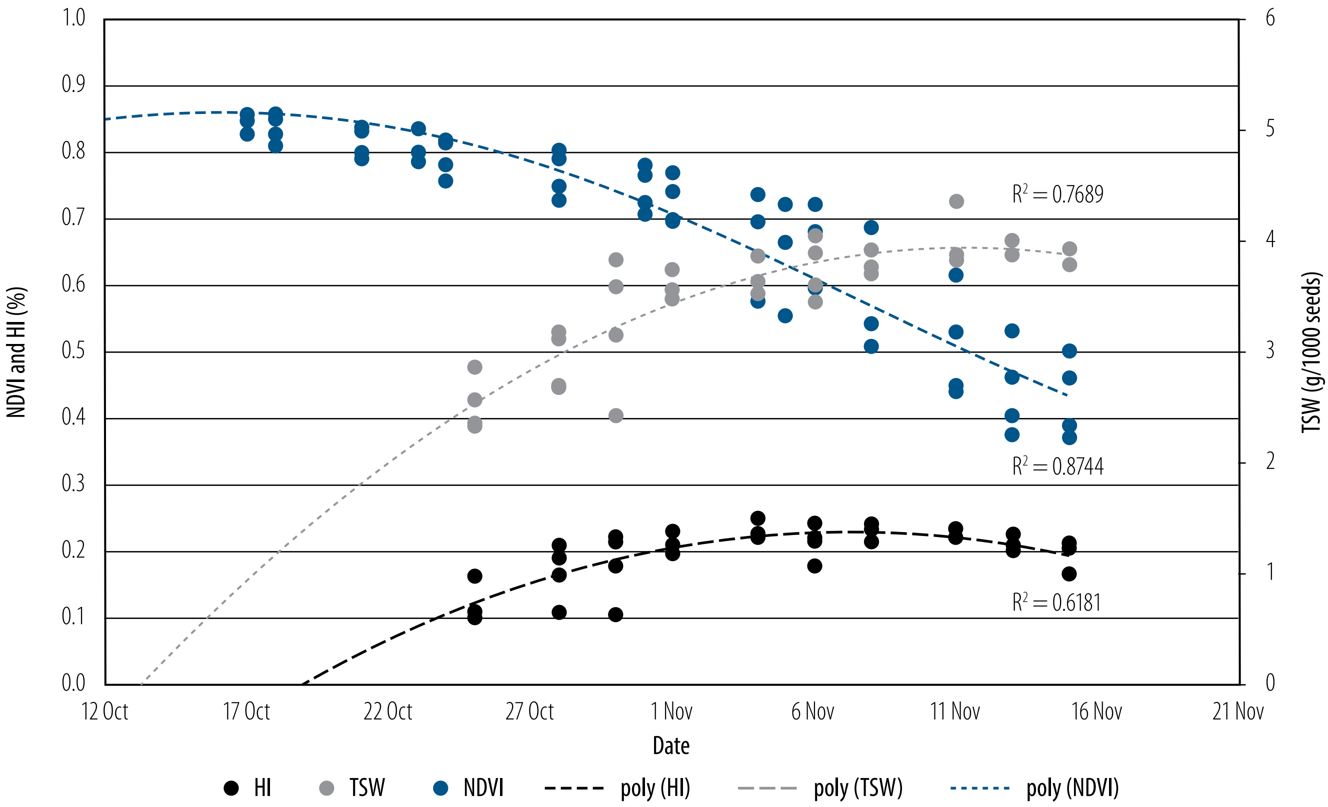


Figure 1 Time series of NDVI, TSW and HI for Archer sown on 30 April.

Some treatments had strong relationships between NDVI and TSW. ATR Bonito$^{\text{(b)}}$ sown on 14 April is an example (Figure 2). As NDVI drops, seed size continues to increase until it begins to plateau at approximately 4 g/1000 seeds, at which point NDVI reduces to 0.6. In the high yielding irrigated experiment, all plots reached an NDVI of approximately 0.85. Monitoring NDVI via imaging might therefore be used to determine physiological maturity, assuming the relationship can be shown to be consistent across varieties and seasons.

Only four of the 12 treatments provided useful results for determining the relationship between NDVI and TSW: ATR Bonito$^{\text{(b)}}$ sown on 27 March and 14 April, Archer sown on 30 April and Nuseed Diamond sown on 27 March all exhibited relationships between NDVI and TSW (Table 1).

- Two treatments were lodged and therefore abandoned.
- Due to the limited plot area, only a short sampling window was available so physiological maturity was missed in two treatments, with sampling being too late and TSW already reaching maximum, or too early with TSW not reaching a maximum.

- Four treatments had the correct timing for physiological maturity, however, variability in these treatments resulted in poor relationships.

Table 1 Summary of the relationships between NDVI and maturity, based on TSW.

Variety	Sowing date	NDVI at maturity	R^2 (NDVI × TSW)
Archer	30 April	0.60	0.51
ATR Bonito	27 March	0.65	0.52
ATR Bonito	14 April	0.50	0.81
Nuseed Diamond	27 March	0.55	0.69

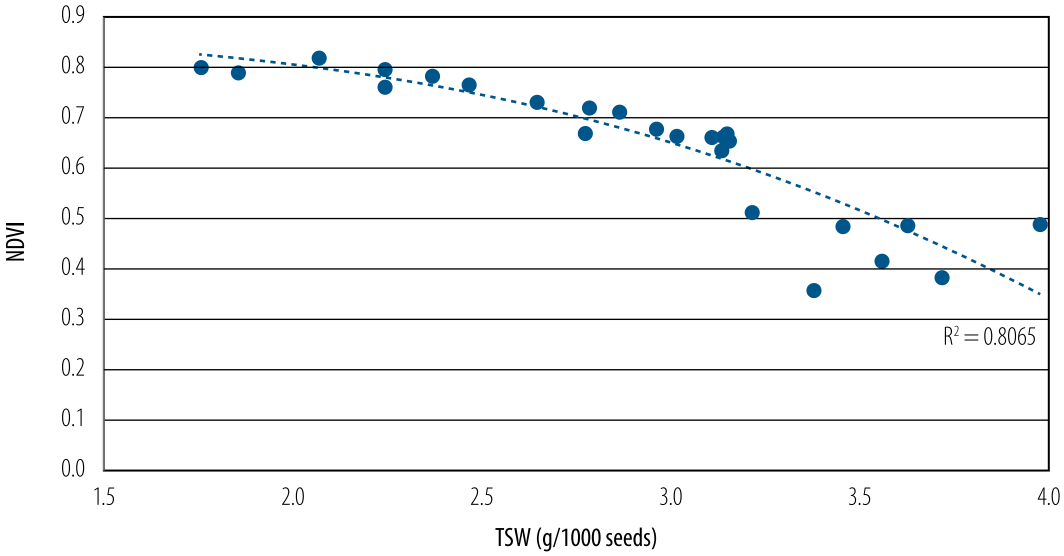


Figure 2 Relationship between NDVI and TSW for ATR Bonito⁽ᵈ⁾ sown on 14 April.

Conclusion

The results show there is potential to use remote sensing to determine maturity with strong relationships found between NDVI and TSW for some varieties and sowing dates in this experiment. A more comprehensive experiment with larger plot areas and longer sampling periods would be needed to explore the differences between varieties and sowing dates as well as to further explore the reasons why some treatments had poor relationships as identified in this preliminary study. Data from multiple seasons would need to be collected to determine whether there are changes between seasons.

This research was only a preliminary investigation into whether the potential exists for using remote sensing in this way. Further research would need to include remote sensing data from satellite sources that would be more relevant for widespread industry use.

Reference

Graham R, Jenkins L, Hertel K, Brill R, McCaffery D and Graham N, 2017. Re-evaluating seed colour change in canola to improve harvest management decisions. *Doing more with less: 18th Australian Society of Agronomy Conference,* Ballarat, Australia, (eds GJ O'Leary, RD Armstrong and L Hafner), 24–28 September 2017.

Acknowledgements

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Thank you to Tony Napier for accommodating the experiment.

Chickpea and lentil phenology and grain yield response to irrigation – Leeton 2019

Reuben Burrough, Tony Napier and Daniel Johnston (NSW DPI, Yanco); Mark Richards (NSW DPI, Wagga Wagga)

Key findings

- Chickpea and lentil produced high grain yield on irrigated raised beds at Leeton in 2019.
- CICA1521 was the highest yielding chickpea variety with a grain yield of 3.55 t/ha.
- PBA Bolt$^{\phi}$, PBA Ace$^{\phi}$ and PBA Hallmark$^{\phi}$ were the highest yielding lentil varieties, all achieving over 2.50 t/ha.
- Disease pressure and waterlogging were not observed in these experiments, a result of dry seasonal conditions and raised beds for furrow irrigation.
- There were difficulties in machine harvesting lentil on raised beds with more than 1.00 t/ha grain losses compared with hand harvesting.

Introduction

Chickpea and lentil can be a profitable and beneficial rotation crop in many of Australia's grain growing regions. In the irrigated cropping areas of the Riverina NSW, there is the potential for these pulses to be incorporated into irrigated bed farming systems. Two experiments were conducted at Leeton NSW in 2019 to assess the performance of four chickpea and four lentil varieties when grown on irrigated beds, and examine their phenological response to this farming system. Irrigation was applied according to plant water usage calculated from evapotranspiration and a crop growth factor.

Site details

Location	Leeton Field Station
Soil type	Self-mulching grey clay (vertosol)
Previous crop	Barley
Soil tests	• Soil pH_{Ca}: 6.4 (0–30 cm) • Mineral nitrogen (N): 43.9 kg/ha (0–30 cm) • Phosphorus (P) (Colwell): 155 mg/kg (0–30 cm)
Fertiliser	Utiliser pulse mix at 200 kg/ha (nitrogen [N] 7.48; phosphorus [P] 17.64; potassium [K] 6.24; calcium [Ca] 6.4; zinc [Zn] 0.32; manganese [Mn] 3.2)
In-crop rainfall	142 mm (May 2019–November 2019); (long-term average = 240 mm)
Irrigation	• No pre-irrigation. • Estimated 80 mm applied on 29 August and 80 mm applied on 30 October 2019 (total of 1.6 ML/ha).
Target plant density	Chickpea 40 plants/m^2; lentil 120 plants/m^2
Sowing date	16 May 2019

Weed management	Pre-emergent • 900 g/ha Terbyne® Xtreme® (875 g/kg terbuthylazine) + 1.6 L/ha Avadex® Xtra (500 g/L tri-allate) + 2.0 L/ha Rifle® (440 g/L pendimethalin). Post-emergent • 500 mL/ha Status® (240 g/L clethodim); 190 mL/ha Leopard® (200 g/L quizalofop-p-ethyl).
Disease Management	• Dithane® (750 g/kg mancozeb) @ 2 kg/ha on 26 June. • Amistar® 250 SC (250 g/L azoxystrobin) 500 mL/ha, Oriuso® 430SC (430 g/L tebuconazole) 500 mL/ha, Cheers® 720 (720 g/L chlorothalonil) 1.8 L/ha on 18 July and 25 July. • Veritas® (200 g/L tebuconazole, 130 g/L azoxystrobin) 1 L/ha on 2 August. • Dithane® (750 g/kg mancozeb) 2.2 kg/ha on 6 August. • Sumisclex® 500 (500 g/L procymidone) 1 L/ha on 8 August. • Veritas® (200 g/L tebuconazole, 130 g/L azoxystrobin) 1 L/ha, Cheers® 720 (720 g/L chlorothalonil) 2 L/ha on 15 August and 26 August. • Aviator® Xpro® (150 g/L prothioconazole, 75 g/L bixafen) 600 mL/ha on 4 September. • Veritas® (200 g/L tebuconazole, 130 g/L azoxystrobin) 1 L/ha, Cheers® 720 (720 g/L chlorothalonil) 2 L/ha on 15 September. • Cheers® 720 (720 g/L chlorothalonil) 2 L/ha on 26 September and 1 October.
Insect Management	• Pirimidex (500 g/kg pirimicarb) 150 g/ha on 4 September and 24 September. • Pirimidex (500 g/kg pirimicarb) 150 g/ha, Success® Neo (120 g/L spinetoram) 200 mL/ha on 27 September.
Harvest	• Grain yield was obtained from 2 m^2 hand cuts collected from each plot. • Hand cuts were taken starting on 6 November for lentil and 11 November 2019 for chickpea, as varieties reached maturity. • Both experiments were also machine harvested with a plot header on 28 November 2019.

Experiments and treatments

Two separate irrigated pulse experiments were sown on 16 May 2019. The experiments were sown on raised beds with 1.83 metre centres, four rows per bed with 305 mm spacing and 12 metre plot length.

Chickpea varieties × four replicates

PBA Boundary$^{\phi}$, PBA Striker$^{\phi}$, CICA1521 (desi types), Genesis™ 090 (kabuli type)

Lentil varieties × four replicates

PBA Greenfield$^{\phi}$, PBA Bolt$^{\phi}$, PBA Ace$^{\phi}$, PBA Hallmark XT$^{\phi}$

Seasonal conditions and irrigation

Stored soil moisture pre-sowing was below average with only 62 mm of summer rainfall (2018–19). Conditions improved at sowing with 82 mm recorded at Leeton Field Station in autumn, which allowed sowing into a suitable moisture profile. The subsequent 33 mm rainfall was well below average for August to October. Experiments were irrigated once soil water tension reached 100 kPa, indicating the beginning of water stress on the plant. When this threshold was exceeded (twice: 29 August 2019 and 30 October 2019) approximately 80 mm of irrigation water was applied. Frost had a minimal effect on experiments, with no severe frosts during reproductive growth stages.

Results

Phenology

The experiment was sown in mid May, which has been previously identified as an optimal sowing date at Leeton from chickpea and lentil dryland pulse experiments in 2018 (Maphosa et al., 2019).

Chickpea

CICA1521 and PBA Striker$^{\phi}$ were the fastest to reach flowering, starting in early September. PBA Boundary$^{\phi}$ was slower to flower and the slowest to start pod set, beginning in October (Table 1). Despite later podding, PBA Boundary$^{\phi}$ was as fast as CICA1521 and PBA Striker$^{\phi}$ to physiological maturity, resulting in a slightly shortened podding phase of 36 days. These three varieties reached physiological maturity during the first week of November.

The kabuli variety, Genesis™ 090 was the slowest to flower and mature, reaching physiological maturity from mid November.

Genesis™ 090 had a similar flowering period to the faster desi varieties, but podding duration was 44 days, five days longer than the next longest podding duration (CICA1521, Table 1). This longer podding phase before maturity contributed to the longer total season length for Genesis™ 090.

Table 1 Key phenology dates for chickpea sown mid May at Leeton, 2019.

Variety	10% flowering	Flowering duration	10% podding	Podding duration	Physiological maturity day	Days to physiological maturity
PBA Boundary	13 Sep 2019	29	1 Oct 2019	36	6 Nov 2019	174
CICA1521	8 Sep 2019	34	28 Sep 2019	39	6 Nov 2019	174
PBA Striker	9 Sep 2019	34	29 Sep 2019	38	6 Nov 2019	175
Genesis 090	15 Sep 2019	31	30 Sep 2019	44	13 Nov 2019	181
l.s.d. ($P<0.05$) (days)	3.9	n.s.	1.4	1.2	0.9	0.9

n.s., not significant.

Lentil

All lentil varieties began flowering in mid September. PBA Hallmark XT$^{\phi}$ and PBA Ace$^{\phi}$ were significantly faster to flower than PBA Greenfield$^{\phi}$, by four and three days respectively. PBA Bolt$^{\phi}$ flowered earlier than PBA Greenfield$^{\phi}$, but the difference was not significant.

The initial podding date was uniform across the varieties, beginning in late September. PBA Bolt$^{\phi}$ was the fastest developing variety, reaching physiological maturity in early November, with PBA Ace$^{\phi}$ three days later. PBA Greenfield$^{\phi}$ and PBA Hallmark XT$^{\phi}$ were significantly slower to mature, five days after PBA Bolt$^{\phi}$. All varieties were ready to harvest by mid November (Table 2).

Although PBA Ace$^{\phi}$ had a significantly longer flowering period than all other varieties, it finished the season with statistically similar physiological maturity to the fastest variety, PBA Bolt$^{\phi}$. While PBA Hallmark XT$^{\phi}$ and PBA Greenfield$^{\phi}$ had later maturity, they did not have correspondingly long flowering phases. Both varieties had significantly longer podding duration and delayed maturity compared with the faster maturing varieties PBA Bolt$^{\phi}$ and PBA Ace$^{\phi}$ (Table 2).

Table 2 Key phenology dates for lentil sown mid May at Leeton, 2019.

Variety	10% flowering	Flowering duration	10% podding	Podding duration	Physiological maturity day	Days to physiological maturity
PBA Hallmark XT	10 Sep 2019	30	25 Sep 2019	46	9 Nov 2019	178
PBA Ace	11 Sep 2019	34	26 Sep 2019	42	6 Nov 2019	175
PBA Bolt	12 Sep 2019	27	25 Sep 2019	39	3 Nov 2019	171
PBA Greenfield	14 Sep 2019	30	26 Sep 2019	43	8 Nov 2019	176
l.s.d. ($P<0.05$) (days)	2.5	3.2	n.s.	3.7	3.9	3.9

Grain yield

Chickpea

CICA1521 was the highest yielding chickpea variety with an average of 3.55 t/ha and was significantly higher yielding than all other varieties (Figure 1).

PBA Striker$^{\phi}$ was the second highest yielding variety with 3.17 t/ha, but was not significantly different from PBA Boundary$^{\phi}$ with 3.05 t/ha.

Genesis™ 090 was the lowest yielding variety with 2.09 t/ha and was significantly lower yielding than all other varieties.

Lentil

PBA Bolt$^{\phi}$, PBA Ace$^{\phi}$ and PBA Hallmark XT$^{\phi}$ were the highest yielding varieties with statistically similar yields ranging from 2.54 t/ha to 2.79 t/ha (Figure 2). PBA Greenfield$^{\phi}$ was significantly lower yielding than all other varieties with 1.88 t/ha. This sowing date could have been later than optimal for PBA Greenfield$^{\phi}$ resulting in the observed yield deficit.

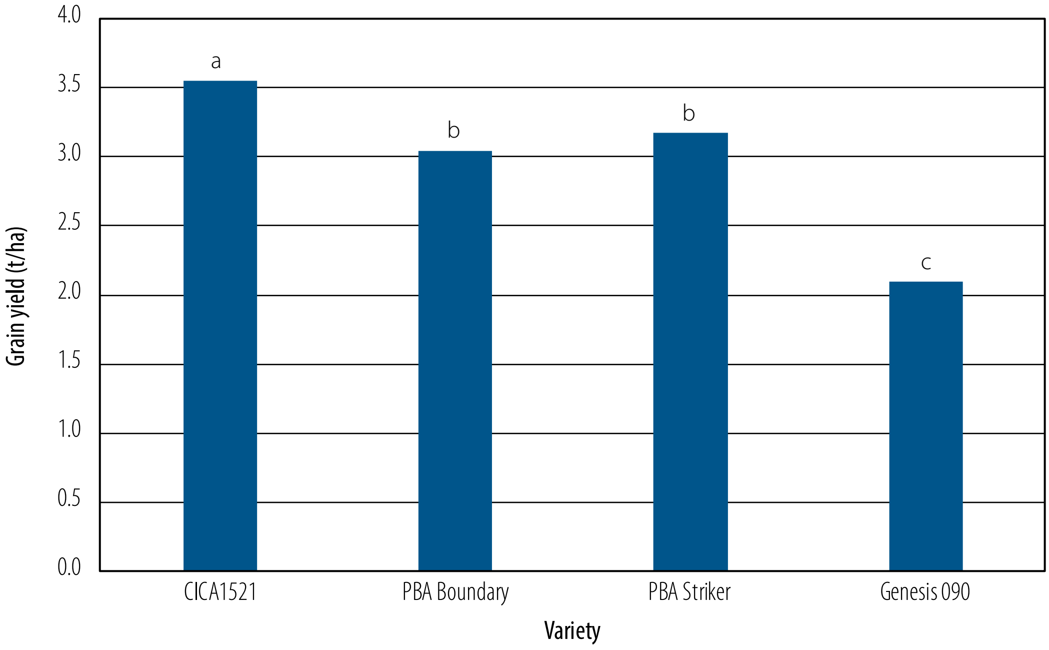

Figure 1 Grain yield (t/ha) of four chickpea varieties sown in mid May at Leeton, 2019; letters denote significantly different grain yield; l.s.d. ($P<0.05$) = 0.22 t/ha.

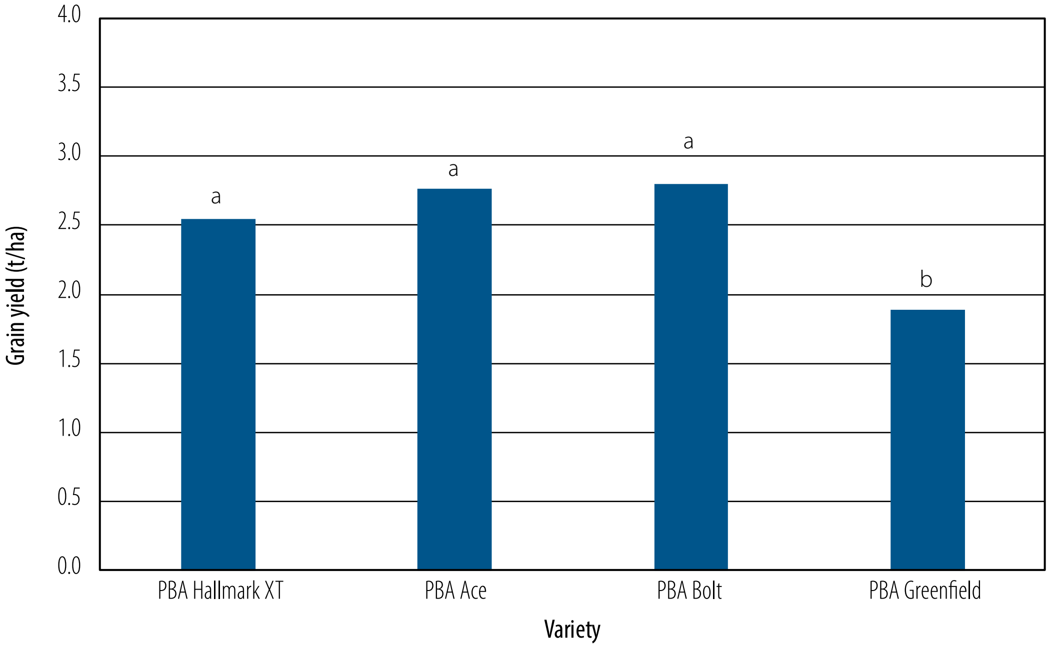

Figure 2 Grain yield (t/ha) of four lentil varieties sown in mid May at Leeton 2019; letters denote significantly different grain yield; l.s.d. ($P<0.05$) = 0.30 t/ha.

Harvest index and biomass

Chickpea

CICA1521 had an average biomass at harvest of 10.25 t/ha, significantly more than all other varieties. Despite the high biomass, CICA1521 also had a significantly higher harvest index (HI) of 0.34 (Table 3). PBA Boundary$^{\phi}$ and PBA Striker$^{\phi}$ had statistically similar harvest biomass at 9.47 and 9.66 t/ha, respectively, and no significant difference in HI at 0.32 and 0.33, respectively. Genesis™ 090 produced the least biomass (7.89 t/ha) and had the lowest HI (0.26).

Lentil

PBA Ace$^{\phi}$ harvest biomass averaged 10.55 t/ha, significantly more than all other varieties. PBA Bolt$^{\phi}$, PBA Hallmark XT$^{\phi}$ and PBA Greenfield$^{\phi}$ had statistically similar harvest biomasses, between 8.83 t/ha and 9.21 t/ha. PBA Bolt$^{\phi}$ had the highest HI at 0.31, but this was statistically similar to PBA Hallmark XT$^{\phi}$ at 0.30. PBA Greenfield$^{\phi}$ had a significantly lower HI of 0.21 (Table 3).

After hand cuts were completed, the remaining plot area was harvested with a plot header to assess harvestability on raised beds. Harvesting from raised beds was difficult, particularly with more prostrate lentil varieties causing feed-in difficulties. The average deficit in header yield compared with hand cuts ranged from 0.50 t/ha for chickpea, to 1.05 t/ha in lentil. The highest yielding varieties after header losses were CICA1521 with 2.92 t/ha for chickpea and PBA Bolt$^{\phi}$ with 1.82 t/ha for lentil.

Table 3 Harvest biomass (t/ha), harvest index and header yield shortfall (t/ha) of chickpea and lentil sown mid May at Leeton, 2019.

Species	Variety	Harvest biomass (t/ha)	Harvest index (%)	Header yield deficit versus hand cut yield (t/ha)
Chickpea	PBA Boundary	9.47	0.32	0.42
	CICA1521	10.25	0.34	0.63
	PBA Striker	9.66	0.33	0.42
	Genesis 090	7.89	0.26	0.27
	l.s.d. ($P<0.05$)	0.51	0.01	0.214
Lentil	PBA Hallmark XT	8.83	0.30	1.00
	PBA Ace	10.55	0.27	1.29
	PBA Bolt	9.21	0.31	0.98
	PBA Greenfield	8.98	0.21	0.96
	l.s.d. ($P<0.05$)	0.75	0.02	0.208

Conclusion

The pulses grown on raised beds with supplementary irrigation at Leeton in 2019 generally performed well. The not yet released chickpea variety CICA1521 performed best in terms of yield (3.55 t/ha) and biomass (10.25 t/ha).

PBA Bolt⟮D⟯, PBA Ace⟮D⟯ and PBA Hallmark XT⟮D⟯ lentil varieties also yielded well, all exceeding 2.5 t/ha.

The irrigation strategy of two spring irrigations, totalling 1.6 ML/ha, provided enough moisture for increased grain yield and total biomass. Carefully measuring evapotranspiration helped to prevent unnecessary irrigation. Waterlogging effects and additional disease pressure in chickpea were not observed in this experiment, probably due to the dry seasonal conditions and the raised beds allowing water to infiltrate without extended exposure to standing water.

Difficulty in header harvesting on irrigated beds might require careful variety selection focusing on taller, erect varieties combined with modified harvesting equipment.

Reference

Maphosa L, Napier T, Johnston D and Richards M, 2019. Chickpea phenology and grain yield response to sowing date – Leeton 2018. D Slinger, T Moore and C Martin (eds). *Southern NSW research results 2019*, pp. 77–82. NSW Department of Primary Industries, Australia.

Acknowledgements

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Chickpea phenology and grain yield response to sowing date – Wagga Wagga and Leeton 2019

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Key findings

- There was diversity in phenology between varieties.
- Early sowing extended the crop vegetative period, but increased exposure to frost damage during the flowering phase.
- Desi varieties PBA Striker$^{\phi}$, PBA Slasher$^{\phi}$, PBA Boundary$^{\phi}$ and CICA1521 were the highest yielding varieties at both sites.
- Dry conditions severely limited chickpea grain yield in 2019, but favoured early maturing varieties, particularly with mid May sowing.

Introduction

Grain yield can be optimised by ensuring that critical growth phases such as flowering and podding avoid abiotic stresses such as frost, heat and drought.

In southern NSW, critical growth periods, overall phenology, and environmental effects on pulses are poorly understood. Experiments were conducted in 2019 at Leeton and Wagga Wagga, aiming to determine the optimum sowing date to reduce effects from abiotic stresses and increase grain yield in chickpea. These experiments also aimed to identify phenological drivers of crop development in chickpea and determine which varieties are best adapted to the target environments. Varieties were selected based on prevalence in growing area, performance and diversity in phenology. Four sowing dates (SDs) were assessed, mid April (SD1), late April (SD2), mid May (SD3) and late May (SD4).

Site details – 1

Location	Wagga Wagga Agricultural Institute
Soil type	Red kandosol
Soil pH$_{Ca}$	6.6 (0–5 cm), 5.0 (5–10 cm), 4.6 (10–15 cm), 4.9 (15–20 cm), 5.4 (20–25 cm)
Previous crop	Wheat
Fertiliser	Granulock®Z Soygran 100 kg/ha (nitrogen [N]: 5.5, phosphorus [P]: 15.3, potassium [K]: 0.0, sulfur [S]: 7.5)
Post sowing water application	SD1: 15 mm on 17 April
Rainfall	• Fallow (November 2018–March 2019): 253 mm • In-crop (April 2019–October 2019): 145 mm • In-crop long-term average: 322 mm
Target plant density	45 plants/m^2

Weed management	Knock down herbicide • 2 L/ha Gladiator® CT (450 g/L glyphosate) on 18 April. Pre-emergence (at sowing) • 900 g/ha Terbyne® Xtreme (875 g/kg terbuthylazine). • 1.7 L/ha Avadex® Xtra (500 g/L tri-allate), incorporated by sowing (IBS). • 300 g/ha Terbyne® Xtreme (875 g/kg terbuthylazine), post sowing pre-emergent (PSPE). Post-emergence (18 June) • 300 mL/ha Select® Xtra (360 g/L clethodim), 500 mL/ha Uptake™ spraying oil (582 g/L paraffinic oil).
Disease management	• Dithane® (750 g/kg mancozeb) 2.2 kg/ha on 2 July and 22 July. • Fortress® 500 (500 g/L procymidone) 500 mL/ha on 6 August and 23 August.
Pest management	• Talstar® 250 EC (250 g/L bifenthrin) 30 mL/ha on 18 June. • Trojan® (150 g/L gamma-cyhalothrin) 20 mL/ha on 3 September and 4 October.
Harvest date	Harvest index cuts were taken as varieties reached maturity and plots were machine harvested on 29 November 2019.

Site details – 2

Location	Leeton Field Station
Soil type	Red dermosol
Soil pH_{Ca}	6.0 (0–10 cm), 6.4 (10–30 cm)
Previous crop	Barley
Fertiliser	Utiliser pulse mix 55 kg/ha (N: 7.48, P: 17.64, K: 6.24, calcium [Ca]: 6.4, zinc [Zn]: 0.32)
Water application	• Pre sowing flood irrigation on 8 April (approximately 2 ML/ha) • Post sowing: none
Rainfall	• Fallow (November 2018–March 2019): 310 mm • In-crop (April 2019–October 2019): 162 mm • In-crop long-term average: 193 mm
Target plant density	30 plants/m^2
Weed management	Knock down herbicide • 3 L/ha Sprayseed® 250E (135 g/L paraquat dichloride, 115 g/L diquat dibromide) on 11 April. • 3 L/ha Roundup PowerMax® (540 g/L glyphosate) on 15 April. Pre-emergence (at sowing) • 900 g/ha Terbyne® Xtreme (875 g/kg terbuthylazine). • 1.6 L/ha Avadex® Xtra (500 g/L tri-allate), incorporated by sowing (IBS).

	- 2 L/ha Rifle® 440 (440 g/L pendimethalin). Post-emergence - 300 g/ha Terbyne® Xtreme (875 g/kg terbuthylazine), post sowing pre-emergent (PSPE). - 85 mL/ha Verdict® 520 (520 g/L haloxyfop) on 14 May (SD1), 6 June (SD2), 18 June (SD3) and 20 June (SD4). - 190 mL/ha Leopard® 200EC (200 g/L quizalofop-p-ethyl) on 2 August and 7 August.
Disease management	- Dithane® (750 g/kg mancozeb) 2.2 kg/ha on 14 May (SD1), 6 June (SD2), 26 June and 6 August. - Amistar® 250 SC (250 g/L azoxystrobin) 500 mL/ha, Oriuso® 430SC (430 g/L tebuconazole) 500 mL/ha, Cheers® 720 (720 g/L chlorothalonil) 1.8 L/ha on 18 July and 25 July. - Veritas® (200 g/L tebuconazole, 130 g/L azoxystrobin) 1 L/ha on 2 August. - Dithane® (750 g/kg mancozeb) 2.2 kg/ha on 6 August. - Sumisclex® 500 (500 g/L procymidone) 1 L/ha on 8 August. - Veritas® (200 g/L tebuconazole, 130 g/L azoxystrobin) 1 L/ha, Cheers® 720 (720 g/L chlorothalonil) 2 L/ha on 8 August and 26 August. - Aviator® Xpro® (150 g/L prothioconazole, 75 g/L bixafen) 600 mL/ha on 4 September. - Veritas® (200 g/L tebuconazole, 130 g/L azoxystrobin) 1 L/ha, Cheers® 720 (720 g/L chlorothalonil) 2 L/ha on 15 September. - Cheers® 720 (720 g/L chlorothalonil) 2 L/ha on 26 September and 1 October.
Insect management	- Transform® (500 g sulfoxaflor) 300 mL/ha on 8 August. - Pirimidex (500 g/kg pirimicarb) 150 g/ha, Success® Neo (120 g/L spinetoram) 200 mL/ha on 4 September and 27 September.
Harvest date	Hand cuts for harvest index: 5 November and 6 November; machine harvest: 13 November.

Treatments

Eight chickpea varieties, five Desi and three Kabuli, were sown on four sowing dates.

Desi varieties

PBA Boundary$^{\phi}$, PBA Striker$^{\phi}$, PBA Slasher$^{\phi}$, CICA1521 and PBA HatTrick$^{\phi}$

Kabuli varieties

Genesis™ 079, Genesis™ 090 and Kalkee

Sowing date (SD)

SD1: 15 April

SD2: 30 April

SD3: 15 May

SD4: 30 May

Results

Seasonal conditions

The drought conditions in the 2019 growing season reduced yield potential at both sites. Wagga Wagga received 145 mm rainfall from April to October, which is significantly lower than the long-term average of 322 mm. Leeton received 162 mm rainfall from April to October and was closer to the long-term average of 193 mm. In addition, several severe frosts at both sites during winter and spring impeded crop growth and pod set. Below average rainfall and above average temperatures also affected the September and October flowering and grain filling periods.

Phenology

Time to emergence took longer when sowing date was delayed, ranging from nine days (SD1 at Wagga Wagga) to 29 days (SD4 at Leeton). This delayed emergence was due to decreased soil temperature in late autumn, requiring a longer time to satisfy the minimum growing degree days required for emergence.

Interactions between variety (V) and sowing date (SD) were found with PBA Striker$^{\phi}$ the first variety to emerge at Leeton, while Genesis™079 emerged earliest at Wagga Wagga. Averaged across varieties, SD2 had the highest establishment (47 plants/m^2) at Wagga Wagga while SD4 had the highest establishment (47 plants/m^2) at Leeton.

Generally, the vegetative, flowering and podding phases shortened when sowing was delayed (Figure 1). However, podding initiation generally occurred at the same time, because chickpea in general will not set and/or retain pods until a mean daily temperature of around 15 °C is achieved (Berger et al., 2004; Clarke and Siddique, 2004; Warren et al., 2019).

Table 1 Grain yield at Leeton and Wagga Wagga in 2019.

Variety	**Leeton**					**Wagga Wagga**				
	Grain yield (t/ha)					**Grain yield (t/ha)**				
	SD1	**SD2**	**SD3**	**SD4**	**Mean**	**SD1**	**SD2**	**SD3**	**SD4**	**Mean**
CICA1521	1.06	1.10	1.91	1.70	1.44	0.14	0.64	0.92	0.94	0.66
Genesis079	1.20	1.51	1.51	1.52	1.44	0.24	0.60	0.76	0.68	0.57
Genesis090	0.92	1.51	1.19	1.28	1.23	0.18	0.60	0.64	0.64	0.52
Kalkee	0.56	1.29	1.30	1.04	1.05	0.15	0.59	0.75	0.60	0.52
PBA Boundary	0.90	1.89	1.42	1.62	1.46	0.13	0.48	0.85	0.71	0.54
PBA HatTrick	0.51	1.37	1.56	1.20	1.16	0.10	0.48	0.67	0.75	0.50
PBA Slasher	1.12	1.86	1.78	1.72	1.62	0.15	0.60	0.75	0.79	0.57
PBA Striker	1.32	1.88	1.76	1.73	1.67	0.28	0.81	0.98	0.87	0.74
Mean	0.95	1.55	1.55	1.48		0.17	0.60	0.79	0.75	
l.s.d. ($P \leq 0.05$)										
Variety	0.21					0.08				
SD	0.13					0.06				
Variety × SD	n.s					0.13				

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

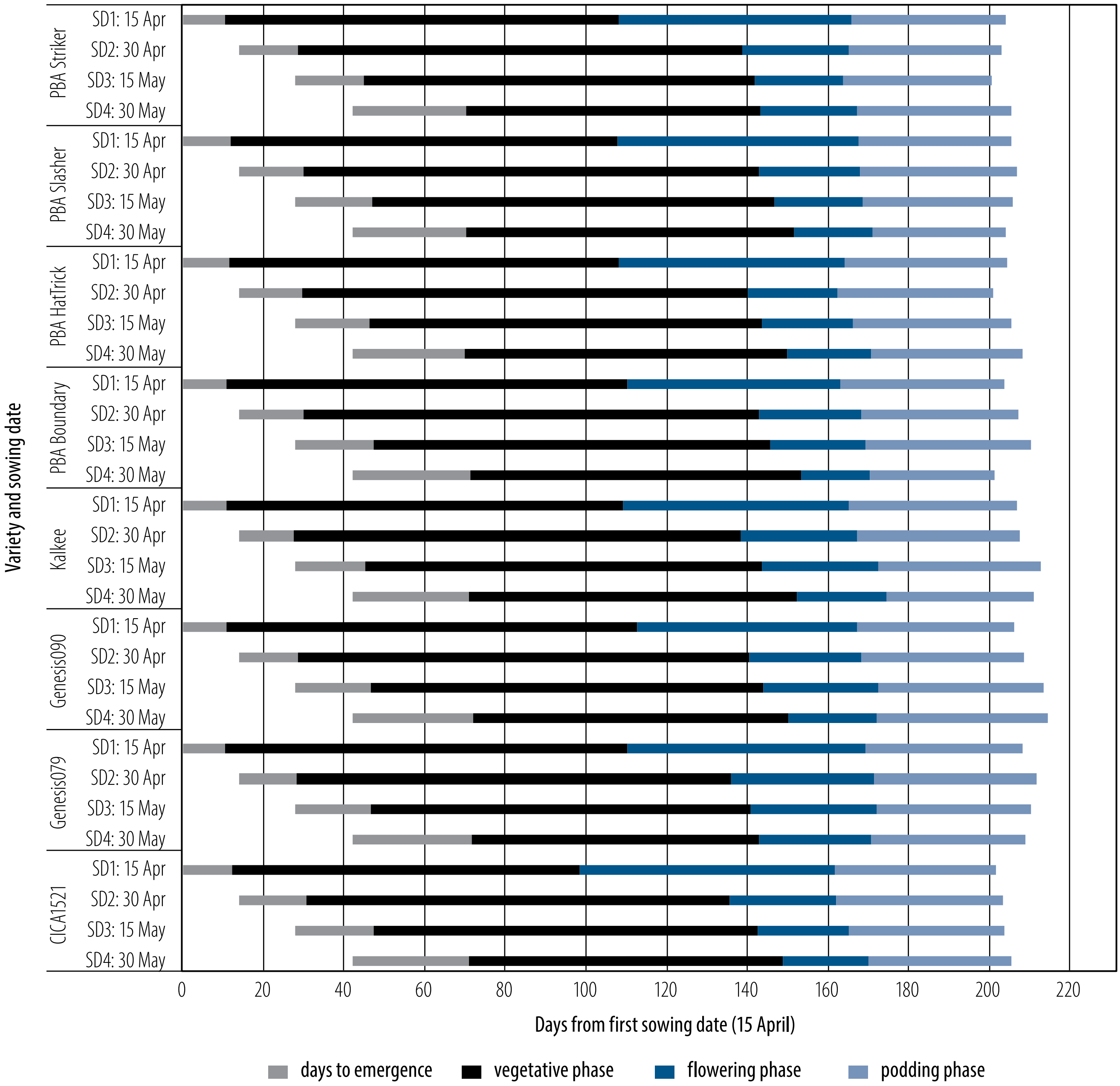


Figure 1 Influence of sowing date at Wagga Wagga on emergence, start and duration of key chickpea phasic growth stages.

Grain yield and yield components

Averaged across varieties, SD2, SD3 and SD4 were equal highest yielding at Leeton, while at Wagga Wagga SD3 and SD4 had the highest grain yields (Table 1).

The varieties PBA HatTrick$^{\Phi}$ and Kalkee were the lowest yielding at Leeton, while at Wagga Wagga the lowest yielding varieties were Kalkee and Genesis™090. Kalkee was consistently low yielding and therefore is likely not suited to the environments of southern NSW. PBA Striker$^{\Phi}$, an early maturing variety, was the highest yielding at both sites. This highlights the importance of early–mid season maturity for avoiding late season abiotic constraints such as heat and/or moisture stress.

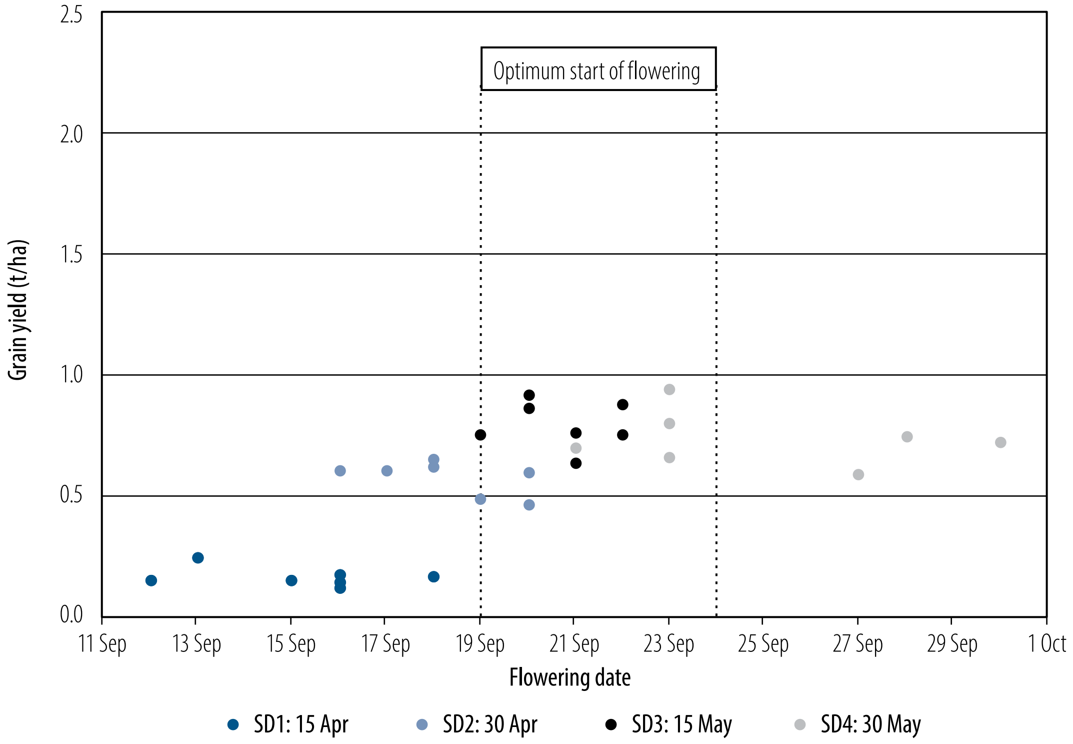
Filled pods, total pod number and seed numbers per plant were lowest for SD1 at both sites. The low number of pods could be due to pod abortion and/or drop during prolonged unfavourable conditions (frost/heat stress). Also, ascochyta blight infection was first observed in SD1 at Leeton and a management program was implemented to minimise disease effects across all treatments.

Harvest index ranged from 0.13 (SD1) to 0.37 (SD4) at Leeton and 0.04 (SD1) to 0.38 (SD4) at Wagga Wagga, with V × SD interactions at both sites (data not presented). Later sowing resulted in lower biomass, ranging from 3.96 t/ha (SD4) to 7.36 t/ha (SD1) at Leeton and 1.94 t/ha (SD4) to 4.58 t/ha (SD1) at Wagga Wagga, with V × SD interactions at Wagga Wagga only (data not presented). However, the higher biomass from SD1 was not correlated with greater grain production, probably due to SD1 depleting available soil water before grain filling was complete.

Relationship between phenology and grain yield

The optimum start of flowering was deduced to be around 19 September to 24 September for Wagga Wagga and 6 September to 13 September for Leeton from the 2019 data (figures 2 and 3). The later start at Wagga Wagga is driven by the cooler weather at this location relative to Leeton. In 2019, starting flowering around these dates ensured that chickpea avoided abiotic stresses, such as frost, early in the growing season, and heat and terminal drought later in the season.

Experiments conducted in 2019 have been combined with data collected in 2018; variety phenology and performance have been analysed to create a two-year average. This analysis was used to generate a preliminary guide for optimal sowing periods in southern NSW (Table 2). As data was collected over two years that had low rainfall and increased incidence of abiotic stresses, these guidelines are only suitable for similar seasons.



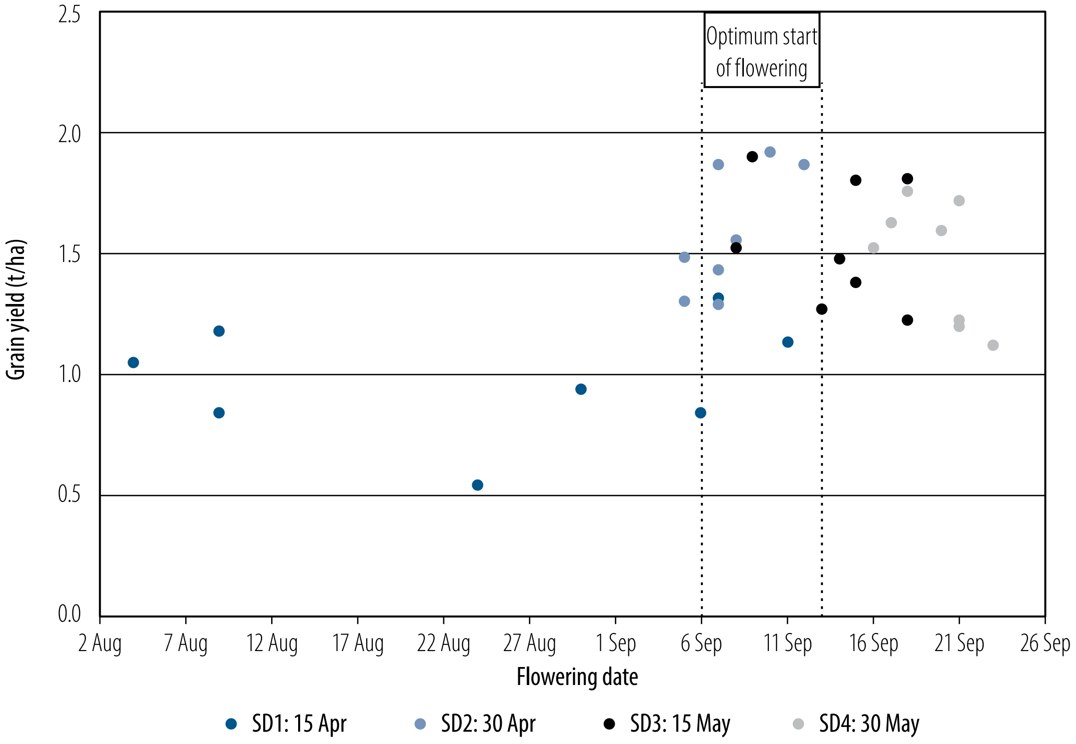
Dots represent date of 50% flowering by varieties across sowing dates, optimal start of flowering is marked by vertical lines.

Figure 2 Optimum start of flowering for chickpea at Wagga Wagga in 2019.

Table 2 Preliminary guidelines for optimum sowing periods for chickpea varieties common across 2018 and 2019 experiments.

Variety	Maturity	Optimum sowing period for yield (southern NSW, low rainfall season)			
		Mid April	Late April	Mid May	Late May
CICA 1521	Early	⬛	⬜	🟦	⬜
PBA Striker	Early	⬛	⬜	🟦	⬜
PBA Boundary	Mid/late	⬛	⬜	🟦	⬜
PBA Slasher	Early	⬛	🟦	🟦	🟦
Genesis079	Early	⬛	⬜	🟦	🟦
Kalkee	Late	⬛	⬜	🟦	⬛
Genesis090	Mid/late	⬛	🟦	🟦	🟦

Dark grey indicates unsuitable sowing time, light grey indicates earlier or later than recommended, yield reduction likely, light blue indicates preferred sowing time. Guidelines only suitable for low rainfall seasons.



Dots represent date of 50% flowering by varieties across sowing dates, optimal start of flowering is marked by vertical lines.

Figure 3 Optimum start of flowering for chickpea at Leeton in 2019.

Conclusion

The 2019 experiments indicate that sowing date can be used to target the optimum start of flowering to maximise grain yield for the different locations. It is important to note that this data was collected during a year that was characterised by significantly drier than average growing conditions, increased incidences of abiotic stresses, and lower yields.

Matching sowing date and varietal phenology (sowing date × variety combination) ensures that the sensitive growth stages such as flowering and podding occur at optimal times. Results from 2019 indicate that sowing around mid May in these environments gives the varieties tested the best opportunity to avoid abiotic stresses and allows efficient conversion of biomass to grain yield. Early sowing or longer maturing varieties are at greater risk of exposure to potential frost damage and late season adverse conditions such as terminal drought and heat stress. Early sowing also results in low harvest index as most of the accumulated biomass is not converted to grain yield.

Preliminary optimal sowing guidelines for chickpea in southern NSW in low rainfall seasons have been developed using this data. Additional research is required to quantify the affect on chickpea phenology and grain yield in average or high rainfall years.

References

Berger JD, Turner NC, Siddique KHM, Knights EJ, Brinsmead RB, Mock I, Edmondson C and Khan TN, 2004. Genotype by environment studies across Australia reveal the importance of phenology for chickpea (*Cicer arietinum* L.) improvement. *Australian Journal of Agricultural Research*, vol. 55, pp. 1071–1084.

Clarke HJ and Siddique KHM, 2004. Response of chickpea genotypes to low temperature stress during reproductive development. *Field Crops Research*, vol. 90, pp. 323–334.

Warren A, Graham N, Raman R and Hobson K, 2019. The physiology and genetics of cold temperatures in chickpeas – what do we know and where is the research heading? https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2019/02/the-physiology-and-genetics-of-cold-temperatures-in-chickpeas-what-do-we-know-and-where-is-the-research-heading. Viewed 27 May 2020.

Acknowledgements

This experiment was part of the 'Adaptation of profitable pulses in the central and southern zones of the northern grains region' project, BLG112, March 2018 to June 2020, a joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

Thank you to Nelson West and Ollie Owen for their technical assistance.

Lentil phenology and grain yield response to sowing date – Wagga Wagga and Leeton 2019

Mark Richards, Dr Aaron Preston, Dr Lance Maphosa, Dr Maheswaran Rohan, Karl Moore, Scott Clark (NSW DPI, Wagga Wagga); Tony Napier, Reuben Burrough and Daniel Johnston (NSW DPI, Leeton)

Key findings

- There was diversity in phenology between varieties.
- Early sowing extended the crop vegetative period, but increased exposure to frost damage during flowering.
- Dry conditions severely limited lentil grain yield in 2019, but favoured early maturing varieties, particularly with mid May sowing.
- High yielding lentil varieties were PBA Ace$^{\phi}$, PBA Bolt$^{\phi}$ and PBA Hurricane XT$^{\phi}$ at Wagga Wagga, and PBA Hallmark XT$^{\phi}$ and PBA Bolt$^{\phi}$ at Leeton. Nipper$^{\phi}$ demonstrated broad adaptation at Wagga Wagga.

Introduction

Grain yield can be optimised by ensuring that critical growth phases such as flowering and podding avoid abiotic stresses such as frost, heat and drought.

In southern New South Wales (NSW), critical growth periods, overall phenology, and environmental effects on pulses are poorly understood. Experiments conducted in 2019 at Leeton and Wagga Wagga, aimed to determine the optimum sowing date for lentil to reduce effects from abiotic stresses and increase grain yield. These experiments also aimed to identify phenological drivers of crop development in lentil and determine which varieties are best adapted to the target environments.

Varieties were selected based on their prevalence in the growing area, performance, and diversity in phenology. Four sowing dates (SDs) were assessed: mid April (SD1), late April (SD2), mid May (SD3) and late May (SD4).

Site details – 1

Location	Wagga Wagga Agricultural Institute
Soil type	Red kandosol
Soil pH_{Ca}	6.6 (0–5 cm), 5.0 (5–10 cm), 4.6 (10–15 cm), 4.9 (15–20 cm), 5.4 (20–25 cm)
Previous crop	Wheat
Fertiliser	Granulock®Z Soygran 100 kg/ha (nitrogen [N]: 5.5, phosphorus [P]: 15.3, potassium [K]: 0.0, sulfur [S]: 7.5)
Post sowing water application	SD1: 15 mm on 16 April
Rainfall	• Fallow (November 2018–March 2019): 253 mm • In-crop (April 2019–October 2019): 145 mm • In-crop long-term average: 322 mm

Target plant density	120 plants/m^2
Weed management	Knock down herbicide • 2 L/ha Gladiator® CT (450 g/L glyphosate), 1 L Amicide® Advance 700 (700 g/L 2,4D amine) on 25 January. • 2 L/ha Gladiator® CT (450g/L glyphosate) on 18 April. Pre-emergence (at sowing) • 900 g/ha Terbyne® Xtreme (875 g/kg terbuthylazine). • 1.7 L/ha Avadex® Xtra (500 g/L tri-allate), incorporated by sowing (IBS). • 300 g/ha Terbyne® Xtreme (875 g/kg terbuthylazine), post sowing pre-emergent (PSPE). Post-emergence (18 June) • 300 mL/ha Select® Xtra (360 g/L clethodim), 500 mL/ha Uptake™ spraying oil (582 g/L paraffinic oil). Disease management • Dithane® (750 g/kg mancozeb) 2.2 kg/ha on 2 July and 22 July. • Fortress® 500 (500 g/L procymidone) 500 mL/ha on 6 August and 23 August.
Insect management	• Talstar® 250 EC (250 g/L bifenthrin) 30 mL/ha on 18 June. • Trojan® (150 g/L gamma-cyhalothrin) 20 mL/ha on 3 September and 4 October.
Harvest date	Harvest index cuts were taken as varieties reached maturity and plots were machine harvested on 29 November 2019.

Site details – 2

Location	Leeton Field Station
Soil type	Red dermosol
Soil pH_{Ca}	6.0 (0–10 cm), 6.4 (10–30 cm)
Previous crop	Barley
Fertiliser	Utiliser pulse mix 55 kg/ha (N: 7.48, P: 17.64, K: 6.24, calcium [Ca]: 6.4, Zinc [Zn]: 0.32)
Water application	• Pre sowing: flood irrigation on 8 April (approximately 2 ML/ha) • Post sowing water application: none
Rainfall	• Fallow (November 2018–March 2019): 310 mm • In-crop (April 2019–October 2019): 162 mm • In-crop long-term average: 193 mm
Target plant density	120 plants/m^2
Weed management	Knock down herbicide • 3 L/ha Sprayseed® 250E (135 g/L paraquat dichloride, 115 g/L diquat dibromide) on 11 April.

	• 3 L/ha Roundup PowerMax® (540 g/L glyphosate) on 15 April. Pre-emergence (at sowing) • 900 g/ha Terbyne® Xtreme (875 g/kg terbuthylazine). • 1.6 L/ha Avadex® Xtra (500 g/L tri-allate), incorporated by sowing (IBS). • 2 L/ha Rifle® 440 (440 g/L pendimethalin). Post-emergence • 300 g/ha Terbyne® Xtreme (875 g/kg terbuthylazine), post sowing pre-emergent (PSPE). • 85 mL/ha Verdict® 520 (520 g/L haloxyfop) on 14 May (SD1), 6 June (SD2), 18 June (SD3) and 20 June (SD4). • 190 mL/ha Leopard® 200EC (200 g/L quizalofop-p-ethyl) on 2 August and 7 August.
Disease management	• Dithane® (750 g/kg mancozeb) 2.2 kg/ha on 14 May (SD1), 6 June (SD2), 26 June and 6 August. • Amistar® 250 SC (250 g/L azoxystrobin) 500 mL/ha, Oriuso® 430 SC (430 g/L tebuconazole) 500 mL/ha, Cheers® 720 (720 g/L chlorothalonil) 1.8 L/ha on 18 July and 25 July. • Veritas® (200 g/L tebuconazole, 130 g/L azoxystrobin) 1 L/ha on 2 August. • Dithane® (750 g/kg mancozeb) 2.2 kg/ha on 6 August. • Sumisclex® 500 (500 g/L procymidone) 1 L/ha on 8 August. • Veritas® (200 g/L tebuconazole, 130 g/L azoxystrobin) 1 L/ha, Cheers® 720 (720 g/L chlorothalonil) 2 L/ha on 8 August and 26 August. • Aviator® Xpro® (150 g/L prothioconazole, 75 g/L bixafen) 600 mL/ha on 4 September. • Veritas® (200 g/L tebuconazole, 130 g/L azoxystrobin) 1 L/ha, Cheers® 720 (720 g/L chlorothalonil) 2 L/ha on 15 September. • Cheers® 720 (720 g/L chlorothalonil) 2 L/ha on 26 September and 1 October.
Insect management	• Transform® (500 g sulfoxaflor) 300 mL/ha on 8 August. • Pirimidex (500 g/kg pirimicarb) 150 g/ha, Success® Neo (120 g/L spinetoram) 200 mL/ha on 4 September and 27 September.
Harvest date	• Hand cuts for harvest index: 28 October and 29 October; PBA Greenfield⦶ SD4 on 4 November. • Machine harvest: 31 October; PBA Greenfield⦶ SD4 harvested on 4 November.

Treatments

Eight lentil varieties were sown on four sowing dates.

Lentil varieties

PBA Ace⦶, PBA Blitz⦶, PBA Bolt⦶, PBA Greenfield⦶, PBA Hallmark XT⦶, PBA Hurricane XT⦶, PBA Jumbo 2⦶ and Nipper⦶

Sowing date (SD)

SD1: 15 April

SD2: 30 April

SD3: 15 May

SD4: 30 May

Results

Seasonal conditions

The drought conditions in the 2019 growing season reduced yield potential at both sites. Wagga Wagga received 145 mm rainfall from April to October, significantly lower than the 322 mm long-term average. Leeton received 162 mm rainfall from April to October, close to the long-term 193 mm average, in addition to the approximately 2 ML/ha of flood irrigation. Also, several severe frosts at both sites during winter and spring negatively affected crop growth and pod set.

Below average rainfall and above average temperatures also affected the September and October flowering and grain filling periods.

Also, at Leeton, ascochyta blight infection was seen in a neighbouring experiment, hence the disease management regime was increased to minimise any effects.

Phenology

Days to emergence were longer at both sites when sowing date was delayed, ranging from seven days (both sites) to 19 days at Leeton.

Overall phenological development (duration of vegetative phase, flowering, and podding) decreased with delayed sowing dates (Figure 1), at both sites and displayed variety (V) by sowing date (V × SD) interactions. PBA Blitz$^{\phi}$ was the earliest to flower at both sites, with Nipper$^{\phi}$ and PBA Greenfield$^{\phi}$ the slowest. Sowing date had no effect on establishment at Wagga Wagga, while late sowing (SD3 and SD4) resulted in higher establishment at Leeton, with V × SD interaction at Leeton only (data not presented).

Grain yield and yield components

There was a significant interaction between variety and sowing date at both sites. Averaged across varieties, grain yield at Wagga Wagga was higher for the mid and late May sowing dates (SD3 and SD4; 0.70 t/ha and 0.76 t/ha) than mid and late April sowing dates (SD1 and SD2; 0.19 t/ha and 0.52 t/ha) respectively. At Leeton, grain yield was higher from late April to late May sowing dates (SD2, SD3 and SD4; 1.17 t/ha, 1.25 t/ha and 1.17 t/ha) than the mid April sowing date (SD1; 0.72 t/ha) (Table 1).

PBA Bolt$^{\phi}$ and PBA Hallmark XT$^{\phi}$ had consistently high yields from the end of April sowing (SD2) at Leeton. At Wagga Wagga, all varieties except PBA Ace$^{\phi}$ and Nipper$^{\phi}$ had high yields from SD3 whilst PBA Hallmark XT$^{\phi}$, PBA Ace$^{\phi}$ and PBA Bolt$^{\phi}$ were also the highest yielding from SD4.

Averaged across sowing dates, the slower maturity PBA Greenfield$^{\phi}$ was the lowest yielding at Leeton and all varieties except Nipper$^{\phi}$ yielded similarly at Wagga Wagga. Nipper$^{\phi}$ demonstrated broad adaptation at Wagga Wagga with the highest yield when averaged across all sowing dates and was the best performing variety when sown early (SD1).

At Wagga Wagga, which was not pre-watered, grain yields from the mid April sowing date (SD1) were very low, for example PBA Ace$^{\phi}$ and PBA Hallmark XT$^{\phi}$, yielded 0.07 t/ha and 0.08 t/ha respectively (Table 1). However, this could also be partly due to frosts, which were more severe at Wagga Wagga than at Leeton.

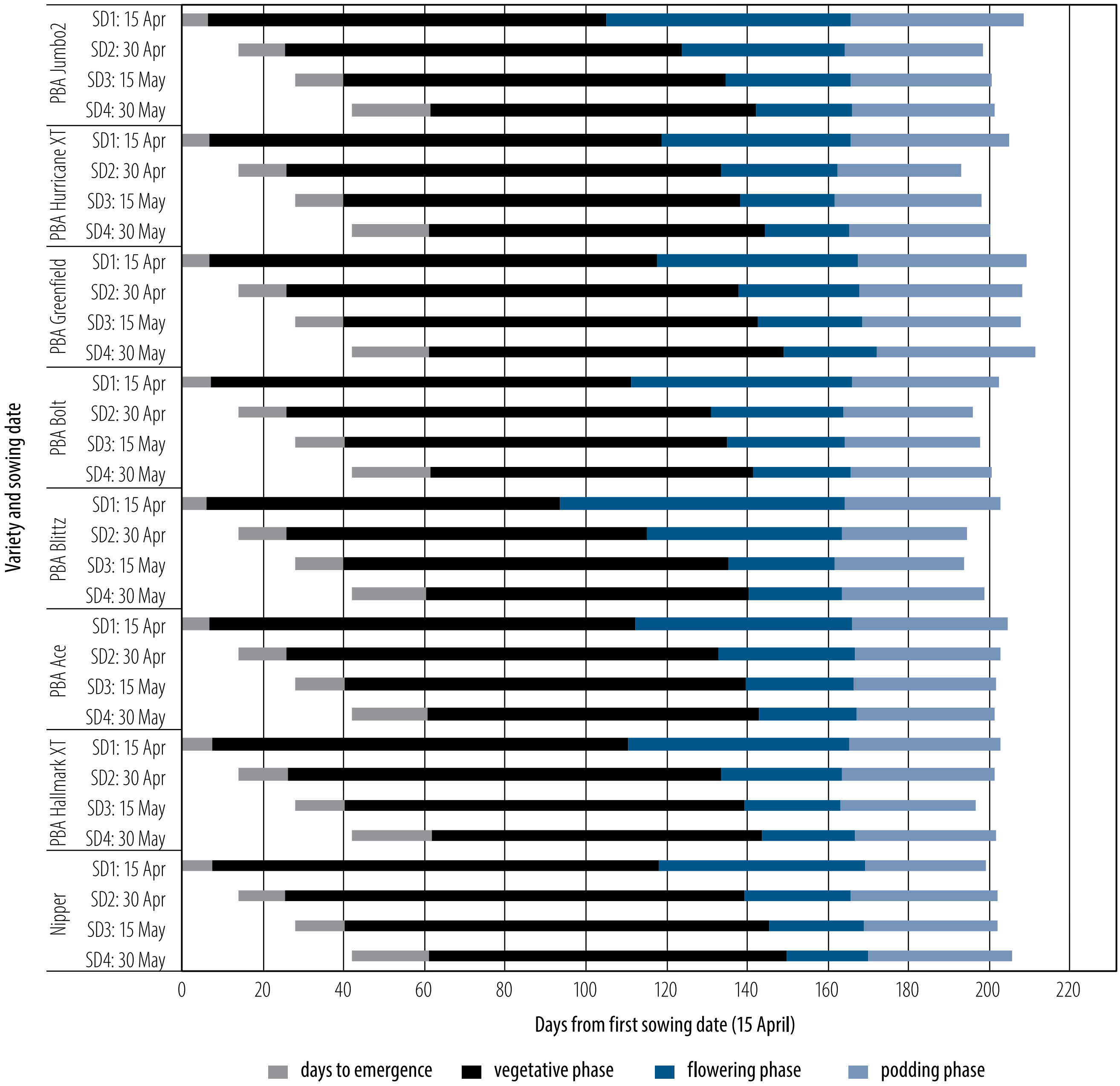


Figure 1 Influence of sowing date at Leeton on emergence, start and duration of key lentil growth stages.

Sowing date did not affect the grain weight of 100 seeds (100 gwt) at Leeton, while it decreased with delayed sowing at Wagga Wagga (data not presented). Yield components responded differently at each site, with filled pod number/seed number driving yield at Leeton and 100 gwt being the key driver at Wagga Wagga. Delaying sowing resulted in a higher harvest index, ranging from 0.10 (SD1) to 0.31 (SD4) at Leeton and 0.06 (SD1) to 0.34 (SD4) at Wagga Wagga, with V × SD interactions at both sites (data not presented).

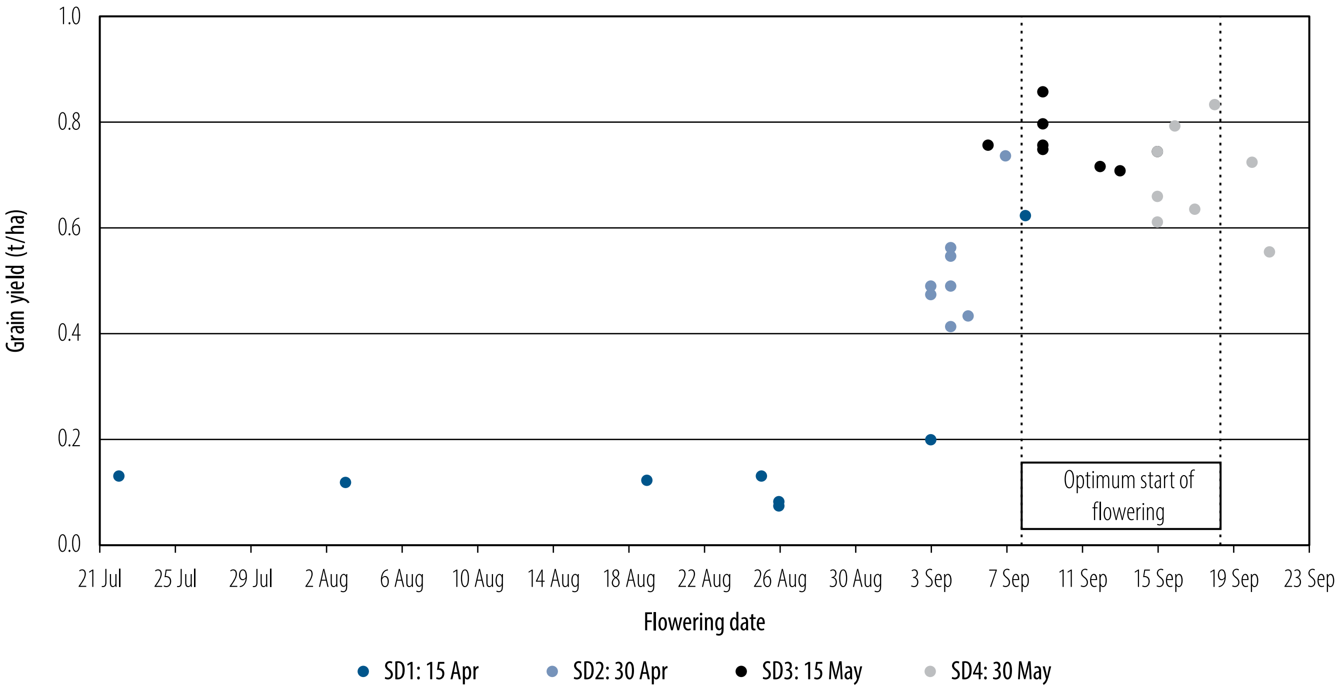
The bottom pod height measured from plant components (not field), was lower when sowing date was delayed, and ranged from 16.9 cm (SD4) to 25.0 cm (SD1) at Wagga Wagga, and 14.8 cm (SD4) to 25.6 cm (SD1) at Leeton, where it showed no V × SD interaction (data not presented).

Table 1 Grain yield at Leeton and Wagga Wagga in 2019.

Variety	Leeton					Wagga Wagga				
	Grain yield (t/ha)					Grain yield (t/ha)				
	SD1	SD2	SD3	SD4	Mean	SD1	SD2	SD3	SD4	Mean
Nipper	0.72	0.97	0.98	0.99	0.92	0.63	0.74	0.71	0.73	0.70
PBA Hallmark XT	0.74	1.53	1.52	1.41	1.30	0.08	0.55	0.76	0.79	0.55
PBA Ace	0.82	1.04	1.10	1.17	1.03	0.07	0.49	0.72	0.84	0.53
PBA Blitz	0.64	1.05	1.34	1.33	1.09	0.13	0.49	0.76	0.61	0.50
PBA Bolt	0.76	1.68	1.54	1.36	1.34	0.12	0.47	0.86	0.75	0.55
PBA Greenfield	0.59	0.60	0.71	0.55	0.61	0.20	0.43	0.75	0.56	0.49
PBA Hurricane XT	0.70	1.47	1.38	1.17	1.18	0.13	0.41	0.80	0.64	0.50
PBA Jumbo2	0.76	1.03	1.46	1.35	1.15	0.12	0.56	0.75	0.66	0.52
Mean	0.72	1.17	1.25	1.17	1.08	0.19	0.52	0.76	0.70	0.54
l.s.d. ($P \leq 0.05$)										
Variety	0.17					0.06				
SD	0.21					0.06				
Variety x SD	0.35					0.13				

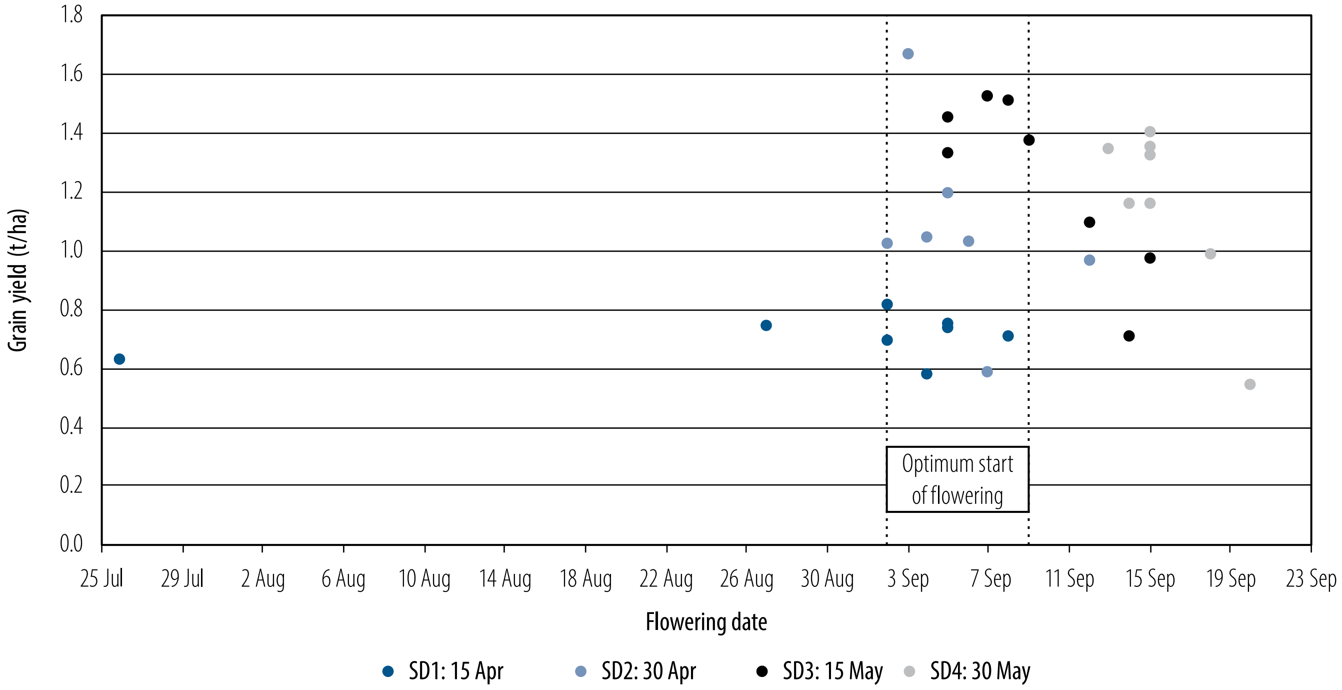
Relationship between phenology and grain yield

The optimum start of flowering was deduced to be in the period 8 September to 18 September for Wagga Wagga and 2 September to 9 September for Leeton from the 2019 data (figures 2 and 3). The later start at Wagga Wagga was driven by the slightly cooler weather at this location relative to Leeton. In 2019, starting flowering around these dates ensured that lentil avoided abiotic stresses, such as frost, early in the growing season, and heat and terminal drought later in the season.



Dots represent date of 50% flowering by varieties across sowing dates, optimal start of flowering is marked by vertical lines.

Figure 2 Optimum start of flowering for lentil at Wagga Wagga in 2019.



Dots represent date of 50% flowering by varieties across sowing dates, optimal start of flowering is marked by vertical lines.

Figure 3 Optimum start of flowering for lentil at Leeton in 2019.

Experiments conducted in 2019 have been combined with data collected in 2018; the variety phenology and performance was analysed to create a two-year average. This analysis was used to generate a preliminary guide for optimal sowing windows in southern NSW (Table 2). As data was collected in two years with low rainfall and increased incidences of abiotic stresses, these guidelines are only suitable for similar seasons.

Table 2 Preliminary guidelines for optimum sowing periods for selected lentil varieties, generated from 2018 and 2019 experiments.

Variety	**Maturity**	**Optimum sowing period for yield (southern NSW, low rainfall season)**			
		Mid April	**Late April**	**Mid May**	**Late May**
PBA Ace	Mid	⬛	⬜	🟦	🟦
PBA Jumbo2	Mid	⬛	⬜	🟦	⬜
PBA Hallmark XT	Early	⬛	⬜	🟦	🟦
PBA Hurricane XT	Mid	⬛	⬜	🟦	⬜
PBA Bolt	Early/mid	⬛	⬜	🟦	⬜
Nipper	Mid/late	⬜	🟦	🟦	⬜
PBA Blitz	Early	⬛	⬜	🟦	⬜
PBA Greenfield	Mid/late	⬛	⬜	⬜	⬛

Dark grey indicates unsuitable sowing time, light grey indicates earlier or later than recommended, with yield reduction likely, light blue indicates preferred sowing time. Guidelines only suitable for low rainfall seasons.

Conclusion

The 2019 experiments indicate that there is an optimum start of flowering for the different locations; sowing date can be optimised to target this. It is important to note that this data was collected during a year that was characterised by drier than average growing conditions, increased incidence of abiotic stresses and lower yields.

Matching sowing date and varietal phenology (sowing date × variety combination) ensures that the sensitive growth stages such as flowering and podding occur at optimal times. Results from 2019 indicate that sowing around mid May gives the varieties tested here the best opportunity to avoid abiotic stresses and allows efficient conversion of biomass to grain yield. In dry seasons PBA Greenfield$^{\Phi}$, with its longer total growth phase across all sowing dates, is at greater risk of exposure to adverse conditions such as terminal drought and heat stress. Early sowing in a dry season also results in low harvest index as most of the accumulated biomass is not converted to grain yield. However, the higher biomass will generally equate to greater nitrogen fixation.

Preliminary optimal sowing guidelines for lentil in southern NSW in low rainfall seasons have been developed using data from experiments in 2018 and 2019. Additional research is required to quantify the impact on lentil phenology and grain yield in average or high rainfall years.

Acknowledgements

This experiment was part of the 'Adaptation of profitable pulses in the central and southern zones of the northern grains region' project, BLG112, March 2018 to June 2020, a joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

Thanks to Nelson West and Ollie Owen for their technical assistance.

The effects from surface residue on the phenology and grain yield of chickpea and lentil – Wagga Wagga 2018

Mark Richards, Dr Lance Maphosa, Dr Aaron Preston, Dr Iain Hume, Dr Maheswaran Rohan, Karl Moore and Scott Clark (NSW DPI, Wagga Wagga)

Key findings

- Total number, severity and length of frosts increased as surface residues increased.
- Increasing the amount of surface residue delayed plant growth, lengthened growth phase duration, and overall time to maturity for both chickpea and lentil.
- For both chickpea and lentil, high surface residues, above 9 t/ha, significantly reduced biomass accumulation and grain yield.

Introduction

Some modern equipment such as stripper fronts and disc seeders allow for high levels of stubble residue from previous crops to be retained. This increases the retention of soil water following rainfall, however, the effects of stubble residue on following pulse crop growth and development are poorly understood.

Retained stubble affects thermal profiles in the crop growth environment, both above the stubble surface and below the soil surface. Stubble acts as an insulator, limiting the soil's heat absorption during the day, and reduces stored heat from radiating back into the crop canopy at night. This results in cooler soil during the day and lower air temperature above the stubble at night (compared with bare soil), potentially increasing the severity of chilling and/or frost (Verrell, 2016). This experiment, which was part of a larger project based at Tamworth (BLG106), was conducted to determine the effect on chickpea and lentil crop development and grain yield from varying amounts of cereal surface residue (mimicking stubble load) and the resulting lower temperatures.

The experiment was conducted in 2018 at Wagga Wagga, NSW under dryland conditions. The surface residue treatments (baled wheat stubble) were applied uniformly immediately after sowing to ensure there was no treatment effect on stored soil water at sowing. It is important to note that the treatments simulated a flattened surface residue, not standing cereal stubble.

Site details

Location	Wagga Wagga Agricultural Institute
Sowing date	15 May
Soil type	Red kandosol
Soil pH_{Ca}	6.5 (0–5 cm), 5.3 (5–10 cm), 4.8 (10–15 cm), 5.1 (15–20 cm), 5.5 (20–25 cm)
Fertiliser	Granulock®Z Soygran 100 kg/ha (nitrogen, [N]: 5.5, phosphorus [P]: 15.3, potassium [K]: 0.0, sulfur [S]: 7.5)
Previous crop	Barley
Rainfall	• Fallow (November 2017–March 2018): 310 mm • In-crop (1 April 2018–31 October 2018): 162 mm • In-crop long-term average: 330 mm

Post sowing water application	5.1 mm – 25 May
Target plant density	40 plants/m^2 chickpea; 120 plants/m^2 lentil.
Weed management	Pre-emergence • 900 g/ha Terbyne® Xtreme (875 g/kg terbuthylazine), 1.6 L/ha Avadex® Xtra (500 g/L tri-allate), 1.7 L/ha TriflurX® (480 g/L trifluralin), incorporated by sowing (IBS). Post emergence • 300 mL/ha Select® Xtra (360 g/L clethodim), 500 mL/ha Uptake™ spraying oil (582 g/L paraffinic oil).
Insect pest management	• Astound® (100 g/L alpha-cypermethrin) 300 mL/ha – 23 May, 21 September. • Astral 250EC (250 g/L bifenthrin) 40 mL/ha – 29 September.
Harvest date	Harvest index cuts were taken as varieties reached maturity; plots were machine harvested on 19 November 2018.

Treatments

Chickpea varieties

CICA1521, PBA Slasherᶲ and PBA HatTrickᶲ

Lentil varieties

PBA Aceᶲ and PBA Jumbo2ᶲ

Wheat surface residue applied

Five surface residue treatments were tested; 0 t/ha, 3 t/ha, 6 t/ha, 9 t/ha, and 12 t/ha.

The temperature was measured across three replicates at surface residue level.

Results

Effect of surface residue on soil water

Moisture levels at sowing were measured using EM38 technology and were confirmed to be consistent across all surface residue treatments. A subsequent decline in EM values across the growing season was attributed to crop water use and losses through evaporation, as shown by greater declines in bare soil and 3 t/ha surface residue.

Between 5 September 2018 and the final measurement after harvest (4 December 2018), soil moisture increased due to rainfall. Final EM38 measurements (Figure 1) indicated that available water was higher (i.e. EM value is higher) with increasing surface residue, with no significant difference between the 3 t/ha, 6 t/ha and 9 t/ha treatments, but all the others were statistically different. More water remained with higher surface residue, as surface residue would have prevented water loss through evaporation, but also intensified frosts, which resulted in less biomass accumulation. Due to their smaller biomass, these plants would have used less water from the soil and had reduced transpiration losses.

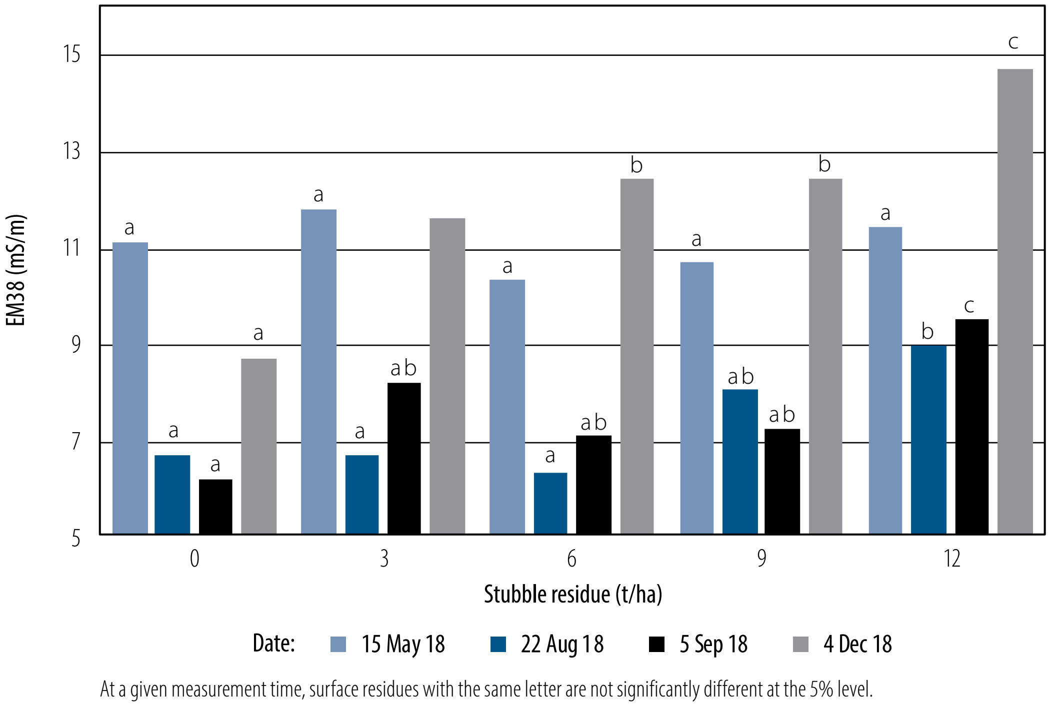


Figure 1 EM38 values in millisiemens per metre (mS/m) collected over four dates and five surface residue amounts (0–12 t/ha).

Effect of surface residue on temperature

The number of frost days (days with a temperature below 0 °C) were recorded in both chickpea and lentil plots (Figure 2). Frost days were mostly recorded during the vegetative growth phase and decreased in frequency throughout flowering and podding. There was a linear response with increasing amounts of surface residue.

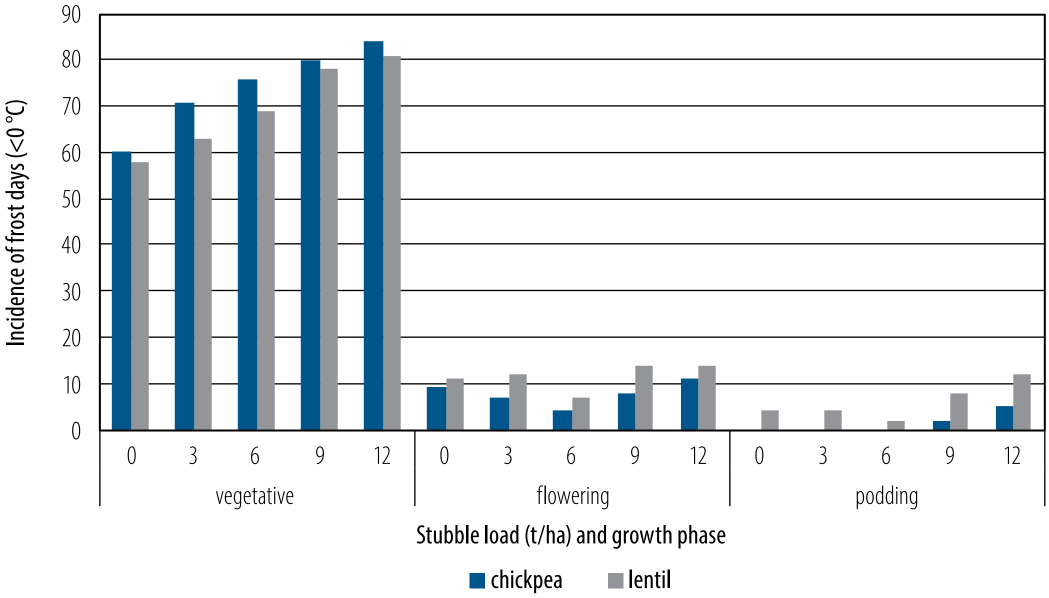


Figure 2 Number of frost days (days with a temperature <0 °C) recorded on stubble surface at each growth phase (vegetative, flowering and podding) for chickpea and lentil at Wagga Wagga in 2018.

Low temperatures at flowering and podding causes flower and pod abortion and is a major factor in unstable yields. As the amount of surface residue increased, during flowering, the cumulative number of hours below 0 °C increased for chickpea (PBA HatTrick$^{\text{⊕}}$) and for lentil (PBA Ace$^{\text{⊕}}$), and the absolute minimum temperature decreased (Table 1).

For chickpea, averaged across three replicates, the lowest absolute minimum temperature on the residue surface was –7.8 °C at 12 t/ha (with up to 11.1 hours of below 0 °C on one day) and –4.6 °C (with up to 8.3 hours of below 0 °C) at 0 t/ha on 17 September. For lentil, at 9 t/ha and 12 t/ha up to 11.8 hours of below 0 °C was experienced compared with 8.5 hours at 0 t/ha. The lowest absolute minimum temperature for lentil was –8.1 °C at 12 t/ha and –4.0 °C at 0 t/ha on 17 September.

Table 1 Lowest daily minimum temperature, daily hours below 0 °C and cumulative hours when surface temperature was below 0 °C during chickpea and lentil flowering period.

Flowering period	Surface residue	Lowest daily minimum (°C)	Maximum daily hours less than 0 °C	Cumulative hours less than 0 °C
Chickpea				
17 Sep–12 Oct	0 t/ha	–4.6	8.3	32.7
17 Sep–12 Oct	3 t/ha	–5.7	9.4	53.1
17 Sep–12 Oct	6 t/ha	–5.7	9.6	59.2
17 Sep–12 Oct	9 t/ha	–6.8	10.4	74.2
17 Sep–12 Oct	12 t/ha	–7.8	11.1	87.8
Lentil				
12 Sep–19 Oct	0 t/ha	–4.0	8.5	35.5
12 Sep–19 Oct	3 t/ha	–5.4	8.5	56.8
12 Sep–19 Oct	6 t/ha	–5.0	8.5	56.0
12 Sep–19 Oct	9 t/ha	–8.1	11.8	123.8
12 Sep–19 Oct	12 t/ha	–8.1	11.8	125.5

Chickpea phenology

The duration of the vegetative, flowering and podding phases differed between treatments and varieties (data not shown). For all three varieties the vegetative phase was significantly shorter at 0 t/ha due to higher surface temperatures. In PBA Slasher$^{\text{⊕}}$ and PBA HatTrick$^{\text{⊕}}$, the vegetative phase was significantly shorter at 3 t/ha than the 6 t/ha, 9 t/ha and 12 t/ha treatments. For all three varieties, 0 t/ha had the longest flowering duration and there was a significant variety × surface residue interaction. Podding duration showed no varietal difference, but was longer at higher surface residue (12 t/ha). Plants took longer to reach physiological maturity at 12 t/ha than at 0 t/ha.

Lentil phenology

The duration of the vegetative, flowering and podding phases differed between residue treatments and varieties, but there was no interaction (data not shown). At all surface residue treatments, PBA Jumbo2$^{\text{⊕}}$ flowered earlier than PBA Ace$^{\text{⊕}}$. Increasing amounts of surface residue extended the vegetative phase duration.

The vegetative phase duration increased from 113 days for PBA Jumbo2$^{\text{⊕}}$ and 116 days for PBA Ace$^{\text{⊕}}$ on bare soil (0 t/ha) to 129 days for PBA Jumbo2$^{\text{⊕}}$ and 131 days for PBA Ace$^{\text{⊕}}$ with high (12 t/ha) residue loads.

Surface residue, in addition to delaying flowering, also reduced flowering duration compared with bare soil, possibly due to flowering starting when temperatures were higher and hence accelerating plant development. Generally, there was a trend towards delayed physiological maturity as surface residue increased. There was a significant increase in days to physiological maturity from 0 t/ha to 12 t/ha surface residue, but with no varietal differences.

Chickpea biomass, grain yield and yield components

Plant establishment decreased with increasing surface residue (Table 2). However, no varietal responses or interactions between variety and surface residue were found. This was due to the increased difficulty for emerging seed to push through the higher surface residue treatments.

Harvest biomass and grain yield were significantly lower at 12 t/ha than all other surface residue treatments (Table 2). Varietal differences were found, but had no interaction with surface residue treatment; PBA HatTrick⁽ᶲ⁾ had the largest biomass, followed by CICA1521 and PBA Slasher⁽ᶲ⁾ with the lowest biomass.

Grain yield ranged from a low of 0.85 t/ha for PBA Slasher⁽ᶲ⁾ at 12 t/ha up to 1.5 t/ha in CICA1521 at 0 t/ha (Table 2). At all surface residue treatments, CICA1521 was highest yielding and PBA Slasher⁽ᶲ⁾ lowest yielding. There were differences in yield components and harvest index (Table 2). CICA1521 had the largest 100 grain weight (21.01 g) at 0 t/ha surface residue (bare soil) and PBA Slasher⁽ᶲ⁾ had the smallest grain weight (15.17 g) at 12 t/ha surface residue. Pod number per plant ranged from 14 for CICA1521 (13 filled) at 0 t/ha surface residue, to 31 for PBA HatTrick⁽ᶲ⁾ (25 filled) grown at 9 t/ha surface residue. Seeds per plant ranged from 20 at 0 t/ha to 30 at 12 t/ha surface residue and there were no varietal differences. Harvest index ranged from 0.41 for PBA HatTrick⁽ᶲ⁾ grown at 9 t/ha surface residue to 0.51 for CICA1521 at 0 t/ha surface residue.

Lentil biomass, grain yield and yield components

For plant establishment there were no varietal differences for surface residue load or interactions between variety and surface residue (Table 3).

There were differences due to variety and surface residue treatment on harvest biomass, but there was no interaction between variety and surface residue treatment (Table 3). Across all surface residues, PBA Ace⁽ᶲ⁾ had higher biomass than PBA Jumbo2⁽ᶲ⁾.

There were no varietal differences in grain yield, but surface residue had an effect, with a significant decrease in grain yield as surface residue increased above 3 t/ha (Table 3). The 12 t/ha treatment was the lowest yielding at 0.96 t/ha, while the 3 t/ha surface residue treatment was the highest yielding with a grain yield of 1.47 t/ha. The differences in yield mirrored the differences in 100 grain weight where 12 t/ha surface residue resulted in low grain weight. There were no significant effects for variety, surface residue and interaction on total, filled and unfilled pod number, and on harvest index.

Conclusion

The 2018 growing season at Wagga Wagga was one of the most difficult on record with a high level of frost incidence and below average growing season rainfall of 162 mm April–October, compared with the long-term average of 330 mm. We found that as surface residue amounts increased, in-crop surface minimum temperatures declined, and lethal frost frequency and the duration of radiant frost increased. As a result, the observed delay in flowering for both chickpea and lentil with high surface residue is likely due to lower temperatures and a greater number of frost days (less than 0 °C) delaying floral initiation and overall plant growth. The longer growth duration, especially in chickpea, in the 12 t/ha surface residue treatment, was due to the significant vegetative frost damage and subsequent regrowth observed in this treatment. The subsequent regrowth was insufficient to compensate for the severe vegetative frost damage.

For chickpea, there was a linear decline in grain yield with increasing surface residue. The higher pod number (filled and unfilled) and seed number did not compensate for the lower grain weight at 12 t/ha and hence the 12 t/ha was significantly lower yielding than all other surface residue treatments.

Table 2 Chickpea establishment, biomass, yield and yield components at harvest for different surface residues at Wagga Wagga in 2018.

Variety	Surface residue (t/ha)	Establishment (plants/m^2)	Biomass (t/ha)	100 grain weight (g)	Pod no./ plant	Filled pod no./plant	Unfilled pod no./ plant	Yield (t/ha)	Harvest index
CICA1521	0	42.3	2.90	21.01	14	13	1	1.48	0.51
	3	38.7	3.03	20.29	15	14	1	1.47	0.49
	6	40.3	2.95	19.15	20	17	3	1.39	0.47
	9	32.3	2.94	18.64	24	21	3	1.35	0.46
	12	28.7	2.01	17.79	21	19	2	1.01	0.50
	Mean	37.1	2.87	18.06	26	21	5	1.24	0.43
PBA HatTrick	0	39.7	3.00	19.69	21	17	4	1.38	0.46
	3	41.0	3.13	18.97	22	18	4	1.37	0.44
	6	37.7	3.05	17.83	27	21	6	1.29	0.42
	9	33.7	3.04	17.32	31	25	6	1.24	0.41
	12	33.7	2.11	16.47	28	23	5	0.91	0.43
	Mean	37.1	2.87	18.06	26	21	5	1.24	0.43
PBA Slasher	0	42.3	2.65	18.40	17	15	2	1.32	0.50
	3	38.7	2.78	17.68	19	16	2	1.31	0.47
	6	37.7	2.70	16.54	23	19	4	1.23	0.46
	9	37.0	2.69	16.02	27	23	4	1.18	0.44
	12	30.0	1.76	15.17	24	21	3	0.85	0.48
	Mean	37.1	2.52	16.76	22	19	3	1.18	0.47
Mean of all varieties	0	41.4	2.85	19.70	17	15	2	1.39	0.49
	3	39.4	2.98	18.98	19	16	2	1.38	0.47
	6	38.6	2.90	17.84	23	19	4	1.30	0.45
	9	34.3	2.89	17.33	27	23	4	1.26	0.44
	12	30.8	1.96	16.48	24	21	3	0.92	0.47
l.s.d. (*P*<0.05)									
Surface residue		7.93	0.34	0.87	5.15	4.3	1.34	0.14	0.01
Variety		n.s	0.2	0.37	3.55	2.96	0.92	0.10	0.01
Interaction (surface residue × variety)		n.s	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.03

n.s., not significant.

Table 3 Lentil biomass, yield and yield components at harvest for different surface residues at Wagga Wagga in 2018.

Variety	Surface residue (t/ha)	Establishment (m^2)	Biomass (t/ha)	100 grain weight (g)	Seeds/ plant	Pod no./ plant	Filled pod no./plant	Unfilled pod no./ plant	Grain yield (t/ha)	Harvest index
PBA Ace	0	131.0	2.98	4.72	25.0	22.0	19	3	1.33	0.44
	3	124.0	3.36	4.63	30.0	23.0	20	2	1.54	0.46
	6	118.0	3.17	4.62	24.0	19.0	17	2	1.35	0.43
	9	114.0	2.79	4.33	33.0	23.0	22	1	1.14	0.41
	12	102.0	2.66	4.19	25.0	25.0	21	4	1.02	0.38
	Mean	117.8	2.99	4.50	27.4	22.4	20	2	1.27	0.42
PBA Jumbo2	0	117.0	2.94	5.46	23.0	23.0	20	3	1.37	0.46
	3	124.0	2.85	5.38	20.0	18.0	16	2	1.40	0.49
	6	120.0	2.68	5.37	18.0	17.0	14	2	1.19	0.44
	9	106.0	2.85	5.08	24.0	20.0	19	1	1.16	0.41
	12	115.0	2.29	4.94	22.0	26.0	20	4	0.91	0.39
	Mean	116.4	2.72	5.25	21.4	20.8	18	2	1.20	0.44
Mean of all varieties	0	124.0	2.96	5.09	24.0	22.5	20	3	1.35	0.45
	3	124.0	3.10	5.01	25.0	20.5	18	2	1.47	0.48
	6	119.0	2.93	5.00	21.0	18.0	16	2	1.27	0.44
	9	110.0	2.82	4.71	28.5	21.5	21	1	1.15	0.41
	12	108.5	2.47	4.57	23.5	25.5	21	4	0.96	0.39
l.s.d. ($P<0.05$)										
Surface residue		n.s	0.35	0.16	n.s.	n.s.	n.s.	n.s.	0.15	n.s.
Variety		n.s	0.18	0.07	0.1	n.s.	n.s.	n.s.	0.09	n.s.
Interaction (surface residue × variety)		n.s	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s	n.s.

n.s., not significant.

Similarly, for lentil the lower temperatures at 12 t/ha surface residue resulted in decreased biomass accumulation, lower grain weight and yield. Conversely, the 3 t/ha surface residue treatment had the highest yield, thus indicating that lower surface residue quantities can make a beneficial contribution.

The results of this experiment highlight the need for improved understanding of the interaction between variable surface residue and abiotic stressors across pulse species and the implications of high stubble loads/residues in stubble retention and disc seeding systems. While there is generally a low probability of seeding into high surface residue loads greater than 9 t/ha in the dryland cereal growing areas of southern NSW, this experiment highlights the potential risk to pulse production.

Reference

Verrell A, 2016. Stubble and its impact on temperature in chickpea crops. *GRDC Update paper*, Grains Research and Development Corporation, https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/07/stubble-and-its-impact-on-temperature-in-chickpea-crops. Viewed on 20 April 2020.

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Research update for the long-term subsoil acidity experiment (2016–2019)

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Key findings

- Lime is the most effective amendment to increase pH and reduce exchangeable aluminium (Al).
- Deep placement of organic materials had a limited effect on soil pH, but reduced exchangeable aluminium percentage (Al%) significantly.
- The combination of lime with organic materials could facilitate alkalinity downwards in the soil profile in the short term.
- However, applying a large amount of organic materials could acidify soil over a longer term due to nitrification.
- No crop response was observed over the past three years due to severe drought conditions.

Introduction

Subsoil acidity is a major constraint to ongoing productivity in the high rainfall zone (500–800 mm) of south-eastern Australia (Scott et al., 2000). Approximately 50% of Australia's agriculture zone (~50 M ha) has a surface soil pH <5.5 in calcium chloride (pH_{Ca}, hereafter) and half of this area also has subsoil acidity (SoE, 2011). In southern NSW, there are 13.5 M ha of agricultural soils exhibiting a subsurface soil acidity problem (Dolling et al., 2001). The agricultural production loss from soil acidity was estimated as $387 million a year in NSW alone (SoE, 2011).

Applying lime to the surface is a widely accepted practice to combat soil acidification in top soils (Scott et al., 2000; Ryan, 2018). However, lime moves very slowly down the soil profile so subsoil acidity will only be ameliorated after decades of regular lime application where soil surface pH_{Ca} is maintained above 5.5 (Li et al., 2019). Results from two soil surveys conducted in 2006 and in 2015–2017 in southern NSW showed that soil acidity is continuing to move further down the soil profile even where lime was applied regularly over a 10 year period (Burns and Norton, 2018). The challenge, therefore, is how to stop further soil acidification and speed up the amelioration process in the subsoil.

To address the problem of subsoil acidification, a long-term field experiment was established in 2016. The objectives were to:

- manage subsurface soil acidity through innovative amelioration methods that will increase productivity, profitability and sustainability
- study soil processes, such as changes in soil chemical, physical and biological properties over the long term.

Site details

Location	Dirnaseer, west of Cootamundra, NSW
Soil type	Red chromosol (Isbell, 1996)

Crop rotation	Phase 1 Phase 2 Phase 3 Phase 4	EGA Gregory$^{\Phi}$ wheat Hyola® 559TT canola La Trobe$^{\Phi}$ barley Morgan$^{\Phi}$ field pea (2016, 2018) PBA Samira$^{\Phi}$ faba bean (2017, 2019)
Rainfall	See Table 1	
Starter fertiliser	14 kg nitrogen (N)/ha, 15 kg phosphorus (P)/ha and 1 kg sulfur (S)/ha as di-ammonium phosphate (DAP, 18% N, 20% P and 1.6% S) for all crops	
Top-dressing fertiliser	See Table 2	

Table 1 Fallow (November–March) and in-crop (April–October) rainfall in experiment years and long-term averages at Dirnaseer, west of Cootamundra, NSW.

Year	Fallow rainfall (mm)	In-crop rainfall (mm)
2016	265	682
2017	302	269
2018	244	173
2019	230	189
Long-term average	257	332

Table 2 Top-dressing fertiliser applied to crops at Dirnaseer, west of Cootamundra, NSW.

Crop	Top-dressing fertiliser
Canola and barley	86 kg N/ha as urea, total N fertiliser input 100 kg N/ha.
Wheat	36 kg N/ha as urea, total N fertiliser input 50 kg N/ha. It was assumed the previous grain legumes fixed at least 50 kg N/ha, thus total N input from fertiliser and biological fixation was equivalent to about 100 kg N/ha or above.
Pulse	No additional N fertiliser input apart from 14 kg N/ha as DAP at sowing.

Treatments Experiment treatments are described in Table 3.

Table 3 Soil amendment and treatment description at Dirnaseer, west of Cootamundra, NSW.

ID	Treatment	Treatment description
1	Nil amendment	No amendment, representing the 'do nothing' approach.
2	Surface liming	Lime was applied at 4.0 t/ha, incorporated to 10 cm deep, calculated to achieve an average pH_{Ca} >5.5.
3	Deep ripping only	Soil was ripped to 30 cm deep with no amendment. However, the surface soil was limed at 2.5 t/ha, incorporated to 10 cm deep, calculated to achieve an average pH_{Ca} of 5.0.
4	Deep liming	Lime was deep-placed in the 10–30 cm depth with ripping. Surface soil was also limed and incorporated to 10 cm, targeted to achieve an average pH_{Ca} of 5.0 at 0–30 cm. Total lime used was 5.5 t/ha.
5	Deep lucerne pellets (LP)	Deep organic amendment in the form of lucerne hay pellets (LP, 15 t/ha) was deep-placed at 10–30 cm deep. The surface soil was limed and incorporated to 10 cm, targeted to achieve an average pH_{Ca} of 5.0.
6	Deep liming plus LP	A combination of treatments 4 and 5, with lime and LP to maximise the benefits of lime and organic materials.

Measurements

Soil chemical analysis

Soil pH_{Ca}, exchangeable cations, soil mineral N.

Rooting depth and root density

Maximum rooting depth and root density for each crop at anthesis.

Crop agronomy

Seedling count at establishment, crop dry matter (DM) at anthesis and grain yield.

Results and discussion

Soil chemical properties

Deep liming and deep liming with LP significantly increased soil pH at 10–20 cm and 20–30 cm in 2017, 12 months after treatments were implemented. During 2018 and 2019, soil pH was maintained at ~6.0 at 10–20 cm for both deep liming and deep liming with LP treatments. However, by 2019 soil pH at 20–30 cm reduced to levels similar to the nil control on both deep liming and deep liming with LP treatments (Figure 1). This is most likely due to nitrification of organic materials and mineral N plant uptake that produced an excess of hydrogen ions. Soil pH for the surface liming treatment was maintained above 5.5, but had no effect on subsoil pH over 2017 to 2019.

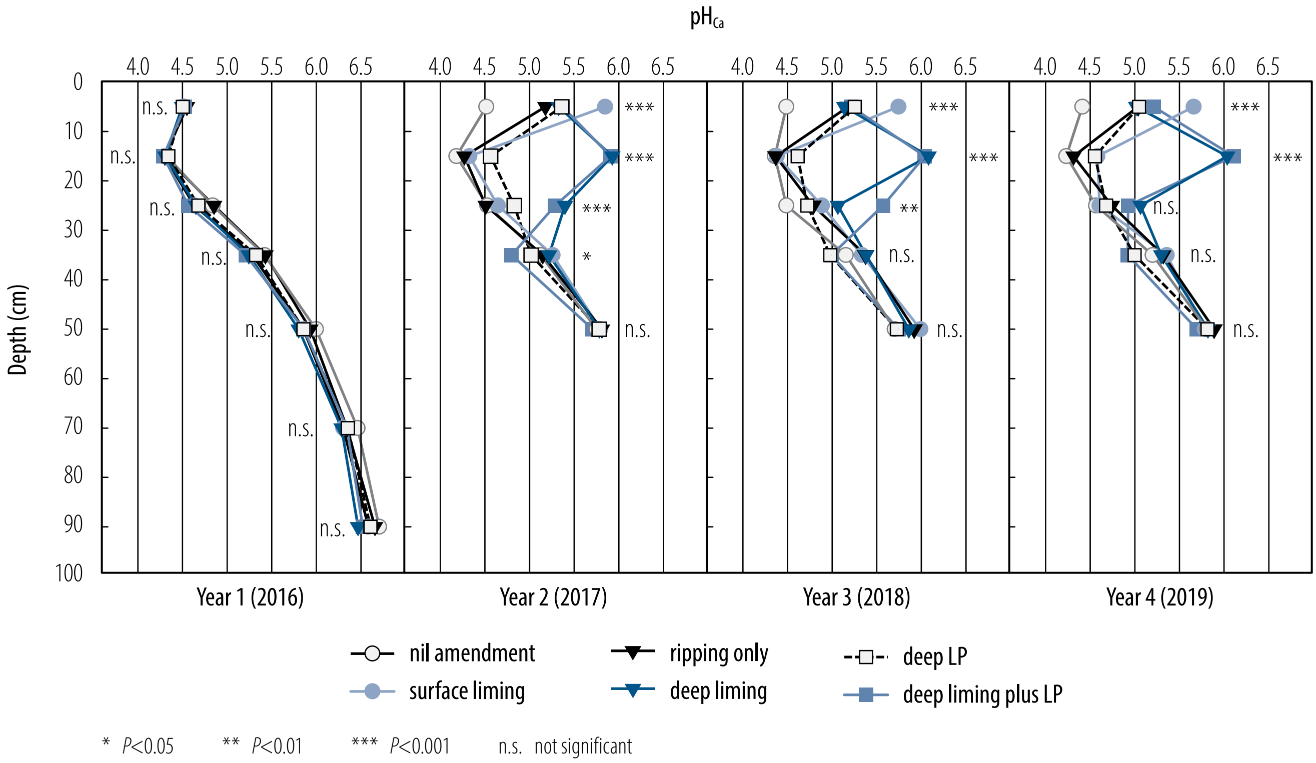


Figure 1 Soil pH (pH_{Ca}) under different soil amendment treatments in autumn in years 1–4.

Decomposed organic materials are known to increase soil pH initially (Butterly et al., 2010b), then reduce the soil pH subsequently due to the nitrification process (Butterly et al., 2010a). When combined with lime, the soluble component from organic materials moved down the soil profile with the alkali (Nguyen et al., 2018), hence ameliorating subsoil acidity. However, results from this experiment showed that pH below the depth of soil amendments (>30 cm) decreased slightly over three years under the LP treatments with and without lime. This indicated that applying a large amount of organic material could acidify the soil in the field over the long term (Figure 2). Further research is required to confirm this finding in the field.

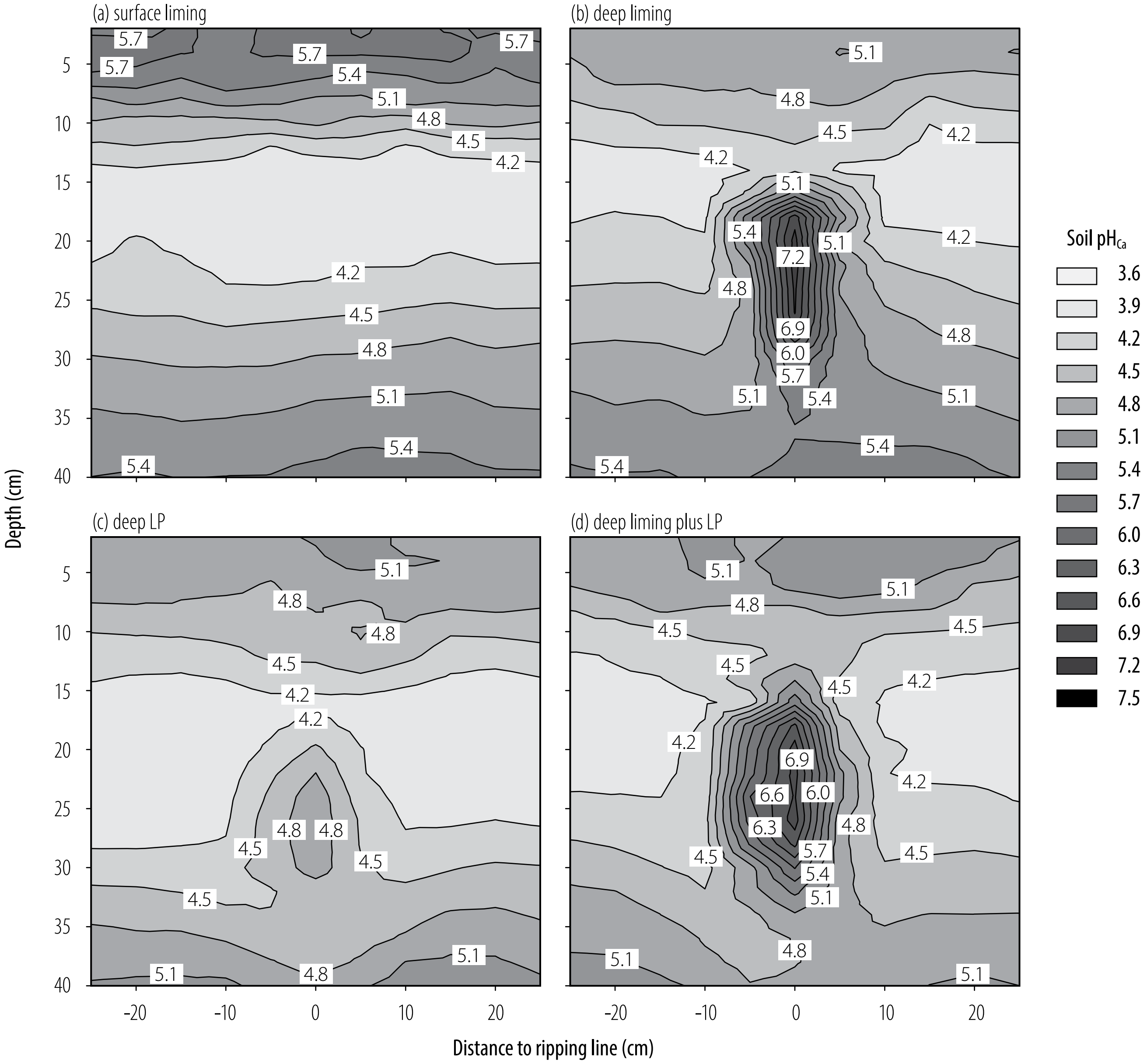


Figure 2 The spatial distribution of soil pH (pH$_{Ca}$) in the soil profile with (a) surface liming, (b) deep liming, (c) deep LP, and (d) deep liming plus LP in 2019, four years after treatments were implemented.

Deep liming with and without LP significantly reduced exchangeable Al% at 10–30 cm one year after treatments were implemented (Figure 3). The exchangeable Al level was maintained below 3% through to 2019.

Although LP did not increase soil pH as much as expected, it did reduce exchangeable Al% significantly at 10–20 cm, compared with the nil treatment. At 20–30 cm, the treatment difference was significant for exchangeable Al% in 2017 and 2018, but not in 2019. It is possible that the soluble organic molecules from organic amendments combines with active Al^{3+} to form insoluble hydroxy-Al compounds as suggested by Haynes and Mokolobate (2001).

There was significantly more soil mineral N at 0–60 cm under deep LP and deep liming with LP treatments in 2017–2019 (*P*<0.001) compared with treatments without LP (Figure 4). On average, there was an additional 100 kg N/ha soil mineral N available in deep LP and deep liming with LP treatments compared with all other treatments in 2017–2019 (Figure 4). This indicates that the nutrients derived from LP could last more than three years, which could have been prolonged by low nutrient removal over the drought-affected years of 2018 and 2019.

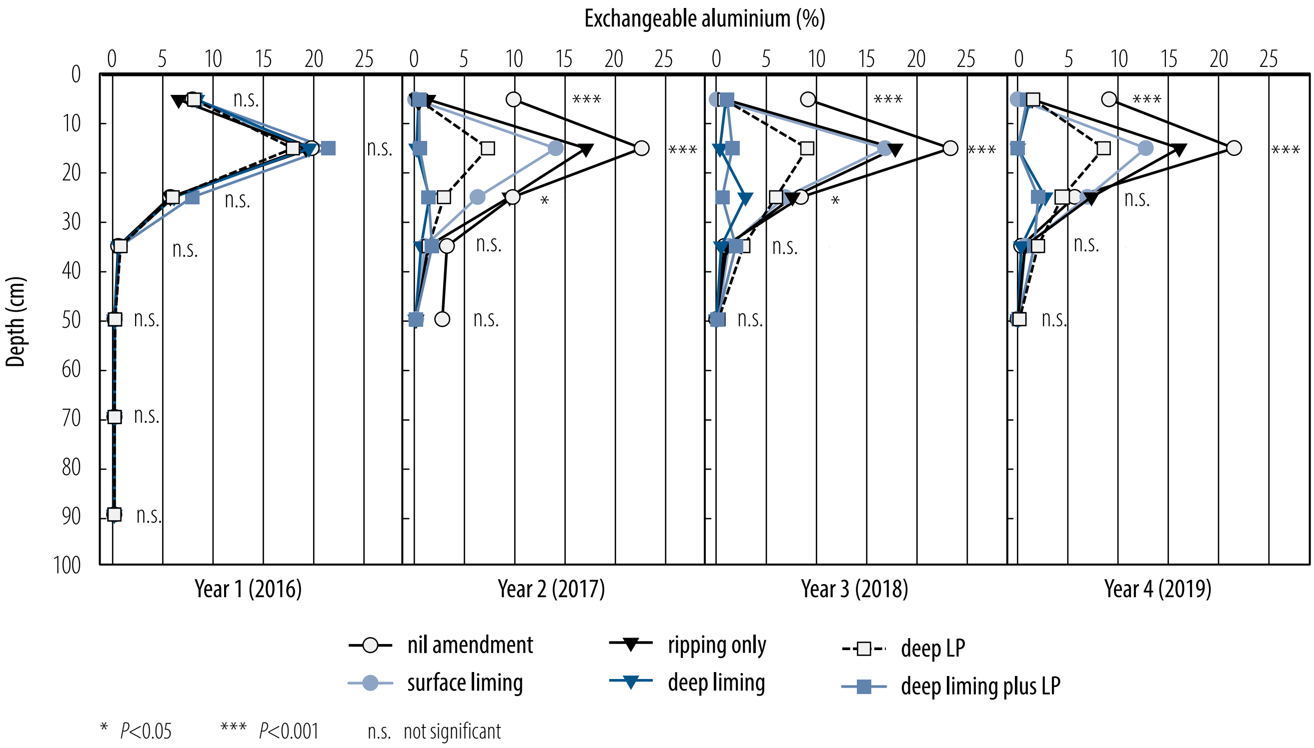


Figure 3 Soil exchangeable aluminium (%) under different soil amendment treatments in years 1–4.

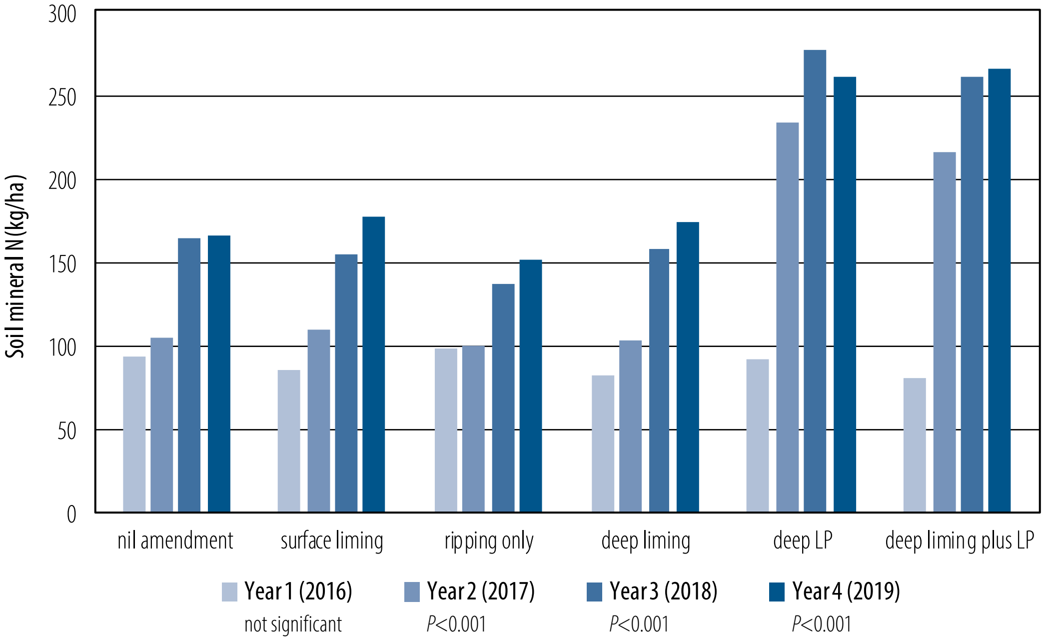
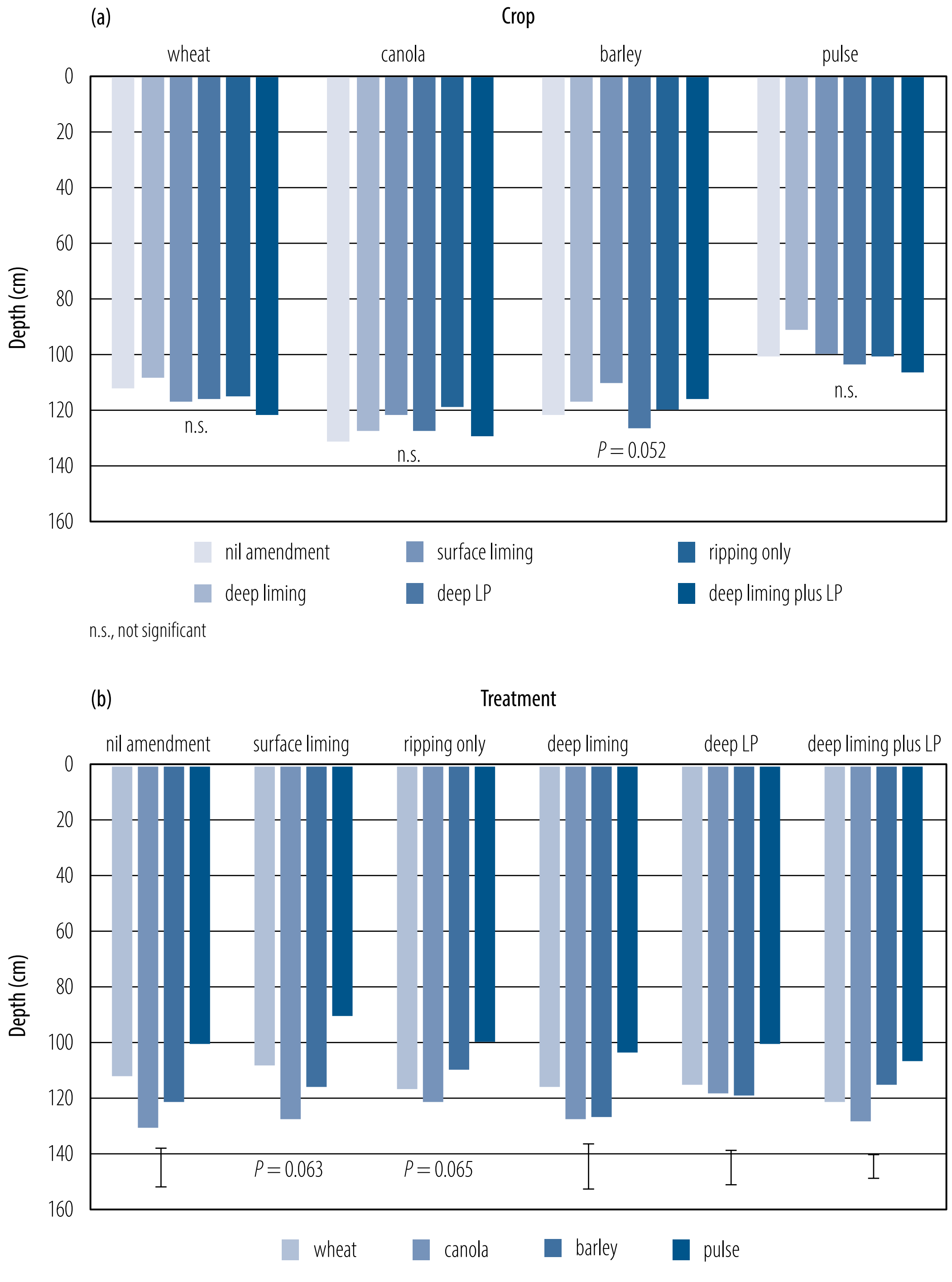


Figure 4 Soil mineral nitrogen (kg/ha) at 0–60 cm under different soil amendment treatments in autumn in years 1–4.

Rooting depth and root density

Averaged across crops and seasons, there was no significant difference in maximum rooting depth between treatments (Figure 5a). However, there were significant differences in maximum rooting depth between crops for most of the treatments (Figure 5b). Canola, in general, had the deepest roots, reaching down to 126 cm, and pulses (field pea or faba bean) had the shallowest rooting depth (100 cm). Wheat and barley rooting depths were intermediate. It was observed that rooting depth was shallower in a wet year (2016), but deeper in dry years (2018 and 2019), highlighting a key crop response to dry seasonal conditions.

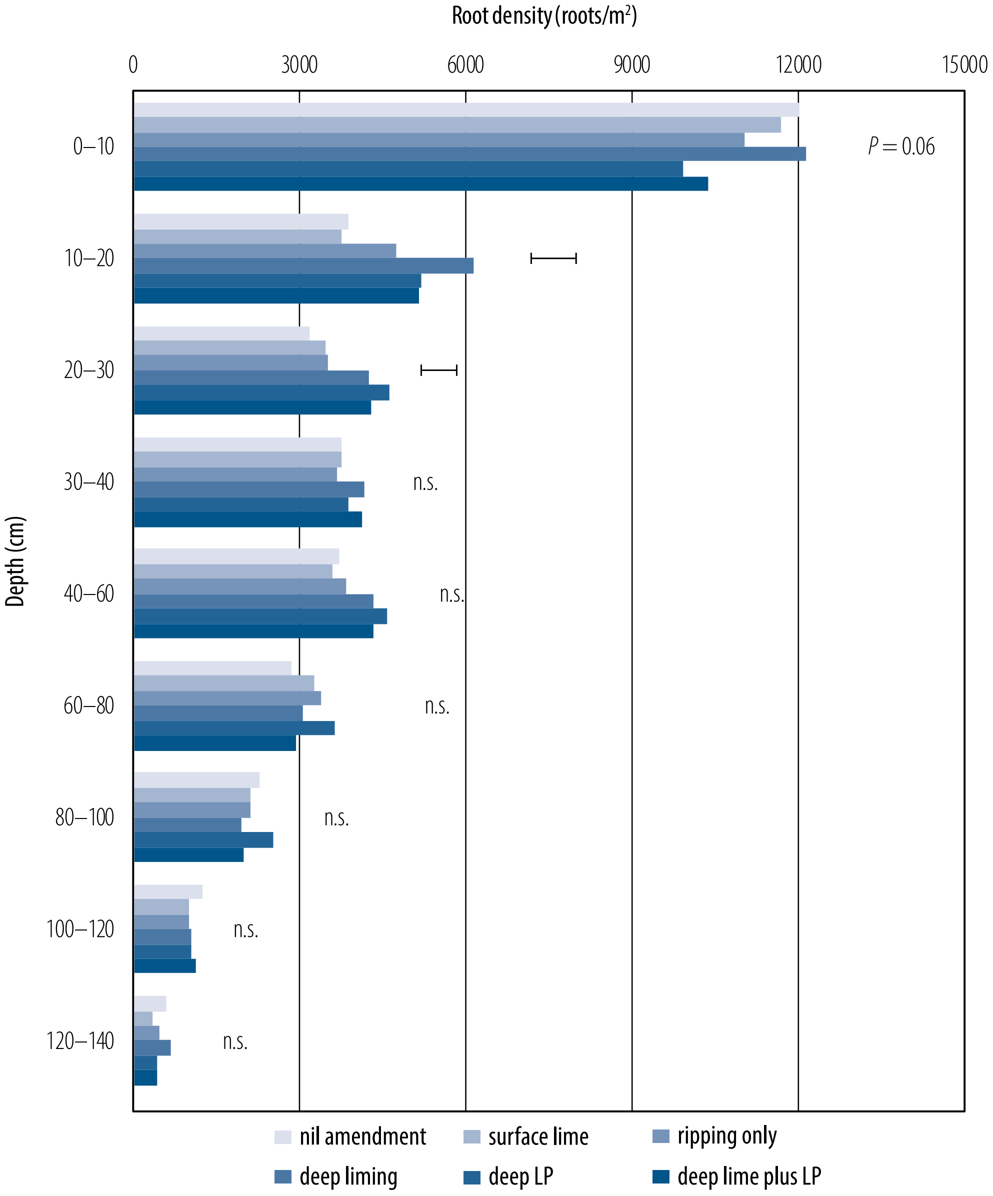


n.s., not significant

Vertical bars represent least significant difference at $P = 0.05$.

Figure 5 Maximum rooting depth (cm) for (a) each crop under different soil amendment treatments and (b) each treatment under different crops at crop anthesis in years 1–4 at the Cootamundra site.

Root density decreased with soil depth with the highest root density located at 0–10 cm depth, which was most evident in dry years. There were significant differences in root density between treatments at 10–20 cm and 20–30 cm depth where soil amendments were applied (Figure 6). The deep ripping treatments, particularly for those with soil amendments, tended to have more roots in these subsurface layers compared with nil and surface limed treatments. There was a tendency for the nil treatment and surface liming treatment to have higher root density compared with other treatments at 0–10 cm depth, particularly in the dry years.



Horizontal bars represent least significant difference at $P = 0.05$.
n.s., not significant

Figure 6 Averaged root density (roots/m²) across crops in 2016–2019 under different soil amendment treatments at crop anthesis at the Cootamundra site.

Grain yield

In 2016, deep LP and deep liming with LP produced the highest grain yield for the wheat crop, but not in canola and barley crops. The wheat crop response on the treatments with LP was due to additional N supplied via LP decomposition in these treatments. The lack of response in canola and barley crops was due to severe lodging late in the growing season. There was no difference in grain yield between treatments for field pea in 2016 (Figure 7). There was no significant difference in grain yield for any crops in 2017–2019. This could have been due to the severe drought conditions, which limited potential yields. The site only received 269 mm, 173 mm and 189 mm of in-crop rainfall over 2017–2019, compared to a long-term average growing season rainfall of 332 mm. Canola yielded less than 1.0 t/ha of grain in 2017–2018 years and about 200 kg/ha in 2019. Faba bean yielded approximately 1.0 t/ha of grain in 2017 and less than 350 kg/ha in 2019, while field pea yielded less than 800 kg/ha in 2018.

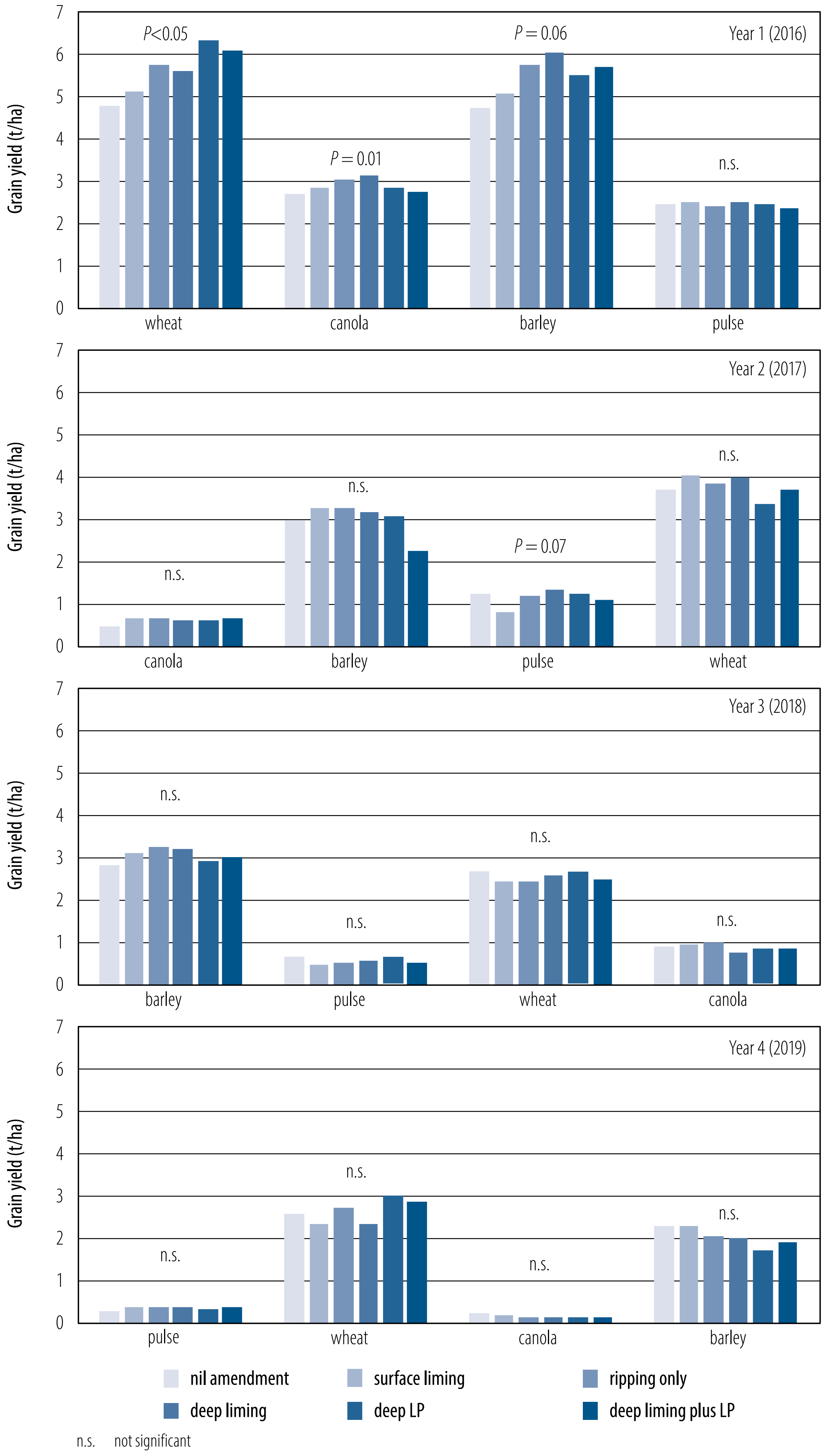


Figure 7 Grain yield (t/ha) in response to different soil amendments in years 1–4.

Conclusions

Lime is the most effective amendment to increase pH and reduce exchangeable Al%. Deep placement of organic materials had a limited effect on soil pH, but significantly reduced the exchangeable Al. However, in the longer term, applying large amounts of organic materials could acidify soils through nitrification and this would need to be offset with additional lime to neutralise this effect.

References

Burns HM and Norton MR, 2018. Subsurface acidity threatens central and southern NSW cropping areas. *National Soils Conference 2018*. Canberra. (Soil Science Australia). pp. 352–353. http://www.soilscienceaustralia.org.au/wp-content/uploads/2019/10/Proceedings-Natl.-Soil-Sci-Conf-Canberra-18-23-Nov-2018-FINAL_reduced-size-1.pdf. Downloaded 29 June 2020.

Butterly C, Baldock J and Tang C, 2010a. Chemical mechanisms of soil pH change by agricultural residues. *Soil Solutions for a Changing World: 19th World Congress of Soil Science*, Brisbane, Australia (World Congress of Soil Science), https://www.iuss.org/19th%20WCSS/Symposium/pdf/0273.pdf. Downloaded 29 June 2020.

Butterly CR, Baldock JA, Xu J and Tang C, 2010b. Is the alkalinity within agricultural residues soluble? Jian–Ming Xu and Pan Ming Huang (eds). *Molecular environmental soil science at the interfaces in the Earth's critical zone*, pp. 314–315.

Dolling PJ, Moody P, Noble A, Helyar KR, Hughes B, Reuter D and Sparrow L, 2001. *Soil acidity and acidification*. National Land and Water Resources Audit: Commonwealth of Australia.

Haynes RJ and Mokolobate MS, 2001. Amelioration of Al toxicity and P deficiency in acid soils by additions of organic residues: a critical review of the phenomenon and the mechanisms involved. *Nutrient Cycling in Agroecosystems*, vol. 59, pp. 47–63.

Isbell RF, 1996. *The Australian Soil Classification*. CSIRO Publishing: Melbourne.

Li GD, Conyers MK, Helyar KR, Lisle CJ, Poile GJ and Cullis BR, 2019. Long-term surface application of lime ameliorates subsurface soil acidity in the mixed farming zone of south-eastern Australia. *Geoderma*, vol. 338, pp. 236–246.

Nguyen HH, Moroni JS, Condon JR, Zander A and Li G, 2018. Increasing subsoil pH through addition of lucerne (*Medicago sativa* L.) pellets in the surface layer of an acidic soil. *Proceedings of the 10th International Symposium on Plant-Soil Interactions at Low pH,* Putrajaya, Malaysia pp. 51–53.

Ryan P, 2018. Assessing the role of genetics for improving the potential yield of Australia's major grain crops on acid soils. *Crop and Pasture Science*, vol. 69, pp. 242–264.

Scott BJ, Ridley AM and Conyers MK, 2000. Management of soil acidity in long-term pastures of south-eastern Australia: a review. *Australian Journal of Experimental Agriculture,* vol. 40, pp. 1173–1198.

SOE, 2011. 2.2.5 Soil acidification. *Australia state of the environment 2011*, pp. 287–293. (State of the Environment 2011 Committee Canberra).

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Improving grain yield by ameliorating sodic subsoil, Rand NSW

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Key findings

- Deep placement of organic and inorganic amendments increased grain yield by 20–40% for three successive years on a sodic subsoil at Rand.
- Deep placement of organic and inorganic amendments increased root growth and soil water use from the deeper clay layers during the grain filling-stage.
- Improvements in grain yield with deep placement of organic and inorganic amendments were associated with reduced subsoil pH and exchangeable sodium percentage, and increased microbial activity.

Introduction

In the Australian grain belt, soil constraints often result in lower water use efficiency (WUE) in grain production. Soil-constrained yields (<15 kg/mm/ha) are much lower than water limited yields (~24 kg/mm/ha). The difference between soil-constrained and potential yield is referred to as the yield gap. Among the various soil constraints, soil sodicity is associated with the largest yield gap, with an estimated yield loss of $A1,300 million per annum (Orton et al., 2018). The yield gap is caused by several physicochemical properties including:

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

In sodic subsoils these factors restrict crop rooting depth and subsequent water and nutrient extraction (Passioura and Angus, 2010) leading to significant yield penalties (Adcock et al., 2007).

Gypsum application has been the most widespread traditional approach to correcting subsoil sodicity, however, the problems with this have included:

- surface application when the problem is evident in the subsoil
- the large quantities of gypsum required to displace significant amounts of sodium
- gypsum's somewhat low solubility.

A new approach was required to consider a wider range of the physicochemical constraints associated with sodic subsoils that also better targeted the subsoil sodic layer. This approach also included providing the building blocks for soil colloid formation to improve structure.

This paper reports 2019 results from a subsoil amelioration experiment aimed at minimising the yield gap on sodic subsoils by treating them with various organic and inorganic amendments in pelletised form.

Site details

Location	Rand, southern NSW
Soil type	Sodosol
Previous crop	Wheat
Design	Randomised complete block design (RCBD) with four replications
Sowing	• Sown with an air seeder spaced at 250 mm using a GPS auto-steer system (10 April 2019) • Seed rate: 4.4 kg/ha
Fertiliser	• 90 kg/ha mono-ammonium phosphate (MAP) (at sowing) • Urea 220 kg/ha (top dressed on 28 June 2019)
Rainfall	• Fallow rainfall (November 2018–March 2019): 196 mm • Fallow rainfall long-term average: 221 mm • In-crop rainfall (April 2019–October 2019): 215 mm • In-crop rainfall long-term average: 319 mm
Harvest date	30 October 2019

Treatments

Outlined in Table 1.

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

Treatments	Organic/inorganic	Rates
Control	–	–
Deep gypsum	Inorganic	5 t/ha
Deep NPK (liquid nitrogen [N], phosphorus [P], potassium [K])	Inorganic	N to match chicken manure
Deep manure	Organic	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 chicken manure
Deep pea straw + NPK	Organic + inorganic	15 t/ha, N to match chicken manure
Deep wheat straw	Organic	15 t/ha
Deep wheat straw + NPK	Organic + inorganic	15 t/ha, N to match chicken manure
Rip only	–	–
Surface gypsum	Inorganic	5 t/ha
Surface manure	Organic	8 t/ha
Surface pea straw	Organic	15 t/ha

Surface amendments were applied on the soil surface; deep amendments were incorporated at 20–40 cm depth in 50 cm bands.

Results

Growing conditions

A field experiment was established on-farm near the township of Rand in southern NSW during February 2017. Treatments and physicochemical properties are detailed in tables 1 and 2, respectively. Paddock history was a cereal–canola rotation for decades.

The soil is a sodosol (Isbell, 2002), with a texture–contrast profile increasing in clay content at depth. The increasing levels of exchangeable sodium relative to calcium and/or magnesium in subsoil results in decreased soil structural stability and increased dispersion potential. The high clay content in this subsoil layer has a bulk density of 1.55 g/cm^3 that restricts water movement and consequently the saturated hydraulic conductivity value is low at 0.03 cm/hr.

The site received less summer rainfall (196 mm) and less growing season rainfall (215 mm) compared with their respective long-term averages (summer 221 mm, growing season 319 mm May to November).

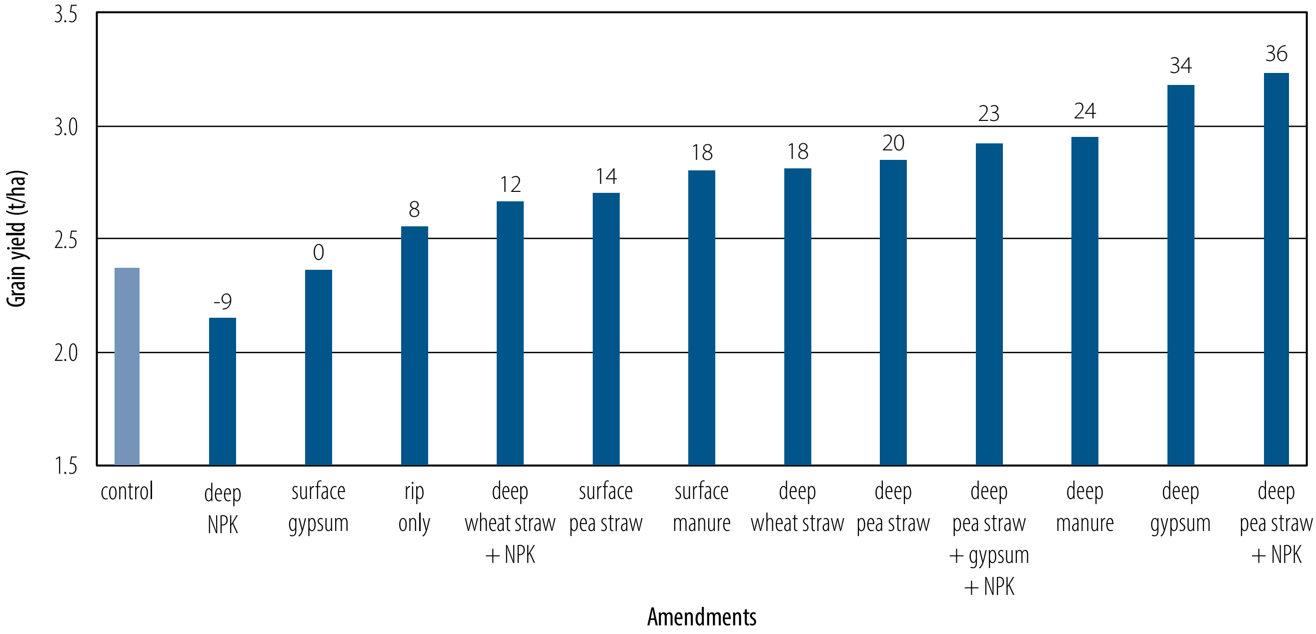
Table 2 Chemical properties at different soil profile depths at the Rand experiment site.

Soil depths (cm)	$pH_{1:5\ water}$	EC (µs/cm)	ESP (%)
0–10	6.6	132.1	3.8
10–20	7.8	104.0	7.3
20–40	9.0	201.5	12.5
40–45	9.4	300.5	18.1
50–60	9.5	401.3	21.8
60–100	9.4	645.0	26.4

Values are means (n = 4).
EC: electrical conductivity; ESP: exchangeable sodium percentage.

Grain yield

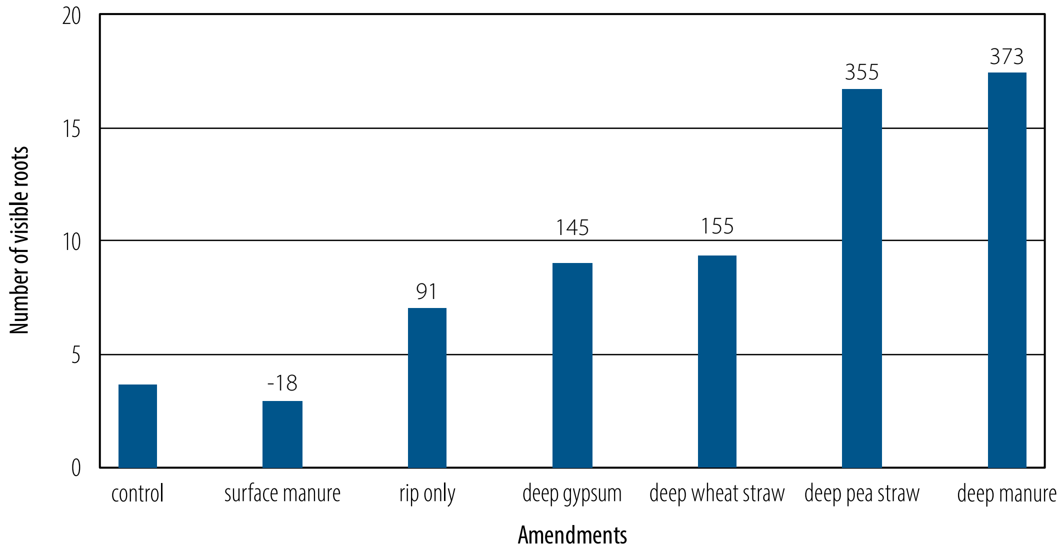
In 2019, canola grain yield was significantly (*P*<0.001) increased following amendments applied in 2017 (Figure 1). The highest increase was observed for deep placement of pea straw + NPK and followed by deep gypsum. Deep nutrients alone did not improve grain yield compared with the control, consequently it can be concluded that the grain yield increases were due to improving soil characteristics and not due to improved nutritional conditions.



Values on the top of each bar represent percent change of grain yield compared with the control.
Each data point is mean value of n = 4.
l.s.d. (*P* = 0.05) = 0.45 t/ha.

Figure 1 The mean effect of surface or deep-placed amendments on canola (cv. Pioneer® 45Y91 (CL)) grain yield grown in alkaline sodic subsoil in Rand, southern NSW in 2019.

Different amendments also significantly affected (*P*<0.05) the number of visible roots in the amended sodic subsoil (20–40 cm depth) (Figure 2). Deep placement of both manure and pea straw increased the number of visible roots by more than three-fold compared with the control. Neutron probe readings taken during flowering also indicated that the highest root counts were associated with improved water extraction. Compared with the control, deep placement of gypsum reduced the soil pH by 0.7 units (8.8 to 8.1) at 20–40 cm depth.



Values on the top of each bar represent percent change of visible roots compared with the control.
Each data point is mean value of n = 3.
l.s.d. (*P* = 0.05) = 8.8.

Figure 2 The mean effect of surface or deep-placed amendments on the number of visible roots at 30 cm at late flowering of canola (cv. Pioneer® 45Y91 (CL)) grown in alkaline sodic subsoil in Rand, southern NSW in 2019.

Conclusion

The marked increase in the grain yield that occurred at Rand with the deep placement of both organic and inorganic amendments indicates the potential of this approach in reducing the yield gap associated with sodic subsoils in major cropping regions of Australia. Placement of the amendments in the study site in 2017 resulted in three consecutive years with significant yield improvement, indicating the residual effects of this approach on the yields for following crops (Gill et al., 2008).

There was no positive yield response to deep placement of nutrients, and this supports other evidence that the responses at Rand are not due to nutritional factors. In a year of intensive drought such as in 2019, the grain yield improvements at Rand could be attributed to the additional root growth in the amended subsoil layer (Figure 2), which facilitated the use of extra subsoil water (Uddin et al., 2020). Under dryland conditions, water captured by roots in the subsoil layer is extremely valuable as its availability can coincide with the grain filling period and has a very high conversion efficiency into grain yield (Kirkegaard et al., 2007).

This experiment also provides significant indications of how the deep placement of both organic and inorganic amendments can improve soil physicochemical properties. Reductions in extremely high soil pH and ESP at 20–40 cm depth (amended layers) were reported within 14 months following deep placement treatments (Tavakkoli et al., 2019). Furthermore, improvement in soil chemical properties were also associated with increasing soil porosity, infiltration rate and microbial activity (data not shown), which leads to improved soil aggregation and ultimately improved soil structure (Uddin et al., 2020).

References

Adcock D, McNeill AM, McDonald GK and Armstrong RD, 2007. Subsoil constraints to crop production on neutral and alkaline soils in south-eastern Australia: a review of current knowledge and management strategies. *Australian Journal of Experimental Agriculture*, vol. 47, pp 1245–1261.

Gill JS, Sale PWG and Tang C, 2008. Amelioration of dense sodic subsoil using organic amendments increases wheat yield more than using gypsum in a high rainfall zone of southern Australia. *Field Crops Research*, vol. 107, pp 265–275.

Isbell RF, 2002. *The Australian soil classification*, revised edn. CSIRO Publishing, Collingwood.

Kirkegaard JA, Lilley JM, Howe GN and Graham JM, 2007. Impact of subsoil water use on wheat yield. *Australian Journal of Agricultural Research*, vol. 58, pp 303–315.

Orton TG, Mallawaarachchi T, Pringle M, Menzies NW, Dalal RC, Kopittke PM, Searle R, Hochman Z and Dang YP, 2018. Quantifying the economic impact of soil constraints on Australian agriculture: A case-study of wheat. *Land Degradation & Development*, vol. 29, pp. 3866–3875.

Passioura JB and Angus JF, 2010. Improving productivity of crops in water-limited environments. DL Sparks (ed) *Advances in Agronomy*, vol. 106, pp. 37–75.

Tavakkoli E, Weng ZH, Tahmasbian I, Uddin S, Poile G, Oates A, Xu BB, Sandral G, Fang Y and Armstrong R, 2019. Understanding the amelioration processes of the subsoil application of amendments. *GRDC Update Paper* presented at the GRDC Grains Research Update, Wagga Wagga, NSW, Australia, 18–19 February 2019.

Uddin S, Oates A, Aslam N, Armstrong D, Pitt W, Hildebrand S, Dehaan R, Sandral G, Fang Y, McDonald G, Schilling R, Armstrong R and Tavakkoli E, 2020. Soil amelioration: magnitude of crop productivity improvements on hostile subsoils? *GRDC Update Paper* presented at the GRDC Grains Research Update, Wagga Wagga, NSW, Australia,18–19 February 2020.

Acknowledgements

This experiment was part of the project 'Understanding the amelioration processes of the subsoil application of amendments in the Southern Region', 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.

Screening wheat genotypes in alkaline sodic subsoil

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Key findings

- Genotypic variability observed in response to wheat grain yield in alkaline sodic subsoil.
- Mace$^{\phi}$, Corack$^{\phi}$, Scepter$^{\phi}$ and Emu Rock$^{\phi}$ were the top performing cultivars over three consecutive years.
- Higher grain yield was attributed to greater subsoil water extraction and capacity to maintain higher harvest index under drought conditions.

Introduction

Among different soil constraints, sodicity is associated with the largest yield gaps across most of the wheat-cropping areas of Australia, with an estimated yield loss of $A1,300 million per annum (Orton et al., 2018). Sodic soils exhibit a range of physicochemical properties including high subsoil exchangeable sodium (Na) concentrations, which cause soil dispersion leading to poor subsoil structure, impeded drainage, waterlogging, denitrification and high soil strength. Genetic improvement is frequently advocated as an avenue for improving crop productivity and adaptation under different hostile soil conditions (Nuttall et al., 2010; McDonald et al., 2012). This paper presents results from a genotype screening experiment conducted in 2019 at Grogan in southern NSW for identifying wheat genotypes and traits linked to sodicity tolerance under field conditions with subsoil sodicity.

Site details

Location	Grogan, southern NSW
Soil type	Sodosol
Previous crop	Canola
Sowing	Direct drilled with DBS tynes spaced at 250 mm using a GPS auto–steer system (17 May 2019).
Target plant density	130 plants/m^2
Fertiliser	• 90 kg/ha mono-ammonium phosphate (MAP) (at sowing). • Urea 163 kg/ha (top dressed on 11 July 2019).
Rainfall	• Fallow (December 2018–April 2019): 200 mm • Fallow long-term average: 223 mm • In-crop (May 2019–November 2019): 124 mm • In-crop long-term average: 356 mm
Harvest date	19 November 2019

Treatment

Genotype	Bremer$^{\phi}$, Condo$^{\phi}$, Corack$^{\phi}$, Emu Rock$^{\phi}$, Gladius$^{\phi}$, EGA Gregory$^{\phi}$, Hartog; Janz; LPB10-2555; Mace$^{\phi}$; Magenta; Scepter$^{\phi}$, LongReach Scout$^{\phi}$, Sunco, Suntop$^{\phi}$, LongReach Trojan$^{\phi}$, Wallup$^{\phi}$

Results

Growing conditions

The soil profile was slightly acidic in the top 10 cm (pH$_{1:5\ water}$ 5.9) and pH dramatically increased with depth (Table 1). The changes in soil sodicity (exchangeable sodium percentage, ESP) followed a similar trend to soil pH with ESP at 10.5% in the topsoil and increasing to 40% in the subsoil (Table 1). The site received slightly less summer rainfall (200 mm, December 2018–April 2019) compared with the long-term average (223 mm). However, during the crop growing season (May–November 2019) the site received 124 mm, which is only 34.8% of the long-term average rainfall (356 mm).

Table 1 Chemical properties at different depths of the soil profile at the Grogan experiment site.

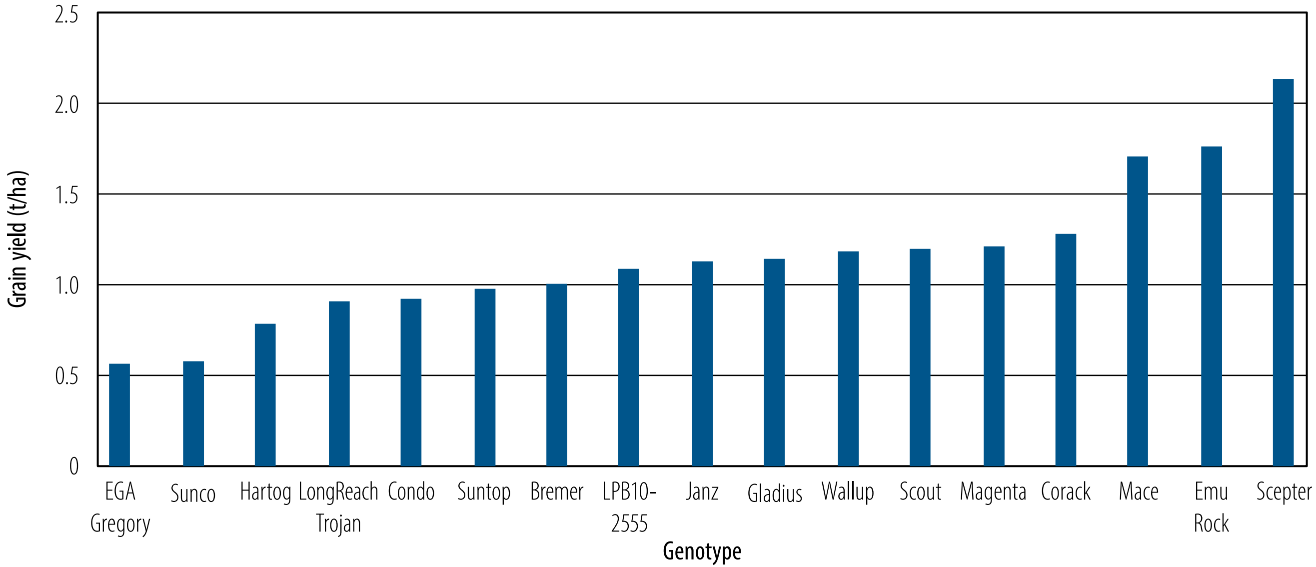
Soil depth (cm)	pH$_{1:5\ water}$	EC (µs/cm)	ESP (%)
0–10	5.9	309.4	10.5
10–20	7.7	133.0	11.9
20–30	8.8	136.9	15.9
30–40	9.1	207.7	20.1
40–60	9.6	338.9	26.3
60–80	9.5	530.4	36.7
80–100	9.4	897.2	40.3
100–120	9.4	1148.2	40.4

Values are means (n = 5). EC, electrical conductivity; ESP, exchangeable sodium percentage.

Grain yield

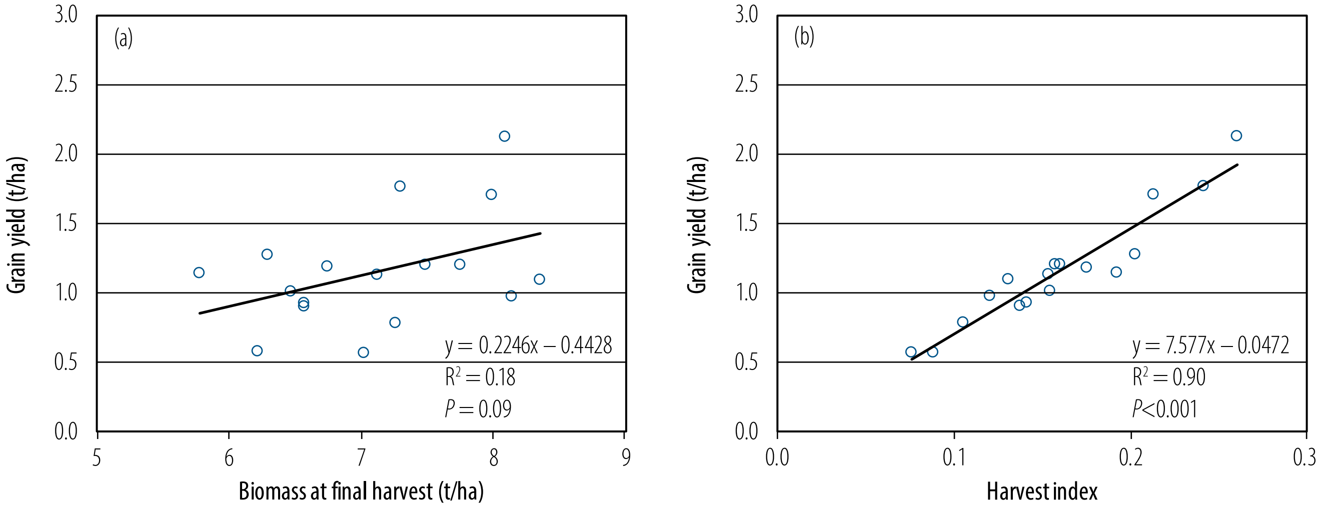
Significant (*P*<0.001) genotypic variation occurred in grain yield among the studied genotypes. Grain yield ranged from only 0.57 t/ha (EGA Gregory$^{(\Phi)}$) to 2.0 t/ha (Scepter$^{(\Phi)}$, Emu Rock$^{(\Phi)}$ and Mace$^{(\Phi)}$: Figure 1). Biomass at final harvest did not significantly differ among the genotypes (data not shown; *P* = 0.11) and there was no significant (*P* = 0.09) correlation between grain yield and biomass at the final harvest (Figure 2a).

Significant variation was observed in harvest index (data not shown; *P*<0.001), which ranged from 0.08 (EGA Gregory$^{(\Phi)}$) to 0.26 (Scepter$^{(\Phi)}$). A significant (*P*<0.001) and positive correlation between harvest index and grain yield was observed among the studied genotypes (Figure 2b).



Each data point is mean value of n = 4.
l.s.d. (*P* = 0.05) = 0.58 t/ha.

Figure 1 Variations in grain yield (t/ha) of 17 wheat genotypes grown in alkaline sodic dispersive subsoil at Grogan, southern NSW in 2019.



Each data point is mean value of n = 4.

Figure 2 Linear regressions between grain yield and biomass at final harvest (a: left) and harvest index (b: right) of 17 wheat genotypes grown in alkaline sodic dispersive subsoil in Grogan, southern NSW in 2019.

Conclusion

Identifying traits associated with superior tolerance to different soil constraints could be a low-cost technique to tackle subsoil constraints (McDonald et al., 2012). The intense drought conditions in the experiment year revealed considerable genotypic variation, with some genotypes having a more than three-fold higher grain yield than other genotypes.

Based on controlled-environment studies, the high yielding varieties, Mace$^{\phi}$ and Emu Rock$^{\phi}$, are moderately tolerant to tolerant to high pH and have roots that can grow relatively well through soils with high bulk density, whereas low yielding varieties such as EGA Gregory$^{\phi}$, Hartog and Sunco are sensitive to one or both of these stresses. The very low harvest index in the experiment suggests that there was severe stress around flowering, which reduced grain set as well as during grain filling. The results suggest that the ability to maintain root growth could have helped to alleviate the stress in varieties such as Emu Rock$^{\phi}$ and Mace$^{\phi}$. The different traits associated with this greater yield performance from wheat genotypes should prove to be crucial in future breeding programs. We might have overlooked the optimum sowing window for the studied genotypes, which is an important factor for grain yield variability under dryland conditions and needs to be considered in any future screening experiment for sodicity tolerance.

References

McDonald GK, Taylor JD, Verbyla A and Kuchel H, 2012. Assessing the importance of subsoil constraints to yield of wheat and its implications for yield improvement. *Crop & Pasture Science*, vol. 63, pp. 1043–1065.

Nuttall JG, Hobson KB, Materne M, Moody DB, Munns R and Armstrong RD, 2010. Use of genetic tolerance in grain crops to overcome subsoil constraints in alkaline cropping soils. *Australian Journal of Soil Research*, vol. 48, pp. 188–199.

Orton TG, Mallawaarachchi T, Pringle M, Menzies NW, Dalal RC, Kopittke PM, Searle R, Hochman Z and Dang YP, 2018. Quantifying the economic impact of soil constraints on Australian agriculture: A case-study of wheat. *Land Degradation & Development*, vol. 29, pp. 3866–3875.

Acknowledgements

This experiment was part of the 'Improving wheat yields on sodic, magnesic, and dispersive soils', UA00159, 2015–20. The project is a collaborative partnership between GRDC, NSW DPI, The University of Adelaide (UA), The University of Queensland (UQ) and the Department of Agriculture and Food Western Australia (DAFWA).

The effect of water management on rice growth and grain yield

Brian Dunn, Tina Dunn, Craig Hodges and Chris Dawe (NSW DPI, Yanco)

Key findings

- Grain yield of rice grown without ponded water (aerobic), was over 2 t/ha lower than rice grown with conventional drill or delayed permanent water practice.
- Reducing the ponding period on a rice crop reduces water use. Aerobic water management takes it to the extreme, with no extended ponding during the crop's growth.
- Different nitrogen management is required for rice grown aerobically, with two applications producing the highest grain yield in this experiment.

Introduction

Improving the water productivity in rice growing is imperative for the continued success of the rice industry in southern NSW. Increasing competition for scarce water resources means rice growers must maximise $/megalitre (ML) returns to remain competitive.

Water productivity can be improved by:

- increasing the dollar value of the product (rice)
- increasing grain yield
- reducing water use
- or a combination of all three.

Decreasing the length of time a rice crop is ponded is known to reduce water use with only a small reduction in grain yield, but little is known about the effect on grain yield with no ponding.

This research investigates the effects on growth and grain yield of the short season rice variety, Viand$^{\Phi}$ from growing with aerobic, delayed permanent water (DPW) and conventional drill sowing water management practices. Nitrogen (N) treatments are included in this research, as modifications in water management change N practice efficiency.

Site details

Three water management experiments, aerobic, DPW and drill were established in adjacent bays at Yanco Agricultural Institute in the 2018–19 season. The site has a transitional red–brown earth soil with a loam surface horizon. Each bay had an independent water supply and drainage infrastructure for convenient water management.

Viand$^{\Phi}$ (a short season semi-dwarf medium grain rice variety) was sown in each experiment at 140 kg/ha seed. All three experiments used a fully randomised design with three replicates. Plot size was 1.5 m × 10 m consisting of six plant rows sown at 25 cm row spacing.

Weather

In the 2018–19 season the experiments were not exposed to either low temperatures (<15 °C) at pollen microspore or extreme heat (>40 °C) at flowering, so grain yields from the aerobic experiment could be considered as approaching their maximum potential.

Treatments

Water management

First flush irrigation

The aerobic and DPW experiments both received their first flush irrigations on 30 October 2018, while the drill experiment was first flushed on 6 November 2018. As rice develops faster when grown in ponded water, the first flush dates were offset to align the reproductive periods within each water treatment.

Subsequent flush irrigation

The drill experiment received two and the DPW experiment six flush irrigations respectively before permanent water (PW) was applied, while the aerobic experiment received 27 flush irrigations with no permanent water (Table 1).

Table 1 First flush and permanent water dates, number of flush irrigations and number of days the crop was ponded for the aerobic, DPW and drill experiments.

Water management treatment	First flush date	Permanent water date	Number flush irrigations	Number days ponded
Aerobic	30 Oct 2018	never	27	0
DPW	30 Oct 2018	23 Dec 2018	6	89
Drill	6 Nov 2018	4 Dec 2018	2	108

Flush irrigation timings in the aerobic experiment were based on cumulative evapotranspiration measured at the CSIRO weather station at Griffith (https://weather.csiro.au/?aws_id=8).

Crop factors (Kc) of 0.6 and 0.8 were applied for 1 November to 15 November and 16 November to 30 November respectively; a Kc of one was applied for the remainder of the season.

The aerobic experiment was managed to maximise grain yield rather than water savings and therefore received little moisture stress, especially during the reproductive period, 1 January to 15 February 2019.

Nitrogen

Ten N treatments were applied to each experiment using a combination of urea rates and timing for applications (Table 2).

The drill and DPW experiments received the same N treatments with urea applied twice:

1. to the dry soil before PW
2. into ponded water at panicle initiation (PI).

The aerobic experiment received N either twice or three times:

1. 4-leaf – 23 November 2018
2. mid tiller – 17 December 2018
3. PI – 31 December 2018.

Table 2 shows the N rate (kg N/ha) and stage applied for all three experiments. Six N applications were consistent across all three experiments (shaded in Table 2). These treatments were used to compare plant growth and grain yield across the water management treatments.

Table 2 Nitrogen rate (kg N/ha) and stage applied for each experiment.

Treatment	Drill and DPW experiments		Aerobic exeriment		
	before PW	at PI	at 4-leaf	at mid tiller	at PI
1	0	0	0	0	0
2	0	60	60	60	0
3	0	120	0	60	120
4	0	180	60	60	60
5	60	0	60	0	0
6	60	60	60	0	60
7	60	120	60	0	120
8	120	0	120	0	0
9	120	60	120	0	60
10	180	0	180	0	0

Multiple N applications are often required in an alternate wet/dry non-ponded rice system as it is lost from the soil due to nitrification/denitrification processes.

Results

Plant population

Establishment was excellent in all three experiments with over 200 plants/m^2 established in each.

Plant dry matter

The drill experiment produced the highest dry matter (1988 g/m^2) when averaged across the six N treatments followed by the DPW and aerobic experiments with 1826 g/m^2 and 1505 g/m^2 respectively. The aerobic experiment produced a lower total dry matter than the drill and DPW experiments for all N treatments (Figure 1).

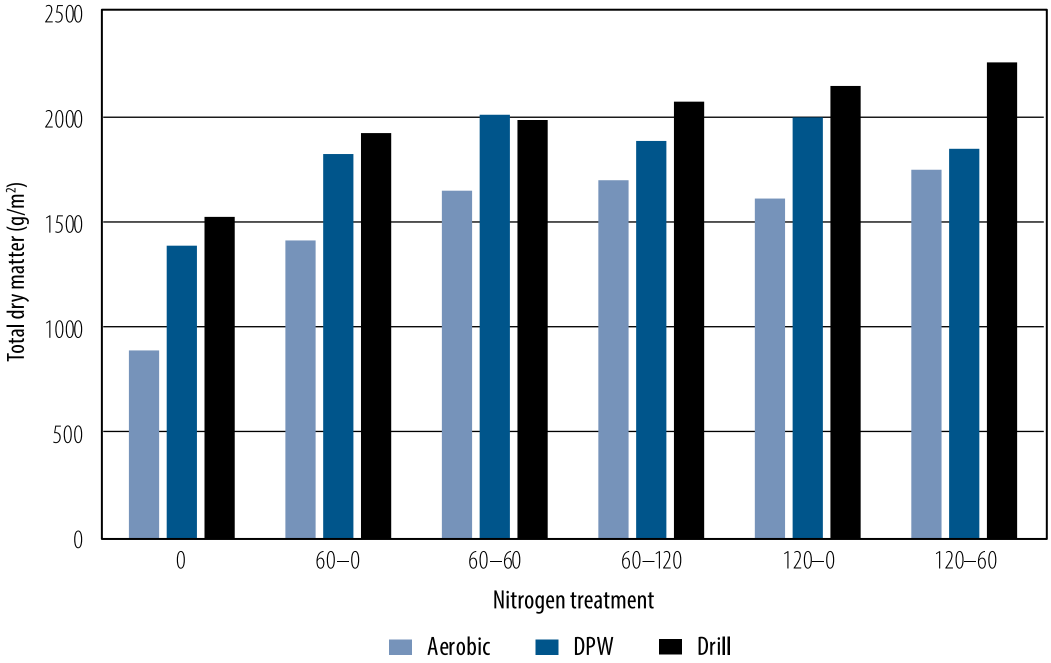


Figure 1 Total dry matter (g/m²) for the six nitrogen treatments which were common across all three water management experiments.

Total nitrogen uptake

Total N uptake is an important measure as water management has a significant effect on N use efficiency. The aerobic experiment had a lower total N uptake than either the drill or DPW experiments for all N treatments (Figure 2), while there was little difference between the drill and DPW experiments. In all three experiments, applying 120 kg N/ha produced the maximum N uptake. Applying 120 kg N/ha in a two-time split produced a higher N uptake in the aerobic experiment than when 120 kg N/ha was applied in a single application (Figure 2).

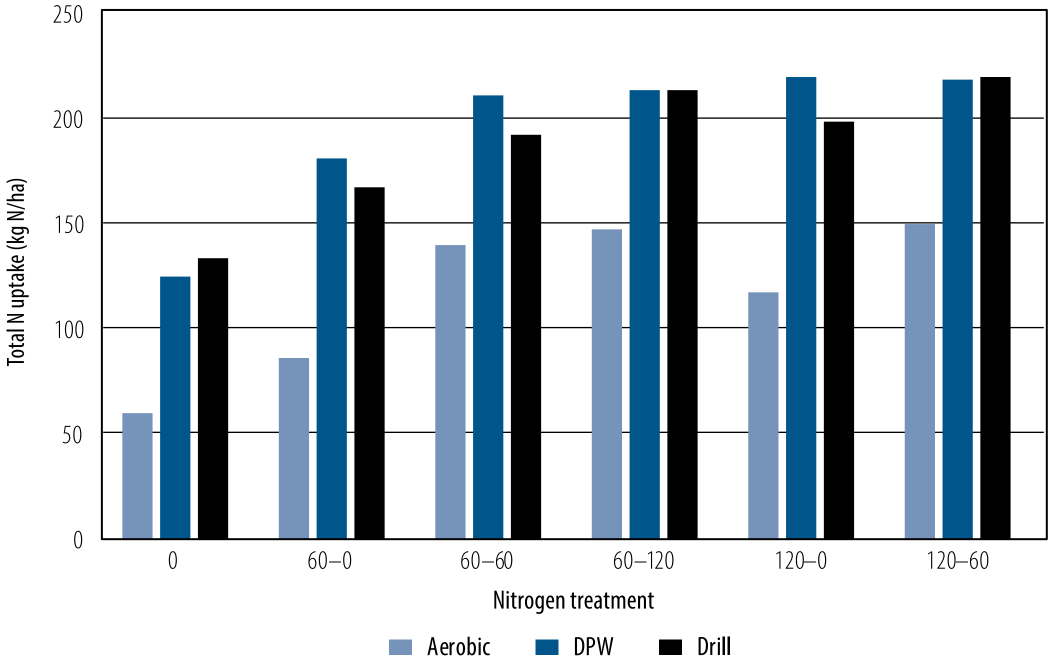


Figure 2 Total nitrogen uptake (kg N/ha) for the six nitrogen treatments common across all three water management experiments.

Grain yield

The drill experiment produced the highest grain yield when averaged across the six N treatments at 11.65 t/ha followed by the DPW and aerobic experiments with 10.99 t/ha and 8.55 t/ha respectively.

The maximum grain yield achieved in the aerobic experiment (from all 10 N treatments) was 10.29 t/ha from the 60–120 split treatment. The 60–60 split treatment produced the highest grain yield for the DPW experiment (12.56 t/ha) and the single PW application of 120–0 produced the highest grain yield for the drill experiment (12.72 t/ha) (Table 3).

Table 3 Grain yield (t/ha at 14% moisture) for the six N treatments common across all three water management experiments.

Nitrogen treatment	Grain yield (t/ha at 14%)		
	Aerobic	DPW	Drill
0	4.72	8.25	9.01
60–0	6.63	11.41	10.97
60–60	10.00	12.56	12.28
60–120	10.29	11.15	12.35
120–0	8.56	11.72	12.72
120–60	10.08	10.90	12.41
l.s.d. (*P*<0.05)	0.71	0.72	0.94

Florets per panicle and floret sterility

When averaged across N treatments, the:

- aerobic experiment produced the lowest number of florets per panicle (64)
- DPW and drill experiments produced 90 and 85 florets per panicle respectively
- DPW experiment had the highest level of sterile florets per panicle at 17%
- drill and aerobic experiments had 13% and 11% sterile florets respectively.

Conclusions

Although seasonal conditions were suitable for the aerobic experiment to approach its maximum grain yield potential, it was lower than either the DPW or drill experiments. Seasonal temperatures did not induce high levels of floret sterility in the aerobic experiment, but a combination of lower dry matter and fewer florets per panicle resulted in a reduced grain yield compared with either the DPW or drill experiments.

The reasons are unclear for the aerobic experiment's lower grain yield. It had no excessive moisture stress during the growth period and the number of N rates and timings ensured it was not N deficient. One possible explanation could be row spacing with further investigation required to determine if the 25 cm row spacing could have made it difficult for the experiment to reach full canopy cover and maximise dry matter production.

Water use was not measured in these experiments, but it is being measured in the 2019–20 season's experiments, which were sown at a narrower 20 cm row spacing. Water use is a major component that is very important in determining the potential value of aerobically grown rice in the future in southern NSW.

Acknowledgements

This experiment was part of the 'Rice variety nitrogen & agronomic management' project, PRJ-009790, 2015–20 with joint investment from AgriFutures and NSW DPI.

Utility of DNA barcoding for rapid species diagnostics of armyworms (Noctuidae) affecting rice crops in NSW

Dr David Gopurenko and Dr R.M.S.P. Rathnayake (NSW DPI, Wagga Wagga); Glen Warren and Dr Mark Stevens (NSW DPI, Yanco)

Key findings

- Morphologically ambiguous armyworm larvae sampled in two Riverina rice fields during 2018–19 were reared through to adult moths and identified as common armyworm (*Mythimna convecta*) and sugarcane armyworm (*Leucania stenographa*).
- Parasitised larvae which did not yield adults were identified to species by matching their DNA barcodes to vouchered armyworm sequence accessions.
- Serial amplification methods ensured DNA barcodes obtained from parasitised larval and/or pupal remnants were of the host moth and not its parasitoids.
- DNA barcoding provided a novel indication that larval parasitoids in the region may be having a greater impact on sugarcane armyworm than on common armyworm.

Introduction

A number of moth species affect rice production in Australia. Among these are the armyworms, a group of noctuid moths that feed on grass crops and cause substantial damage to cereals, sugar cane and pastures throughout Australia (Bailey, 2007). Accurately identifying armyworm larvae to species is critical for biosecurity purposes and to effectively design and implement pest-specific controls.

Keys to visually identify different armyworm larvae are sometimes unreliable and difficult to use with live specimens. Diagnosis to species level might only be possible after live specimens have been reared through to adults with consistent and discernible features. This delays the detection of exotic armyworm larvae and is impractical for studies of potentially useful bio-control organisms that have killed their hosts at the larval or pupal stage. DNA barcoding (Hebert et al., 2004) is a universally applied genetic method that can identify insect pest species across their developmental life stages (Gopurenko et al., 2013). It can also identify them from degraded or trace tissues (deWaard et al., 2010).

DNA barcode campaigns that link vouchered specimens to their sequence of an informative mitochondrial gene have improved diagnostics for a variety of pest moth groups (deWaard et al., 2010; Mitchell and Gopurenko, 2016) including some armyworms (Dumas et al., 2015). The availability of voucher-linked DNA barcodes at the Barcode of Life Data (BOLD) systems sequence repository are useful to genetically identify 11 established pest armyworms in Australia and one other species of biosecurity concern (Table 1).

DNA barcoding was used to identify species of parasitised armyworm larvae sampled from rice fields in the Riverina region of NSW. Identifying the host larvae species visually could not be done with confidence due to similarities among armyworm species in larval morphology, and when parasitism occurred the larvae or pupae died without producing an adult host. To ascertain their species-level identities, DNA barcodes were obtained from larval or pupal remains following a PCR enrichment approach, and genetically queried against existing sequence accessions reported for pest armyworm taxa.

Methods

Sampling details

Late instar armyworm larvae were collected from two rice farms in the Riverina region (Gogeldrie and Leeton) during the 2017–18 and 2018–19 rice seasons and were reared on an artificial diet in the laboratory to either pupation and emergence of adult moths, or until larval or pupal death and parasitoid emergence. Adult moths and parasitoids were identified to species by comparing their morphological features against taxonomic keys; the remains of parasitised host larvae and pupae were preserved in ethanol (90%) and stored at –20 °C until DNA barcoding. Dry-pinned adult moths (N = 6) and larval or pupal remnants from parasitised individuals (N = 37) were subsequently barcoded.

DNA barcoding

DNA barcoding at Wagga Wagga Agricultural Institute followed reported protocols (Gopurenko et. al., 2013) modified for selective PCR amplification of noctuid moths.

Oligonucleotide primer *trnT-LepF* (5′ taaatttacaatttatcgct 3′), designed here to specifically anneal to noctuids, was included with primer *LepR1* (Hebert et al., 2004) in a first round PCR (15 cycles) amplicon used as diluted template (1:100) in a second round PCR (40 cycles) containing universal DNA barcode primers *LepF1* and *LepR1* (Hebert et al., 2004).

Final DNA barcodes (658bp) were queried online (20 February 2020) for best-matched identity against sequence accessions at BOLD. Pairwise neighbour joining (NJ) distances and relationships among DNA barcodes sequences were constructed as a phenetic tree with node supports estimated by bootstrapping (10,000 replicates) using MEGA6 (Tamura et al., 2013). The DNA barcodes we generated were deposited at GenBank (accessions: MT131443–MT131485).

A DNA barcode sequence library (N = 2248) of 12 pest armyworm species of concern to Australian agriculture was downloaded from BOLD to determine their specificity for species diagnostics of query armyworms (Table 1). A NJ distance tree among exemplar haplotypes (N = 390) truncated to 534bp was constructed as described above.

Table 1 Twelve pest armyworms of concern to Australian agriculture. Number of DNA barcode sequences at BOLD repository and exemplar haplotypes. Maximum % intraspecific sequence difference (D^{intra}) and minimum difference to nearest neighbour species (D^{NN}).

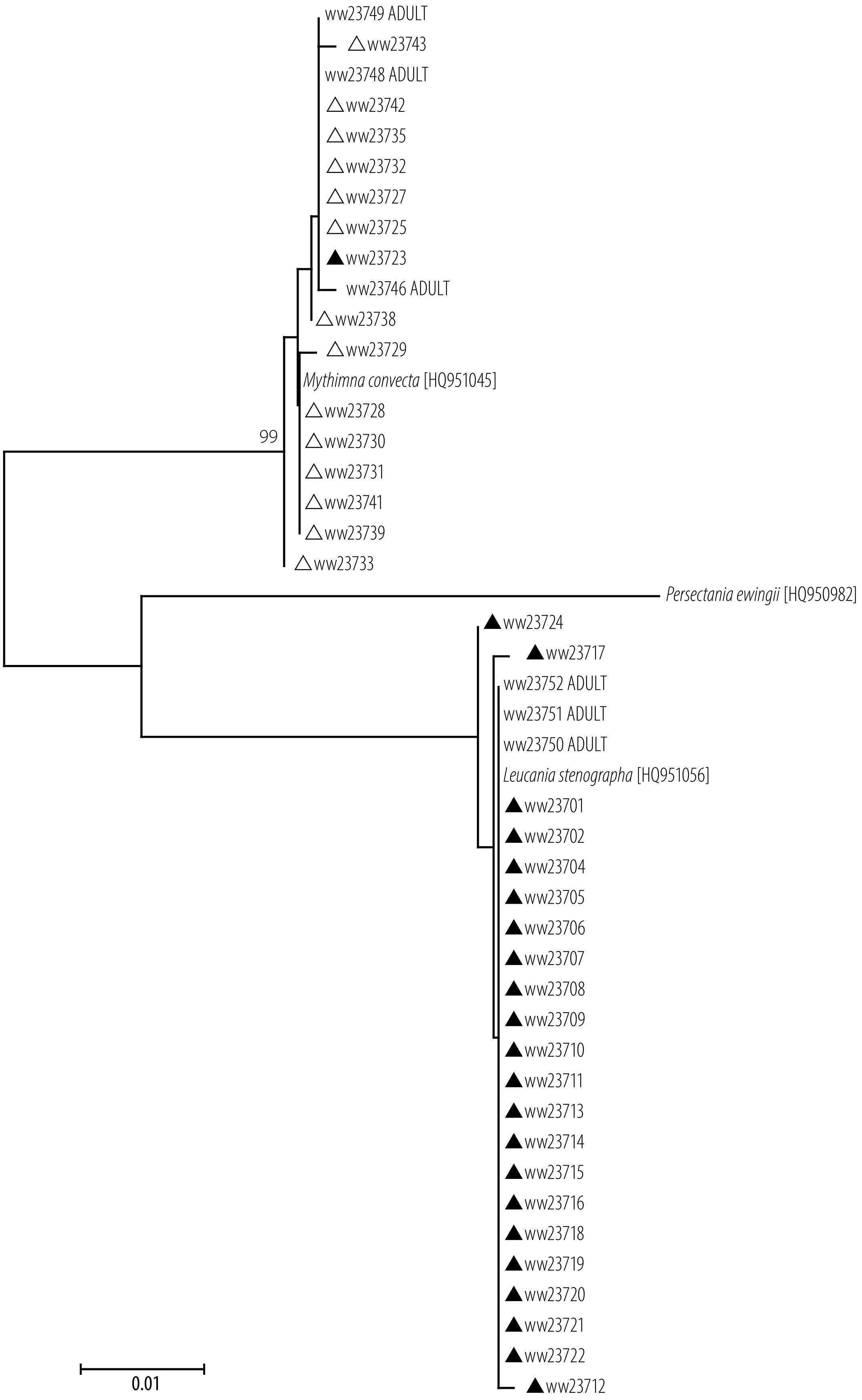
Species	**Armyworm common name**	***N* sequences (haplotypes) from BOLD**	**D^{intra} / D^{NN}**
Leucania abdominalis (Walker, 1856)	Sugarcane	93 (30)	2.76 / 4.49
Leucania loreyi (Duponchel, 1827)	Sugarcane	34 (5)	0.56 / 1.12
Leucania stenographa Lower, 1900	Sugarcane	38 (9)	0.38 / 1.12
Mythimna convecta (Walker, 1857)	Common	52 (9)	0.61 / 1.31
Mythimna separata (Walker, 1865)	Oriental	222 (22)	1.02 / 1.31
Mythimna unipuncta (Haworth, 1809) [1]	True	397 (67)	0.77 / 3.18
Persectania dyscrita Common, 1954	Inland	48 (28)	1.70 / 4.68
Persectania ewingii (Westwood, 1839)	Southern	68 (27)	0.94 / 4.68
Spodoptera exempta (Walker, 1857)	African	114 (20)	4.03 / 4.60
Spodoptera exigua (Hübner, 1808)	Beet	571 (92)	6.53 / 5.74
Spodoptera frugiperda (J.E. Smith, 1797) [2]	Fall	420 (50)	2.81 / 4.60
Spodoptera mauritia (Boisduval, 1833)	Lawn	191 (31)	5.47 / 5.01

[1] Pest species incorrectly reported as present in Australia (e.g. Dang et al., 2015).

[2] Species recently detected (2020) in Australia.

Results

- DNA barcodes from six adult and 37 larvae of armyworm moths sampled from Riverina rice fields were sorted as two genetically shallow clusters (<0.15% maximum sequence difference) separated by >5.95% minimum difference (Figure 1).
- One cluster genetically matched (99–100% similarity) reported sequence accessions of the common armyworm (*Mythimna convecta)* and the other cluster matched to the sugarcane armyworm (*Leucania stenographa*). Species identities of six adult armyworms were congruently determined by morphological examinations and DNA barcoding.



Scale bar = 1% sequence difference.

Larvae sampled from Gogeldrie and Leeton indicated by shaded and unshaded triangles respectively.

GenBank accessions bracketed for reference species.

Figure 1 NJ distance tree of armyworm DNA barcodes from rice fields in NSW.

- All larvae from Leeton (N = 14) were genetically matched to *Mythimna convecta*; in contrast larvae from Gogeldrie (N = 23) comprised both species, but most (N = 22) were *Leucania stenographa*.
- Analysis of BOLD records indicate each of the 12 pest armyworm species of concern to Australia contain a unique cluster of DNA barcodes not shared with other taxa (Figure 2); five species had high levels of intraspecific genetic diversity, and for two of these species, the maximum intraspecific distance exceeded the minimum distance to nearest neighbour species (Table 1).
- Identifying armyworm species in Australia can be accurately determined by query comparison of their DNA barcodes against existing records in BOLD.

Discussion

Our work demonstrates DNA barcoding's useful attributes for identifying species of armyworms in Australia. Publicly available DNA libraries, including described species sampled across their distributions, provide a rich comparative genetic database for species diagnostics (Gopurenko et al., 2015).

For the 12 armyworm species identified as pests of importance to Australia, there are over 2,200 DNA barcodes from northern and southern hemisphere locations available at BOLD for diagnostics. Our analyses indicate each of the 12 armyworm species contain a clustered assembly of DNA barcodes that are not shared with other taxa. Subsequently, identifying query armyworms to species based on their match to these DNA barcodes can be proposed with a high degree of certainty.

This is critically important in cases involving recent incursions of significant pests, such as the fall armyworm (*Spodoptera frugiperda*), which as shown here can be readily identified to species based on its DNA barcodes.

Five species have high levels of intraspecific genetic distance symptomatic of relictual population processes and or undescribed species diversity. Although this signals a need for integrated taxonomic and phylogenetic investigation of these taxa (Dumas et al., 2015), it does not compromise the ability of the existing DNA barcode library to correctly identify query specimens to currently described species.

Our DNA barcode identification of query specimens sampled from Riverina rice fields to the common armyworm (*Mythimna convecta*) and to the sugarcane armyworm (*Leucania stenographa*), accords with the morphological identifications of sampled adults from the region.

The ability of DNA barcoding to identify degraded and parasitised armyworm larvae to species is beyond the normal capacity of standard taxonomic examinations. It demonstrates the additional facility DNA barcoding provides for identifying ecological relationships and associations of particular pests on host plants, and as hosts themselves to other organisms of potential biosecurity concern or usefulness (Gopurenko et al., 2016).

For parasitised armyworms, the ability of DNA barcoding to accurately and rapidly identify the host larvae to species will be critical for rapidly tracing associations between armyworm species and various parasitoids, a process that is otherwise only possible through using lengthy controlled breeding and specificity trials. For this study we used a serial PCR procedure to enrich amplified DNA barcodes from the target noctuid host while negating or minimising co-amplification of barcodes from parasitoids (Diptera and Hymenoptera), which would otherwise confound sanger sequencing. Alternatively, DNA barcodes of an armyworm host and its parasitoids, co-amplified using universal primers in a single PCR reaction, could be obtained by next generation sequencing. This would also allow practical diagnostics to be scaled up using meta-DNA barcoding methods for tracking sequences to specimens, or to pooled specimen replicates.

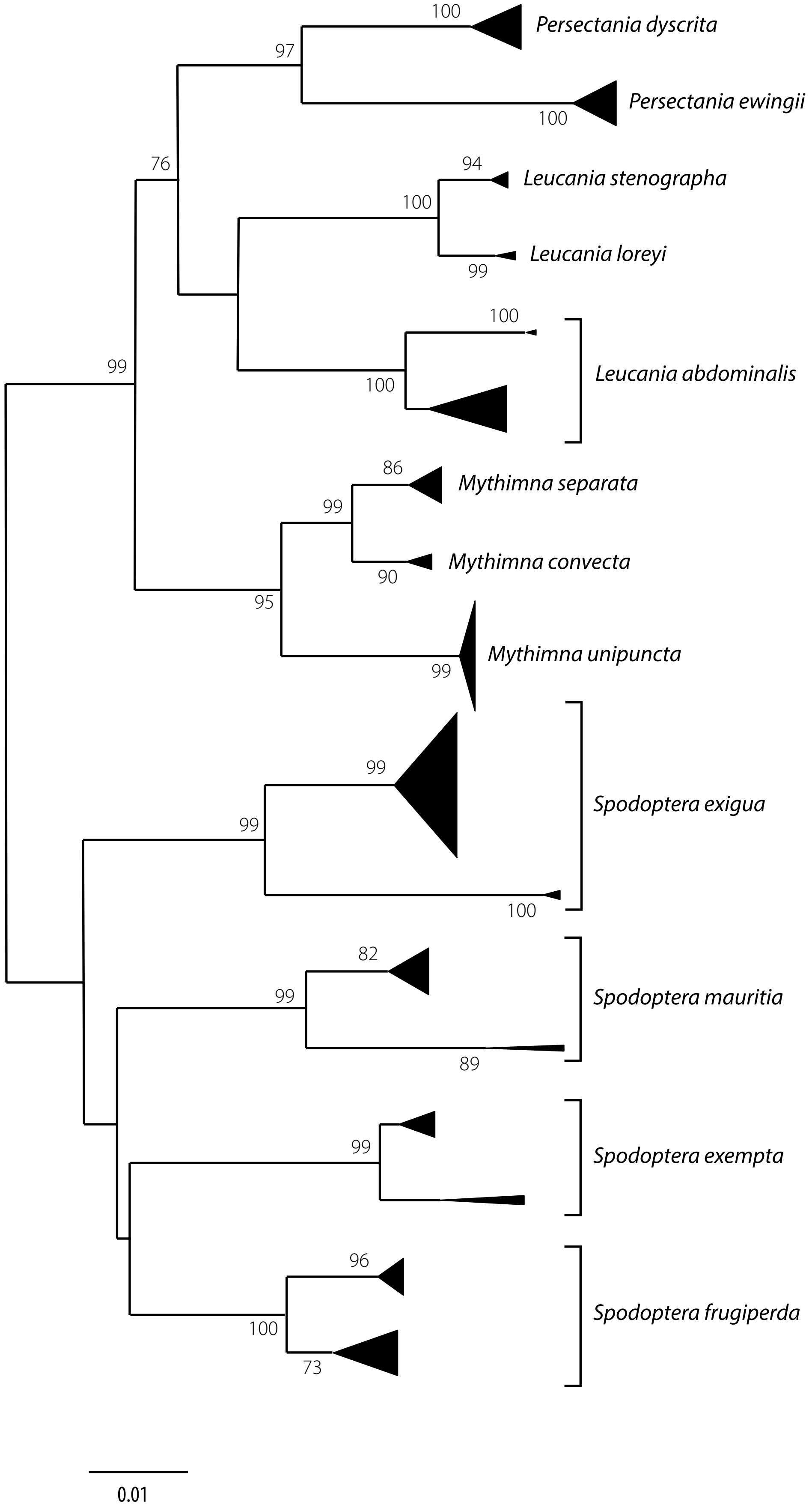


Figure 2 NJ distance tree of exemplar DNA barcode haplotypes (N = 390) reported at BOLD for 12 armyworm species of concern to Australia. NJ tree constructed as in Figure 1. High levels of genetic distance within five species as indicated by bracketed clusters.

Applying DNA barcoding to identify the remains of parasitised lepidopteran larvae that are not morphologically distinct from other closely related species can provide important insights into pest ecology. It can help to unambiguously identify host/parasitoid relationships, rather than having to infer the identity of a host based on the numerical dominance of a particular species in successful adult rearings made from material collected at the same site and time. Additionally, it can reveal differences in community composition not readily apparent from adult rearings.

Considered in isolation, the adult moth numbers reared from larvae collected near Gogeldrie suggested an armyworm community heavily dominated (96%) by common armyworm. Incorporating the DNA barcoding results showed that common armyworm comprised only 53% of the community, a fact masked by very heavy levels of larval parasitism in sugarcane armyworm and having implications for both biological and chemical control programs.

References

Bailey PT (ed.), 2007. *Pests of field crops and pastures: Identification and control*. CSIRO Publishing, Collingwood, Vic.

deWaard JR, Mitchell A, Keena MA, Gopurenko D, Boykin LM, Armstrong KF, Pogue MG, Lima J, Floyd R, Hanner RH and Humble LM, 2010. Towards a global barcode library for *Lymantria* (Lepidoptera: Lymantriinae) tussock moths of biosecurity concern. *PLoS One,* vol. 5, e14280.

Dang Y, Seymour NP, Walker SR, Bell MJ and Freebairn DM, 2015. Strategic tillage in no-till farming systems in Australia's northern grains-growing regions: I. Drivers and implementation. *Soil and Tillage Research*, vol. 152, pp. 104–114.

Dumas P, Barbut J, Le Ru B, Silvain J-F, Clamens A-L, d'Alençon E and Kergoat GJ, 2015. Phylogenetic molecular species delimitations unravel potential new species in the pest genus *Spodoptera* Guenée, 1852 (Lepidoptera, Noctuidae). *PLoS ONE*, vol. 10, e0122407.

Gopurenko D, Bellis G, Yanase T, Wardhana A, Thepparat A, Wang J, Cai D and Mitchell A, 2015. Integrative taxonomy to investigate species boundaries within *Culicoides* (Diptera: Ceratopogonidae): a case study using subgenus *Avaritia* from Australasia and eastern Asia. *Veterinaria Italiana,* vol. 51, pp. 345–378.

Gopurenko D, Fletcher M, Löcker H and Mitchell A, 2013. Morphological and DNA barcode species identifications of leafhoppers, planthoppers and treehoppers (Hemiptera: Auchenorrhyncha) at Barrow Island; N Gunawardene, J Majer, C Taylor and M Harvey (eds.) *Records of the Western Australian Museum, Supplement 83: The Terrestrial Invertebrate Fauna of Barrow Island*. Western Australian Museum, Perth.

Gopurenko D, Fletcher M, Liu J and Gurr GM, 2016. Expanding and exploring the diversity of phytoplasmas from lucerne (*Medicago sativa*). *Scientific Reports,* vol. 6, 37746.

Hebert PDN, Penton EH, Burns JM, Janzen DH and Hallwachs W, 2004. Ten species in one: DNA barcoding reveals cryptic species in the neotropical skipper butterfly *Astraptes fulgerator*. *Proceedings of the National Academy of Sciences USA,* vol. 101, pp. 14812–14817.

Mitchell A and Gopurenko D, 2016. DNA barcoding the Heliothinae (Lepidoptera: Noctuidae) of Australia and utility of DNA barcodes for pest identification in *Helicoverpa* and relatives. *PLoS ONE,* vol. 11, e0160895.

Tamura K, Stecher G, Peterson D, Filipski A and Kumar S, 2013. MEGA6: Molecular Evolutionary Genetics Analysis version 6.0. *Molecular Biology and Evolution,* vol. 30, pp. 2725–2729.

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Validation of DNA barcode based genetic diagnostics to identify the introduced weeds Chilean needle grass (*Nassella neesiana*) and serrated tussock (*Nassella trichotoma*) in eastern Australia

Dr David Gopurenko, Dr Aisuo Wang and Dr Hanwen Wu (NSW DPI, Wagga Wagga)

Key findings

- Over 310 specimens of Chilean needle grass (CNG) and serrated tussock (ST) weeds sampled from eastern Australia are genetically distinguished from other tussock grasses based on DNA barcodes of the external transcribed spacer (ETS) gene.
- ETS sequences unique to CNG or ST can be confidently targeted to develop rapid and portable genetic diagnostic methods to detect the two weeds.
- Validation of the ETS DNA barcodes among CNG indicates potential presence of cryptic diversity in eastern Australia.

Introduction

Chilean needle grass (*Nassella neesiana*) and serrated tussock (*N. trichotoma*) are introduced tussock weeds of national significance in Australia. The weeds displace palatable native grasses from pastures, decrease productivity of grazing livestock, and significantly degrade biodiversity in native grasslands. These weeds are capable of rapid spread, massive seed-set and are expanding their established ranges in Australia. Their abatement is costly, so it is economically imperative to prohibit their expansion into novel areas of Australia.

Morphological keys allow the two weeds to be identified based mainly on their floral characteristics, by which time the weeds will have further established their seedbanks. The ability to identify novel emergences of the two species before they flower would enable early management responses before the weeds establish as additional difficult to manage populations.

Portable diagnostic DNA methods such as loop-mediated isothermal amplification (LAMP; Notomi et al., 2000) will help non-specialist officers to quickly identify emergent weeds in the field (Gopurenko et al., 2018). We developed LAMP methods for detection of CNG and ST (Gopurenko et al., 2018; Gopurenko et al., *in prep.*) based on our earlier DNA barcode analysis of invasive grasses in Australia (Wang et al., 2017). DNA barcodes sequences from the external transcribed spacer (ETS) gene differed between these two weeds and a variety of endemic and invasive grasses often mistaken in the field for them (Wang et al., 2017). Subsequently our LAMP assays were designed for targeted detection of nucleotide sites in the ETS gene that are uniquely diagnostic for CNG or ST.

To further validate the utility of this target gene region for LAMP diagnostics of CNG and ST, we compared ETS DNA barcodes of 315 *Nassella* specimens sampled from eastern Australia. We included cane needle grass (*N. hyalina*) sampled in Australia, reference specimens from endemic Argentinean locations, and ETS accessions reported for 44 *Nassella* species endemic in the Americas (Cialdella et al., 2014), to provide a phylogenetic context to our analyses.

Methods

Sampling

We sampled 315 *Nassella* specimens from 25 locations in eastern Australia during the 2016–2019 summers and visually identified them to three species (Table 1). Reference samples of 13 specimens from Argentina were included in analyses. Specimens were curated at Wagga Wagga Agricultural Institute (WWAI; NSW DPI) in preparation for DNA barcoding.

Table 1 *Nassella* specimens sampled from eastern Australia and Argentina for ETS sequence analysis.

Species [Authority]	**Australia**	**Argentina**	**Total**
Nassella hyalina [(Nees) Barkworth, 1990]	11	1	12
Nassella neesiana [(Trin. & Rupr.) Barkworth, 1990]	158	10	168
Nassella trichotoma [(Nees) Hack. ex Arechav., 1896]	146	2	148
Total	315	13	328

DNA barcoding

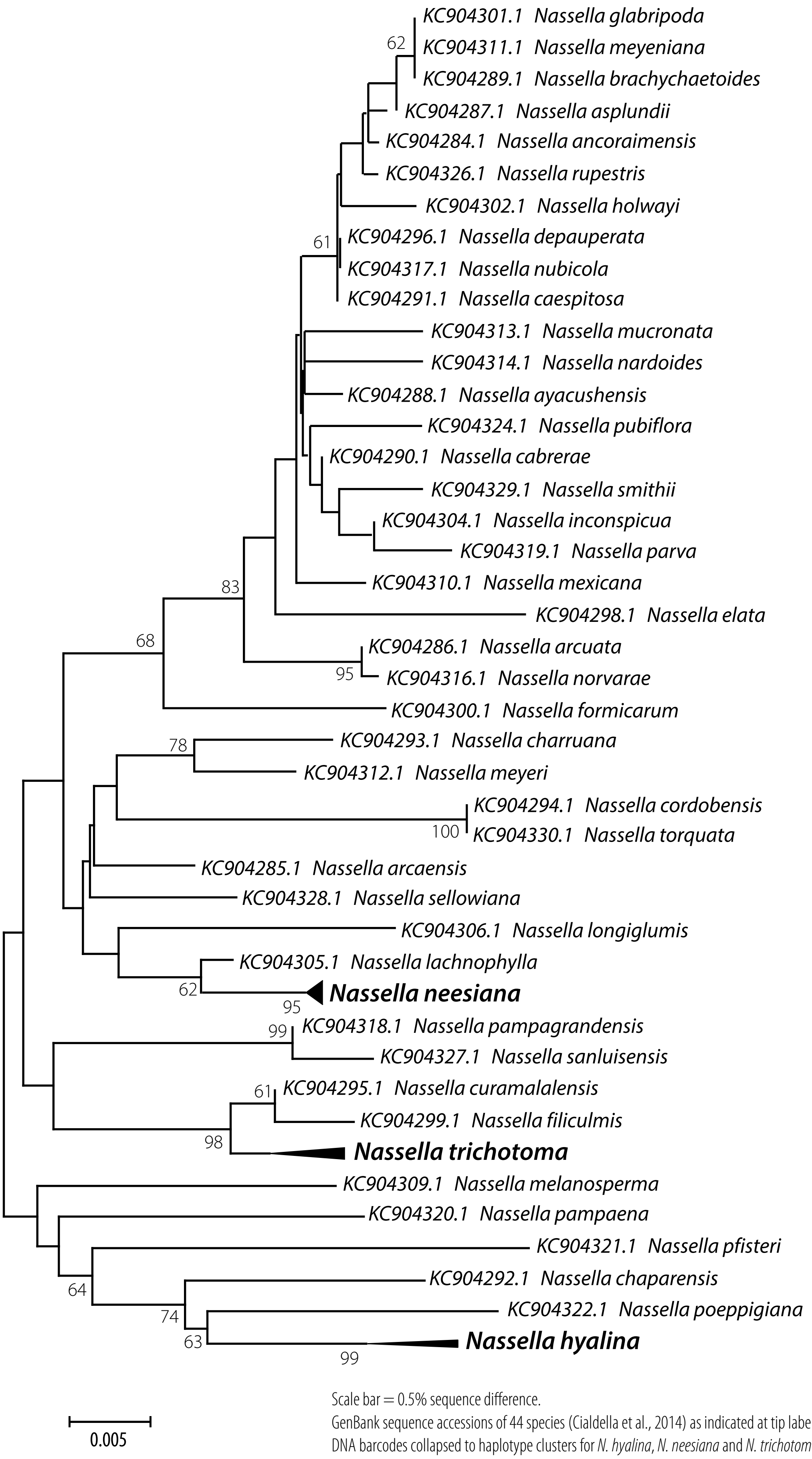
DNA barcoding followed reported protocols (Wang et al., 2017) to amplify and sequence a 484 base-pair (bp) portion of the ETS gene from specimens. ETS sequences were truncated to 412 bp for equal length alignment with accessions obtained from GenBank of 44 *Nassella* species (single replicate species vouchers) from the Americas. Identical sequences within species were collapsed to exemplar haplotypes. Pairwise neighbour joining (NJ) distance relationships among haplotype sequences were constructed as a phenetic tree using MEGA6 (Tamura et al., 2013) with bootstrap replication (N = 10,000) to determine node significance. Oligonucleotide primer sites designed for LAMP diagnostics of CNG and ST (Gopurenko et al., *in prep.*) were aligned against haplotype sequences to determine if nucleotide variation in the sampled populations overlapped with LAMP primer sequence motifs.

Results

- DNA barcodes from three introduced *Nassella* weeds in eastern Australia correctly matched to sequences of vouchered endemic species present in the Americas (Figure 1).
- Sequence diversity observed in all three *Nassella* weed species in eastern Australia was highest in *N. hyalina*, and haplotype diversity was highest in *N. neesiana* (Table 2).
- Primer sites in the ETS gene designed for LAMP diagnostics of CNG and ST are unaffected or are degenerate for the sequence diversity we detected in the weed populations.
- A single ETS sequence accession reported for *N. duriuscula* (Phil.) Barkworth 1990 from Chile was nested as a closely related lineage (99.76% sequence similarity) among *N. neesiana* haplotypes.

Table 2 ETS DNA barcode diversity among sampled *Nassella* species. Sample size (*N*), number of haplotypes (*N* haps) and highest percent sequence difference (*D*) within species indicated.

Species	***N***	***N* haps**	***D***
Nassella hyalina	12	2	1.232
Nassella neesiana	168	7	0.495
Nassella trichotoma	148	4	1.058



Scale bar = 0.5% sequence difference.
GenBank sequence accessions of 44 species (Cialdella et al., 2014) as indicated at tip labels.
DNA barcodes collapsed to haplotype clusters for *N. hyalina*, *N. neesiana* and *N. trichotoma*.

Figure 1 NJ distance tree of *Nassella* species ETS DNA barcode sequences.

Discussion

Validation of the ETS gene region for genetic diagnostics of CNG and ST

The utility of DNA barcoding for genetic identification of introduced grass species in Australia was reported by Wang et al., (2017), who listed several potentially useful genes for DNA-based diagnostics of introduced *Nassella* tussock weeds. Of these, the nuclear ribosomal ETS gene provided clear genetic delimitation of the economically important CNG and ST tussock weeds.

Subsequent development of LAMP methods targeted to sequence motifs in this gene have shown promising levels of validation for rapid genetic identification of CNG and ST (Gopurenko et al., 2018). Critically, fidelity of LAMP diagnostics relies on conservation of the targeted sequence motifs in the focal population. Incompatibilities between oligo-nucleotide primers designed to match targeted sequence motifs in the species population is a primary cause of false negative outcomes in LAMP testing.

To further determine reliability of the ETS gene region for genetic identification and diagnostics of CNG and ST weeds, we report ETS DNA barcodes of 328 *Nassella* specimens sampled mostly from eastern Australia. Our analyses indicate this DNA barcode region remains reliable for accurate sequence-based identification of CNG, ST and potentially other *Nassella* species in Australia. CNG and ST populations each contained few nucleotide mutations at this gene, and critically, these mutations either did not overlap with nucleotide sites in our designed LAMP primers, or in one case, can be adjusted for by degeneracy in our primer design. The ETS gene sequence motifs unique to CNG or ST can be confidently used in the design of LAMP primers for accurate detection of the two weeds.

Ultimately the goal of this work is to provide in-field genetic diagnostics to assist weed officers in their surveillance for early emergence of CNG and ST tussock weeds and to test identities of suspected weeds found in agricultural properties, parks and public road/rail corridors. A multi-step LAMP protocol, designed to allow rapid in-field and portable diagnostics of the two species using minimal equipment (Gopurenko et al., *in prep*.) is in preparation for commercial release. Broad adoption of the protocol by the biosecurity community may lead to requests for broader taxonomic coverage of weeds targeted for in-field detections. As such, requisite DNA sequence libraries of target and associated taxa will need to be accumulated to allow design of species diagnostic oligonucleotide probe sites used in LAMP and other isothermal amplification technologies.

Cryptic diversity among CNG in Australia?

Species identity of CNG in Australia is ubiquitously reported as *Nassella neesiana* and is in agreement with the current work here. In its native distribution, the species is similar to *N. duriuscula* (Phil.) Barkworth 1990, and ETS sequences from single accessions of the two species in Chile indicate they are related as sister taxa (Cialdella et al., 2014). Our DNA barcode analysis of multiple CNG replicates (N = 168) from Australia and Argentina, nests the reported *N. duriuscula* accession intermediate within a genetically shallow clade (<0.5% sequence difference) containing all seven haplotypes identified to *N. neesiana*. This nested genetic relationship has potential implications for taxonomic description of CNG in Australia, which is currently and exclusively recognised as *N. neesiana*. Most of the morphological features used to distinguish *Nassella* species (Barkworth and Torres, 2001) are shared or overlapping between *N. duriuscula* and *N. neesiana* and this, in combination with their close genetic relationship at ETS, raises the question as to whether they are biologically separate species as described by Barkworth 1990. Historical population processes between the two species can also explain the genetic paraphyly shown here, but resolving this issue is beyond the scope of the current paper. Integrative taxonomic and multi-locus molecular examination of sympatric replicates of the two species are needed to resolve this issue.

References

Barkworth ME, 1990. *Nassella* (Gramineae, Stipeae): revised interpretation and nomenclatural changes. *Taxon,* vol. 39, pp. 597–614.

Barkworth ME and Torres MA, 2001. Distribution and diagnostic characters of *Nassella* (Poaceae: Stipeae). *Taxon,* vol. 50, pp. 439–468.

Cialdella AM, Sede SM, Romaschenko K, Peterson, PM, Soreng RJ, Zuloaga FO and Morrone O, 2014. Phylogeny of *Nassella* (Stipeae, Pooideae, Poaceae) based on analyses of chloroplast and nuclear ribosomal DNA and morphology. *Systematic Botany,* vol. 39, pp. 814–828.

Gopurenko D, Wang A and Wu H, 2018. Specificity of LAMP for genetic diagnostics of Chilean needle grass and serrated tussock. *Proceedings of the 21st Australasian Weeds Conference,* Sydney, New South Wales, Australia, (eds S. Johnson, L. Weston, H. Wu and B. Auld), pp. 302–306, Weed Society of New South Wales.

Gopurenko D, Wang A and Wu H (*in preparation*). Portable LAMP diagnostics for onsite genetic identification of Chilean needle grass and serrated tussock.

Notomi T, Okayama H, Masubuchi H, Yonekawa T, Watanabe K, Amino N and Hase T, 2000. Loop-mediated isothermal amplification of DNA. *Nucleic Acids Research,* vol. 28, e63.

Tamura K, Stecher G, Peterson D, Filipski A and Kumar S, 2013. MEGA6: Molecular Evolutionary Genetics Analysis version 6.0. *Molecular Biology and Evolution,* vol. 30, pp. 2725–2729.

Wang A, Gopurenko D, Wu H and Lepschi B, 2017. Evaluation of six candidate DNA barcode loci for identification of five important invasive grasses in eastern Australia. *PLoS ONE,* vol. 12, e0175338.

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This experiment was part of project 'A DNA-based tool for rapid on-site identification of Chilean needle grass and serrated tussock', project code CT-17, June 2017–July 2019. The project was a collaborative partnership between NSW DPI and the Commonwealth Government Agricultural Competitiveness White Paper (Commonwealth of Australia, 2015) Control Tools and Technologies for Established Pest Animals and Weeds Programme administered through the Department of Agriculture and Water Resources. This work was an extension of earlier pilot research projects 'DNA barcoding of invasive grasses (2013–2015)' and 'Improved DNA barcode identification of invasive grasses using next generation sequencing (2015–2016)' funded through the NSW Weeds Action Program.

We are grateful for sampling assistance provided by Brett Jones (Snowy Monaro Regional Council), Neville Plumb (Queanbeyan-Palerang Regional Council), Malcolm Ross (Goulburn Mulwaree Council), Steve Taylor and Jenny Conolly (ACT Parks and Conservation Service), Roger Smith and Andrew Cole (Orange City Council).

Investigating ways to increase the yield of processing tomatoes

Sam North (NSW DPI, Deniliquin)

Key findings

- Tomato canopy size assessed from normalised difference vegetation index (NDVI) was strongly correlated ($R^2 = 0.96$) to total yield at eight of nine sites in 2019–20.
- This relationship will allow researchers to assess the effect of periods of soil water deficit or excess on yield during the 2019–20 season.

Introduction

The Australian processing tomato industry is concentrated in southern NSW and northern Victoria on clay soils irrigated by sub-surface drip. Average yields are around 80 t/ha (ABS, 2018), but the industry has set a target of 200 t/ha so it can be competitive in the face of rising irrigation water prices. The industry has identified soil constraints as a key area for improvement to meet this target.

Soils that are compacted hold less plant available water, are more prone to waterlogging, contain fewer roots, and soil water cannot move quickly to these roots. Crops that grow in such soils are more likely to experience water stress, either through water shortage because the soil cannot supply water to the roots quickly enough at mid-day, or because of transient waterlogging during irrigation. When stomates close in response to these stresses, transpiration is reduced. Two consequences arise when this happens: canopy temperature increases relative to ambient air temperature; and the rate of growth is reduced. Any reduction in growth will lead to a smaller canopy with fewer nodes and trusses and a lower yield potential, so there should, theoretically, be a correlation between canopy temperature as an indicator of plant stress and canopy size, and hence yield.

The goal of our work during the 2019–20 summer cropping season was to investigate:

1. whether yield is associated with canopy size
2. the relationship between canopy size and canopy temperature as an indicator of crop stress
3. the correlation between transient water shortage and/or waterlogging and yield.

Outcomes from this work will inform future investment to meet the industry's 200 t/ha target.

Site details

Table 1 details the location, soils, rotational phase and varieties at the nine sites monitored during the 2019–20 growing season.

Measurements

Sensors and loggers were installed at each site in late December 2019 after the final in-crop cultivation, and removed from the paddock just before picking in April. These sensors measured the following soil and plant parameters hourly during this period:

- soil water (matric) potential at 10, 20 and 35 cm depths – to assess soil water status
- soil water content every 10 cm from 10 to 80 cm deep
- soil redox potential at 10, 20 and 35 cm depths – to assess soil oxygen status
- canopy and air temperature – to assess crop stress.

Crop canopy growth during the season was assessed using normalised difference vegetation index (NDVI) data obtained by Landsat 7 and 8 and Sentinel 2 satellite imagery via the IrriSAT App (https://irrisat-cloud.appspot.com/#). Weather data for each site was obtained from SILO (www.longpaddock.qld.gov.au/silo/). The Brix, soluble solids, number of fruit, moisture content and yield of red fruit, the weight of green and rotten fruit, and the vine dry biomass was obtained from three quadrats (2 m of one plant row) cut at maturity.

Table 1 Details of the nine sites monitored during the 2019–20 tomato growing season.

Soil	Locality	Site	Rotation	Variety
Red loam	Echuca South	BA-7	First year after ripping. New tape.	UG 19406 & 16112
	Thyra	MB	First year crop	H 3402 & 1175
	Echuca South	BA-6	Third year crop	UG 19406 & 16112
	Rochester	KR	Corn in 2018–19	UG 19406 & 18806
	Rochester	MW	Third year crop	H 3402 & H2401
Grey clay	Strathallan	WE	First year after 20 years out of tomato	H 3402 & H2401
	Appin South	CH	First year after 2 years fallow	H 3402
	Corop	KE	Chickpea in 2018–19	H 3402
	Appin South	HE	Second year crop	H 3402 & 1311

Results

Harvest at the monitor sites started at site MB on 28 February and finished at site WE on 16 April. Yields ranged from 80 t/ha to 210 t/ha (Table 2). It is not possible to say whether the yield difference between the red loams (116 t/ha) and the grey clays (162 t/ha) was due to soil type, management, and/or variety.

Regarding management, all the red loam sites were lease blocks managed by Kagome, while all the grey clay sites were managed by individual owner-operators.

Regarding variety, Heinze 3402 was not grown at three of the five red loam sites. These three sites all grew a United Genetics mix of 19406 and 16112 varieties and Brix levels were higher at these three sites (average = 6.1) compared with the sites where Heinze 3402 was grown (average = 4.6). This was not a designed experiment. Rather, it was an observational study, where as much variability as possible was sampled but without replication. As such, statistical comparison of the yields from the nine sites was not applicable to this study. Correlation analyses will be conducted once all data has been collected.

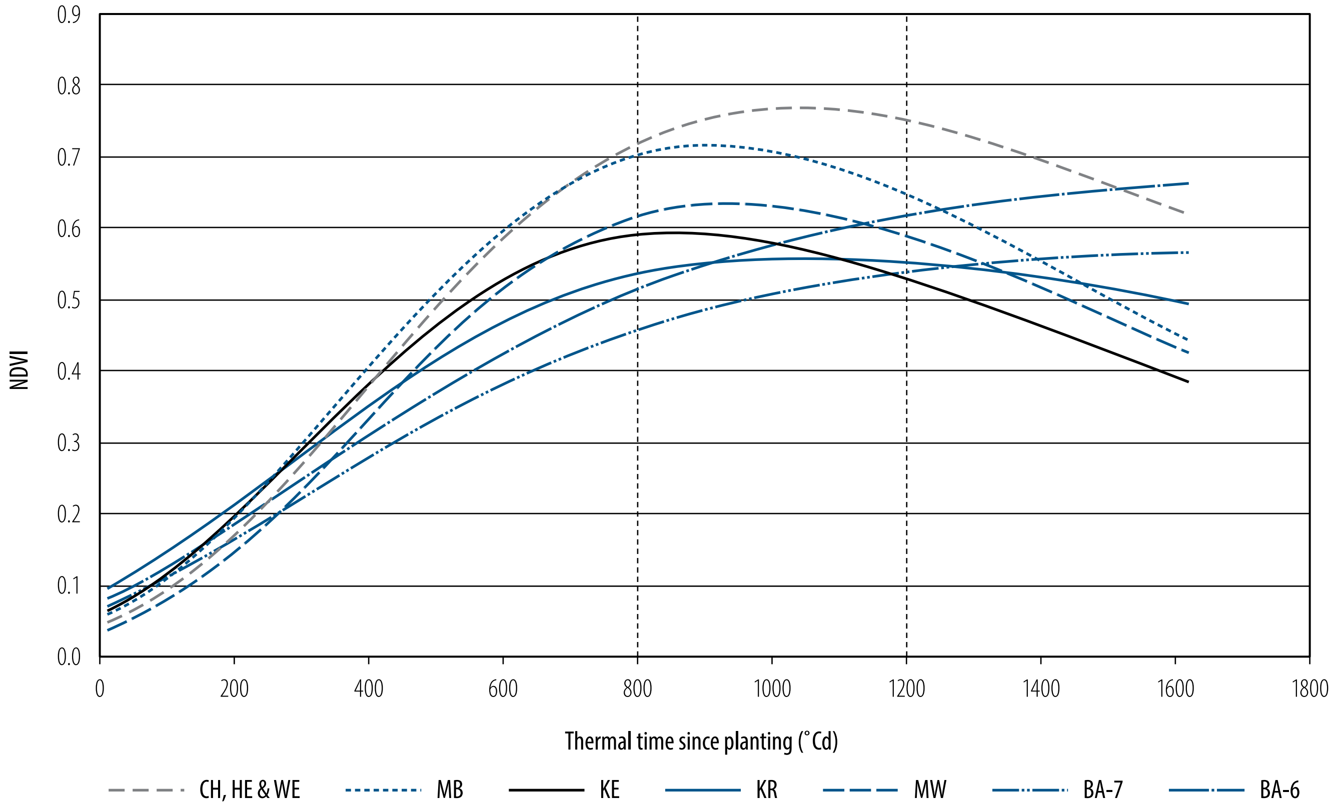
Table 2 Red fruit yield data from each of the nine sites monitored during 2019–20 and the proportion of the total yield (red + green + rotten) that was either green or rotten.

Site	Red fruit					Green fruit (%)	Rotten fruit (%)
	Yield (t/ha)	Brix	Soluble solids	Fruit/m^3	Dry (g/fruit)		
BA-7	81	6.4	5.2	264	2.4	12	3
MB	145	Not collected		329	2.7	9	2
BA-6	83	5.9	4.9	228	2.7	17	3
KR	131	6.0	7.9	274	3.6	16	4
MW	142	4.6	6.6	322	2.5	5	2
WE	165	4.4	7.3	383	2.5	10	17
CH	210	4.9	10.2	473	2.6	8	2
KE	116	4.9	5.7	306	2.4	4	1
HE	158	4.2	6.6	356	2.5	13	4

NDVI data for each field provided an estimate of canopy size every 8–10 days through the growing season, enabling the canopy size of each field to be compared based on accumulated thermal time in degree days (°Cd) since planting or emergence (Figure 1). The nine crops split into three groups:

1. The three highest yielding crops (sites CH, HE, WE) all grew large canopies by 800 °Cd and maintained those canopies through until 1200 °Cd.

2. The crops at sites MB, MW and KE all grew well initially, but growth was checked, and yields suffered accordingly. The factors affecting growth in these three crops varied and further examination is needed. However, water stress is suspected at sites MB; disease at site MW; and waterlogging/disease at site KE.
3. The crops at sites KR, BA-6 and BA-7 did not grow as quickly as the crops at the other six sites, nor did they reach an NDVI of 0.72 (equivalent to a crop factor, K_c, of 0.9) by 800 °Cd. The soil, water and canopy temperature data will help explain the cause of this poor growth when analysis is completed.

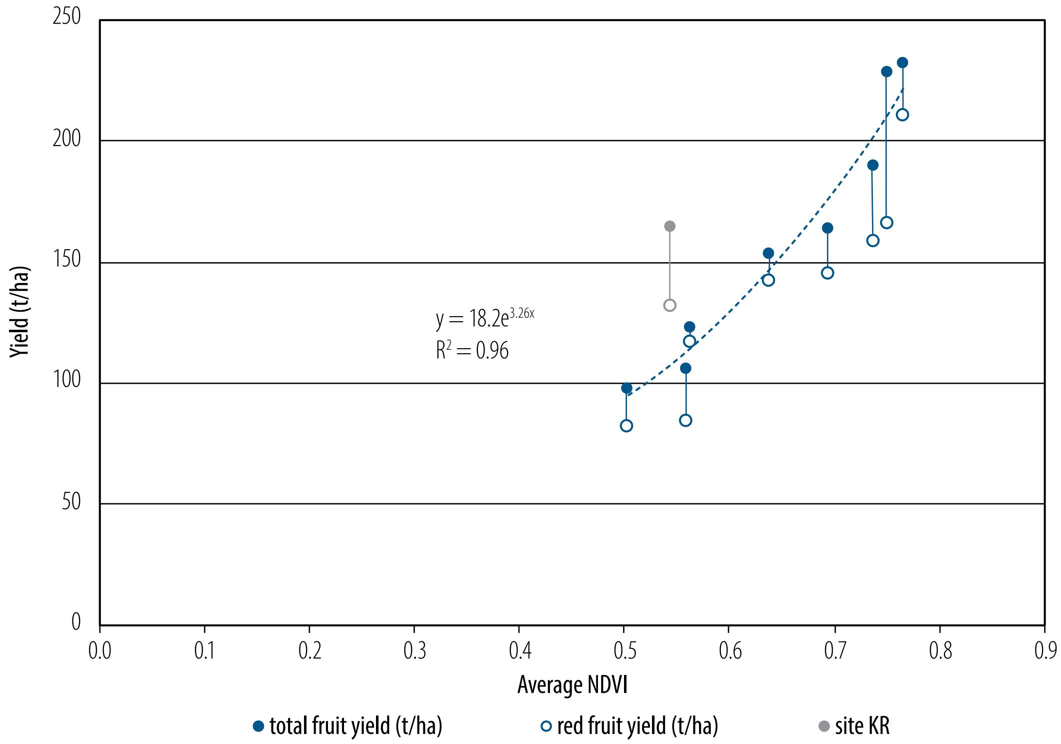


Lines fitted to the data using an asymmetric growth model (Werker and Jaggard, 1997) are shown (R^2>96%).
There was no significant difference in canopy growth at sites CH, HE and WE (*P*= 0.46).

Figure 1 The change in crop normalised difference vegetation index (NDVI) with thermal time since planting for the crops at the nine sites monitored in 2019–20.

Preliminary findings

We have clearly shown that smaller canopy size (assessed using NDVI from IrriSAT) is associated with lower total yield, where total yield is the sum of the yields of red, green and rotten fruit (Figure 2). The next phase of the work is to determine whether smaller canopies are correlated with canopy temperature (as a measure of crop stress) between planting and 800 °Cd, and then determine whether soil water excess or deficit is the key cause of the stress.



Site KR (grey circles) has been omitted from the relationship due to the difference in fruit size at that site.

Figure 2 The relationship between total (red + green + rotten) fruit yield and average crop NDVI during the period from 800 to 1200 °Cd after planting at eight of the nine sites in 2019–20.

Whilst it is too early to draw any conclusions, the data we have analysed to date points to three main ways in which processing tomato yields might be increased:

1. ensure all canopies attain an NDVI of 0.72 (i.e. a K_c of 0.9) by 800 °Cd after planting
2. reduce harvest losses
3. grow larger fruit.

Canopy size between 800 °Cd and 1200 °Cd after planting

Bigger canopies produce more fruit because there are more main stem nodes. The very strong correlation between total (red + green + rotten) fruit yield and average NDVI between 800 °Cd and 1200 °Cd after planting (Figure 2) gives us confidence that we can use IrriSAT to assess canopy growth. If NDVI can be lifted from the average of 0.65 to 0.72, yields would potentially be lifted from 150 t/ha to 215 t/ha. Our next step is to see whether canopy temperature and soil water status can explain the differences in canopy growth across the nine sites.

Harvest losses

Losses in green fruit averaged 14% at five sites, but only 7% at the other four (Table 2). If the losses in the five most affected crops had been reduced from 14% to 10%, then red fruit yields may have been increased by 20%.

Fruit size

Red fruit dry weight at site KR was 44% greater than the average dry weight at the other eight sites (Table 2). As a result, yields at site KR were 50% higher than its canopy size indicated it should have been (see grey compared to blue lines in Figure 2). The reason why the KR crop had such large fruit is currently not known, but it might be due in part to variety. Because Yield = number of fruit × fruit weight, finding ways to increase fruit size should be a goal in the industry's drive to increase yields.

The industry target of 200 t/ha appears achievable with existing varieties and management. However, to achieve this target across the industry, it will be necessary to determine the key factors limiting the yields of under-performing crops. IrriSAT offers the ability to monitor crop growth and identify these under-performing crops early in the season. This study will lead to a better understanding of the factors responsible for poor canopy growth and assist the industry in devising strategies to overcome these impediments.

References

Australian Bureau of Statistics (ABS), 2018. *Agricultural commodities, Australia and state/territory and NRM regions - 2016-17*, data cube: Excel spreadsheet, cat. no. 71210DO002_201617, https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/7121.02016-17?OpenDocument#Data. Viewed 29 April 2020.

Werker AR and Jaggard KW, 1997. Modelling asymmetrical growth curves that rise and then fall: applications to foliage dynamics of sugar beet (*Beta vulgaris* L.). *Annals of Botany*, vol 79, pp. 657–665.

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