Department of Primary Industries

# Southern NSW research results 2019

RESEARCH & DEVELOPMENT – INDEPENDENT RESEARCH FOR INDUSTRY

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## an initiative of Southern Cropping Systems

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**Cover image**: Set of exclusion cages in a canola paddock inoculated with aphids and parasitoid wasps in *Can parasitoid wasps control aphids in canola?* Dr Jo Holloway, NSW DPI, Wagga Wagga (page 108).

ISBN 978-1-76058-339-2 (web)

ISBN 978-1-76058-338-5 (print)

jn 15183

Published by NSW Department of Primary Industries, a part of NSW Department of Planning, Industry and Environment.

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# Foreword

NSW Department of Primary Industries (NSW DPI) welcomes you to the Southern NSW research results 2019. 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
- intensive livestock industries
- feedbase productivity
- drought preparedness, response and recovery
- climate adaptation
- climate mitigation
- agriculture landuse planning
- energy solutions
- value chain efficiency and meat quality.

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.

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.

*The Research and Development Teams*
*NSW Department of Primary Industries*

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# Seasonal conditions 2018

Scott Wallace, Seasonal Conditions Coordinator, Climate Unit (NSW DPI, Orange)

## Climate summary

### Condobolin Agricultural Research and Advisory Station

Rainfall totals were well below average for all months in 2018 except November at Condobolin (Figure 1). Although some moisture was stored from rainfall in November and December 2017, soil moisture status was low for winter crop sowing due to the extremely dry February–April. Consequently, plant establishment was extremely difficult with June being the only month to provide some short -term positivity during the growing season.

Average minimum temperatures at Condobolin were below the long-term average (LTA) from May through to September (Figure 1), with 53 frosts (temperatures below 2 °C). Average maximum temperatures were above the LTA throughout the entire growing season. April was a very warm month with both minimum and maximum temperatures well above average.

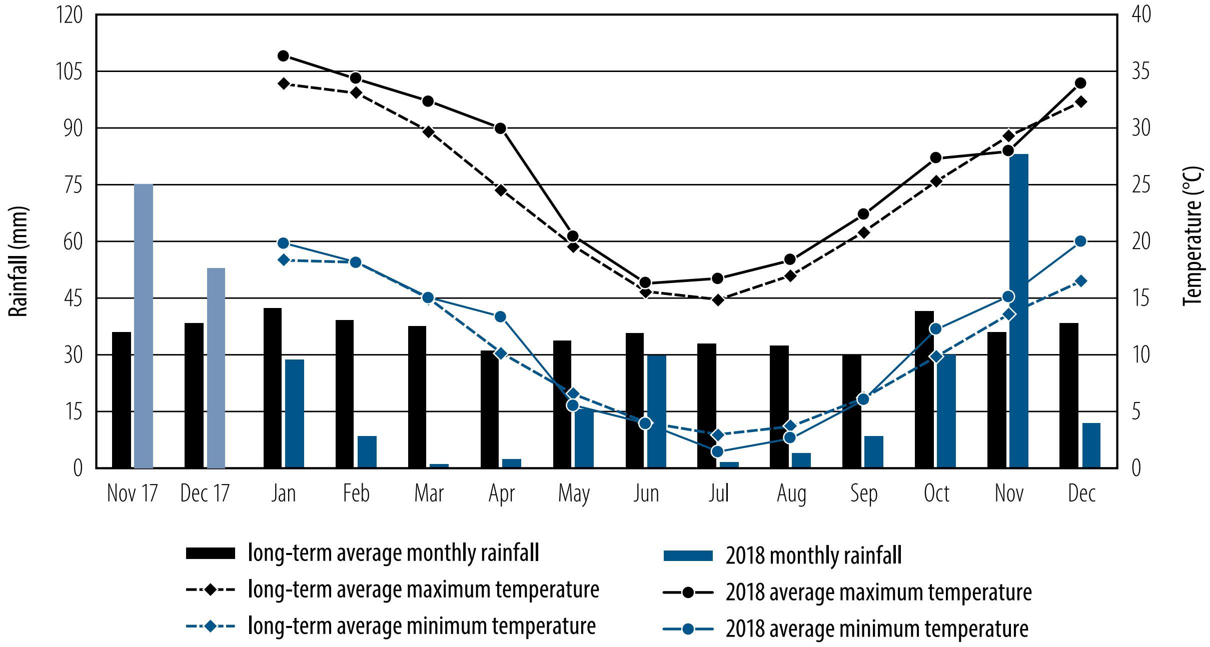

Figure 1. Monthly rainfall and temperature analysis for Condobolin Agricultural Research and Advisory Station in 2018. Monthly rainfall for November and December 2017 is included as this stored fallow moisture affected crop growth and yield in 2018.

### Yanco Agricultural Institute

Rainfall totals during 2018 were well below average for all months except November at Yanco (Figure 2). Despite well-above average rainfall in December 2017, soil moisture status was low in the lead up to sowing, resulting in all canola experiments requiring supplementary watering for establishment. However, some useful rainfall during May and June provided enough moisture to establish the pulse and winter cereal experiments. Conditions then remained very dry during late winter and throughout spring. The above average rainfall during November was too late to be useful for any of the winter cereal and pulse experiments. November and December rainfall was useful in establishing the experiments for the summer soybean variety evaluation program.

Both average minimum and average maximum temperatures for 2018 were above the LTA throughout the entire calendar year (Figure 2) at Yanco. Both April and October were very warm months with minimum and maximum temperatures well above the LTA. The high April temperatures promoted rapid growth in the early sown canola experiment which made the faster maturing varieties more susceptible to frost damage during the winter months. The high October temperatures shortened the growing season for all varieties in the later sown pulse experiments, resulting in reduced yields compared with mid season sowing dates. The warmer conditions during early summer were ideal for establishing summer cropping experiments.

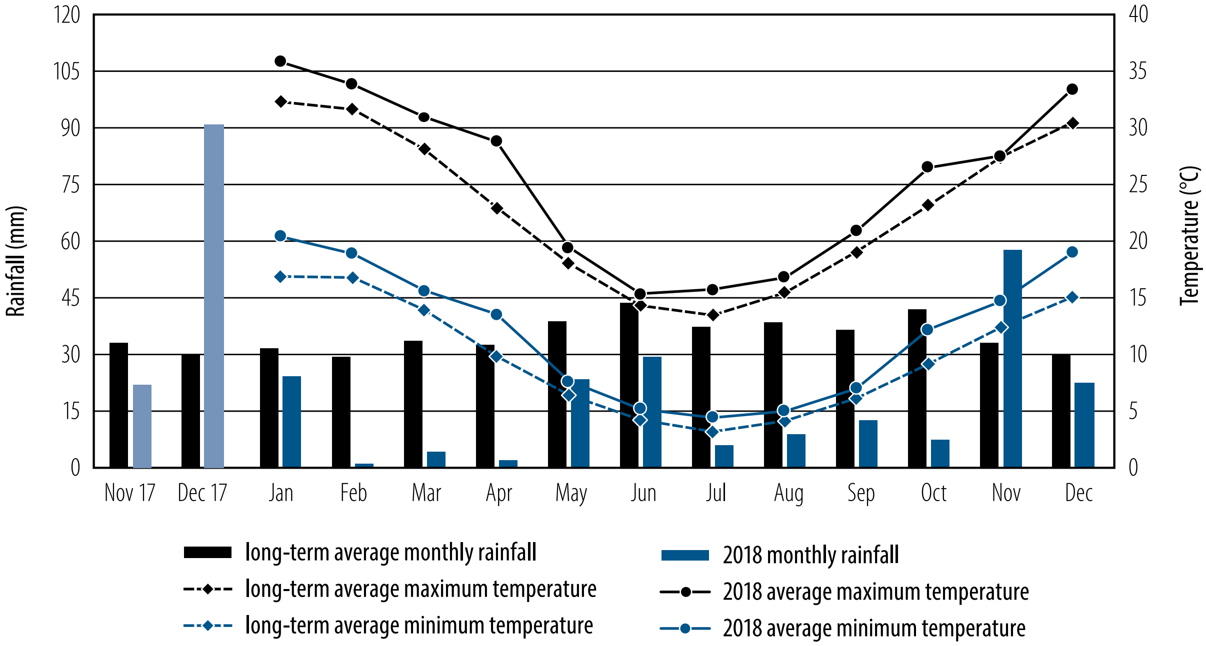

Figure 2. Monthly rainfall and temperature analysis for Yanco Agricultural Institute in 2018. Monthly rainfall for November and December 2017 is included as this stored fallow moisture affected crop growth and yield in 2018.

### Wagga Wagga Agricultural Institute

The 2017–18 fallow period received higher than average summer rain in December, January and February, however rainfall during the autumn months and the sowing period was well below average (Figure 3). The entire growing season had well below average rainfall: June received the most rainfall of 40 mm.

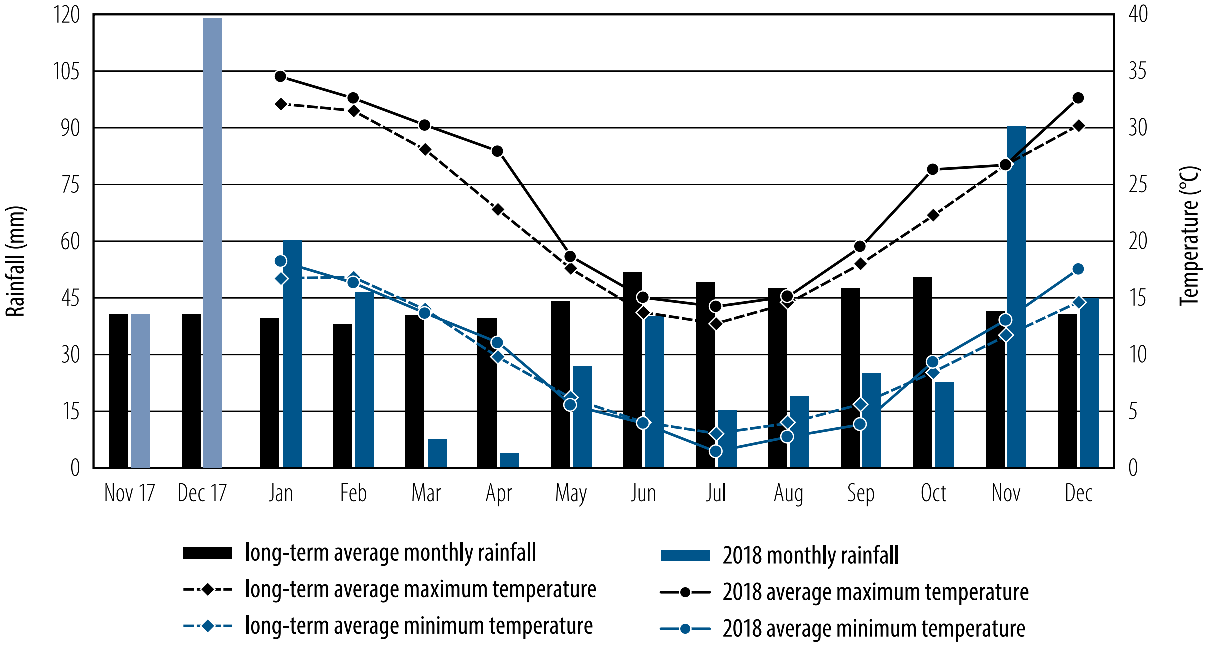

Figure 3. Monthly rainfall and temperature analysis for Wagga Wagga Agricultural Institute in 2018. Monthly rainfall for November and December 2017 is included as this stored fallow moisture affected crop growth and yield in 2018

Average minimum temperatures were below the LTA from July through to September at Wagga Wagga (Figure 3) with a major frost of –4.5 °C on 29 August. Average maximum temperatures were higher in 2018 than the LTA for the entire growing season. There were significant peaks of around 4–5 °C above the LTA in April and October.

## Disease

### Pulses and oilseeds

Below average rainfall and above average temperatures for most of the year reduced the potential severity for foliar diseases in 2018.

Crop surveys indicated that severe frosts in late winter resulted in widespread damage to pulse crops, especially those sown into retained cereal stubble. The surveys also revealed that most broadleaf crop diseases could be found, but at levels below economic thresholds.

Low levels of blackleg of canola were recorded due to the dry winter conditions. There were low level outbreaks of sclerotinia stem rot, but they were restricted to those districts where the disease frequently occurs.

In general, the drier than average spring conditions curbed the potential for foliar disease outbreaks. This resulted in a reduced need for foliar fungicides in crops such as canola and faba bean.

### Cereals

Widespread drought characterised the 2018 season in southern NSW which affected winter cereal sowing times and crop development in many regions.

The winter cereal disease survey results reflected the drought conditions with low levels of leaf diseases.

The survey identified:

- Crown rot (*Fusarium pseudograminearum, F. colmorum and F. graminearum*) was common and widespread across southern NSW reaching medium to high risk levels of yield loss in 44% of barley and 32% of wheat paddocks.
- Take-all and pythium were present at low levels of intensity but were in almost all cereal paddocks at 96% (take-all) and 100% (pythium). This is higher than might be expected during a dry season and demonstrates the diseases' resilience.
- Barley spot form of net blotch was detected in 20% of wheat paddocks.
- Yellow leaf spot was common in wheat paddocks. It was detected in 86% of wheat and 89% of barley survey paddocks.

## Acknowledgements

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

# Agronomy – cereals

## Early sowing options: sowing date influence on phenology and grain yield of long-season wheat genotypes – Wallendbeen 2018

Dr Felicity Harris, Hugh Kanaley, Cameron Copeland and Dean Maccallum (NSW DPI, Wagga Wagga);
Hayden Petty (NSW DPI, Yanco)

### Key findings

- Yields of winter wheats sown early were similar to yields of well-adapted spring types sown within their optimal window.
- New winter genotypes had different phenology responses compared with current commercial genotypes, suggesting that management can manipulate cultivar performance and can vary across growing environments.

### Introduction

Recent trends in earlier sowing have renewed grower interest in winter wheats and breeder focus on selecting and releasing new winter genotypes suited to southern NSW farming systems. In 2018, a field experiment was conducted at Wallendbeen in southern NSW to evaluate current commercial genotypes in conjunction with new breeder lines suited to early sowing. This paper presents results from the Wallendbeen site, focusing on the influence that sowing date (SD) had on the phenology, grain yield and quality of 16 wheat genotypes.

### Site details

| | |
|---|---|
| **Location** | Braeside, Wallendbeen, NSW |
| **Soil type** | Red kandasol |
| **Previous crop** | Canola |
| **Sowing** | Direct drilled with DBS tynes spaced at 250 mm using a GPS auto-steer system<br>Target plant density: 140 plants/$m^2$ |
| **Soil $pH_{Ca}$** | 4.6 (0–10 cm); 5.4 (10–30 cm) |
| **Mineral nitrogen (N)** | 113 kg N/ha at sowing (1.8 m depth) |
| **Fertiliser** | 82 kg/ha mono-ammonium phosphate (MAP) (sowing)<br>Urea 87 kg/ha (spread 7 June) |
| **Weed control** | Pre-emergent: Sakura® 118 g/ha + Logran® 35 g/ha + Avadex® Xtra 1.6 L/ha |
| **Disease management** | Seed treatment: Hombre® Ultra 200 mL/100 kg<br>Fertiliser treatment: Flutriafol (250 g/L) 400 mL/ha<br>In-crop: Prosaro® 300 mL/ha (5 July) |

| | |
|---|---|
| **In-crop rainfall** | 219 mm (April–October); long-term average – 460 mm<br>17 mm recorded between harvest dates |
| **Harvest date** | 27 November 2018<br>5 December 2018 Manning$^{\Phi}$ (SD1, SD2 and SD3) and DS Bennett$^{\Phi}$ (SD3) due to delayed maturity. |

## Treatments

Sixteen wheat genotypes with varying responses to vernalisation and photoperiod (Table 1) were sown on three sowing dates: SD1: 28 March, SD2: 13 April and SD3: 1 May 2018.

Table 1. Expected phenology types of experiment genotypes at Wallendbeen, 2018.

| Phenology type | Sub-category | Genotypes |
|---|---|---|
| Winter | Slow | Manning$^{\Phi}$, RGT Accroc |
| | Mid–slow | DS Bennett$^{\Phi}$, ADV08-0008 |
| | Mid | EGA Wedgetail$^{\Phi}$, LongReach Kittyhawk$^{\Phi}$, ADV13-1292 |
| | Mid–fast | Illabo$^{\Phi}$ |
| | Fast | Longsword$^{\Phi}$ |
| Spring | Very slow | LongReach Nighthawk$^{\Phi}$ (LPB14-0392), RGT Zanzibar, Sunlamb$^{\Phi}$, Sunmax$^{\Phi}$ |
| | Slow | Cutlass$^{\Phi}$ |
| | Mid–slow | LongReach Lancer$^{\Phi}$, LongReach Trojan$^{\Phi}$ |

## Results

### Phasic development

Generally, the genotype and sowing date combinations that flower in mid–late October at Wallendbeen achieve the highest grain yields.

In this experiment, there was significant variation in genotype pre-flowering stages with respect to sowing date (Figure 1), which influenced the flowering by grain yield responses. Faster developing spring types (with minimal response to vernalisation), sown early (when temperatures are warmer and days longer), progressed quickly and suffered significant yield penalties from flowering outside the optimal flowering period (OFP). For example, LongReach Lancer$^{\Phi}$ sown on SD1 at Wallendbeen, flowered on 27 August. However, when sown on SD3 (within an appropriate sowing window for its given phenology type), LongReach Lancer$^{\Phi}$ flowered on 13 October and within the OFP. In contrast, the winter wheats all had a prolonged vegetative phase and achieved relatively stable flowering dates across the sowing treatments (Figure 1). Despite this, there was significant variation in phasic duration among the winter types, indicating varied responses to vernalisation and photoperiod, which also influenced grain yield responses (Figure 2).

Mid-winter types Illabo$^{\Phi}$, EGA Wedgetail$^{\Phi}$ and LongReach Kittyhawk$^{\Phi}$ recorded similar flowering dates from each sowing date, however we observed differences in date of GS30 (start of stem elongation) in response to sowing date. From SD1, LongReach Kittyhawk$^{\Phi}$ reached GS30 six days and 14 days faster than Illabo$^{\Phi}$ and EGA Wedgetail$^{\Phi}$ respectively, while in SD2, LongReach Kittyhawk$^{\Phi}$ was four days faster to GS30 than both Illabo$^{\Phi}$ and EGA Wedgetail$^{\Phi}$. There was no difference in GS30 dates in SD3.

The fastest developing winter type, Longsword$^{\Phi}$ had a shorter vegetative period than the mid-winter types: 17 days faster to GS30 than EGA Wedgetail$^{\Phi}$ in SD1 and six and eight days faster in SD2 and SD3. It was also 4–5 days quicker to flowering thereafter.

The slow-winter types, DS Bennett$^{\Phi}$, Manning$^{\Phi}$ and RGT Accroc, were significantly slower to GS30 and flowering than the other winter types. DS Bennett$^{\Phi}$ showed very stable flowering dates across the three sowing dates, flowering nine days later than EGA Wedgetail$^{\Phi}$ in SD1, six days later in SD2 and two days later in SD3. There was also notable variation in the grain-filling phase among the slower winter types, with RGT Accroc 3–5 days quicker to physical maturity than Manning$^{\text{(}}$, despite similar flowering dates.

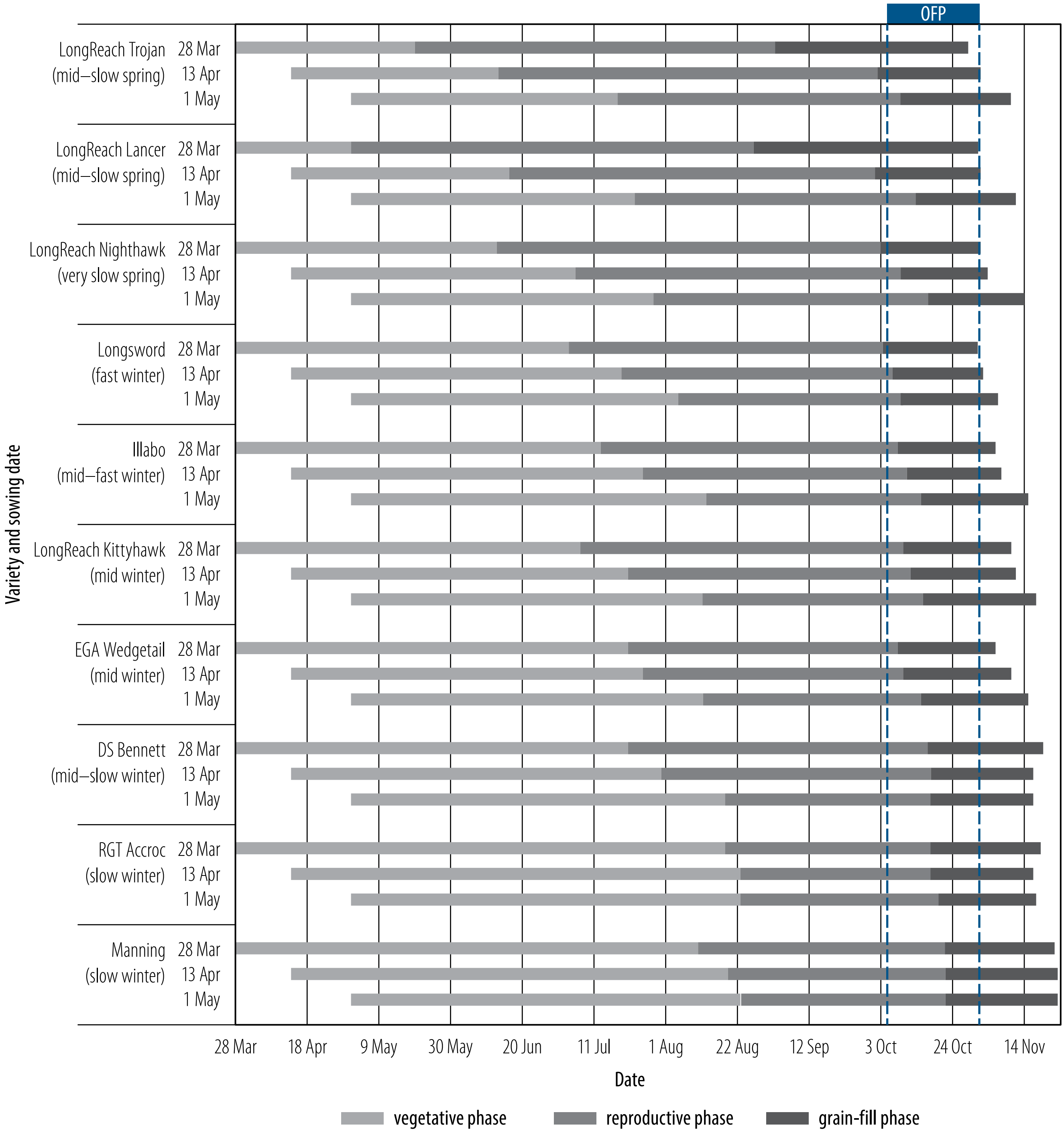

Figure 1. Sowing date influence on phasic development of selected genotypes sown on 28 March, 13 April and 1 May at Wallendbeen, 2018.

*Vegetative phase (sowing to GS30); reproductive phase (GS30 to flowering); grain-fill phase (flowering to maturity). Blue dotted lines indicate optimal flowering period (OFP).*

### Grain yield

Generally, the winter genotypes achieved consistently high yields across sowing dates at the Wallendbeen site in 2018, and some newer winter genotypes indicated a possible yield advantage compared with benchmark variety EGA Wedgetail⁽ᶲ⁾. However, there was an influence of the varied phenology responses reported among the winter types, whereby the accelerated development, and earlier flowering quicker winter types (Illabo⁽ᶲ⁾ and Longsword⁽ᶲ⁾) and spring genotypes (LongReach Lancer⁽ᶲ⁾ and LongReach Trojan⁽ᶲ⁾), resulted in significant yield penalties (Figure 2; Table 2), from SD1. This yield response to sowing date for Illabo⁽ᶲ⁾ and Longsword⁽ᶲ⁾ is consistent with 2017 results (Harris et al. 2018), indicating optimal sowing dates from mid April onwards when ungrazed. Despite the yield penalty from SD1, spring types were capable of similar yields (and flowering dates) as winter types when sown later in SD3, within their recommended sowing window.

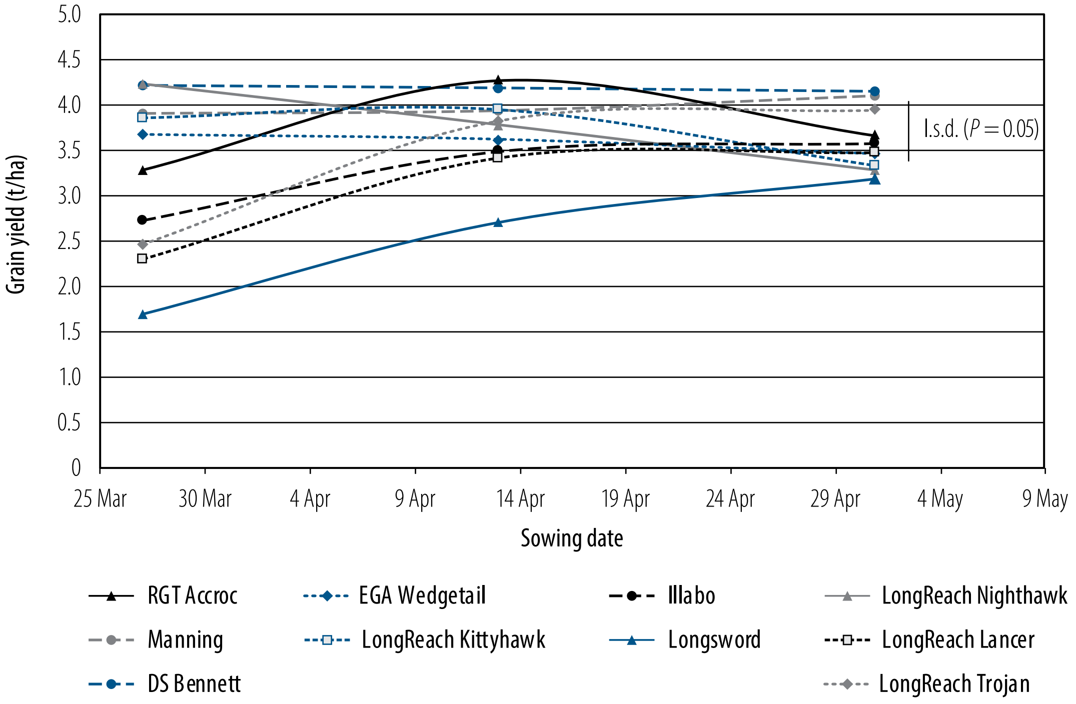

Figure 2. Grain yield responses across three sowing dates: 28 March, 13 April and 1 May at Wallendbeen, 2018; l.s.d., least significant difference.

Table 2. Grain yield of genotypes across three sowing dates at Wallendbeen in 2018.

| Genotype | Grain yield (t/ha) | | |
|---|---|---|---|
| | SD1: 28 March | SD2: 13 April | SD3: 1 May |
| ADV08-0008 | 3.81 | 3.49 | 3.65 |
| ADV13-1292 | 3.11 | 3.37 | 3.56 |
| Cutlass | 0.32 | 3.12 | 3.81 |
| DS Bennett | 4.23 | 4.20 | 4.16 |
| EGA Wedgetail | 3.68 | 3.63 | 3.48 |
| Illabo | 2.73 | 3.50 | 3.59 |
| LongReach Nighthawk | 4.24 | 3.79 | 3.29 |
| LongReach Kittyhawk | 3.87 | 3.96 | 3.35 |
| LongReach Lancer | 2.30 | 3.43 | 3.49 |
| LongReach Trojan | 2.47 | 3.84 | 3.96 |
| Longsword | 1.70 | 2.71 | 3.19 |
| Manning | 3.92 | 3.95 | 4.11 |
| RGT Accroc | 3.30 | 4.29 | 3.68 |
| RGT Zanzibar | 3.51 | 3.25 | 3.64 |
| Sunlamb | 4.07 | 3.65 | 3.83 |
| Sunmax | 4.50 | 3.48 | 3.44 |
| Mean | 3.24 | 3.60 | 3.64 |
| Mean (Winter) | 3.26 | 3.43 | 3.46 |
| Mean (Spring) | 3.62 | 3.88 | 3.82 |
| l.s.d. genotype | 0.38 | | |
| l.s.d. SD | 0.16 | | |
| l.s.d. genotype × SD | 0.66 | | |

### Grain quality

Genotype, sowing date and the interaction between sowing date and genotype significantly affected grain protein, test weight and screenings in 2018 (Table 3). With the exception of Sunmax$^{\Phi}$, LongReach Nighthawk$^{\Phi}$ (SD1) and DS Bennett$^{\Phi}$ (SD3), all commercial genotypes achieved greater than 11.5% grain protein. Most genotypes achieved a test weight of >76 kg/hL, with the exception of Cutlass$^{\Phi}$, Manning$^{\Phi}$ and RGT Accroc (SD1), and Sunlamb$^{\Phi}$ (SD3). Many genotype by sowing time combinations recorded high screenings (>5%) in 2018 (Table 3), however, Longsword$^{\Phi}$ consistently recorded low screenings.

## Summary

Despite below average rainfall in 2018, high grain yields were achieved from various genotype by sowing date combinations. Winter genotypes were generally stable in flowering time and grain yield responses across sowing dates from late March to early May, however, we did report significant differences in phasic development among the winter types, 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 early sowing, however, some were able to achieve comparable grain yields when sown at an optimal time e.g. LongReach Trojan$^{\Phi}$ 1 May (SD3). These results highlight the importance of matching genotype and sowing date to achieve OFP as an effective management strategy to optimise grain yields, as well as highlighting the opportunity for early-sown winter wheat in grain-only systems.

Table 3. Protein (%), screenings (%) and test weight (kg/hL) of genotypes across three sowing dates at Wallendbeen in 2018.

| Genotype | SD1: 28 March | | | SD2: 13 April | | | SD3: 1 May | | |
|---|---|---|---|---|---|---|---|---|---|
| | Protein (%) | Test weight (kg/hL) | Screenings (%) | Protein (%) | Test weight (kg/hL) | Screenings (%) | Protein (%) | Test weight (kg/hL) | Screenings (%) |
| ADV08-0008 | 12.1 | 76.6 | 18.0 | 12.9 | 77.7 | 19.0 | 13.3 | 78.4 | 17.6 |
| ADV13-1292 | 13.2 | 77.1 | 5.9 | 13.0 | 80.1 | 5.2 | 13.1 | 80.6 | 5.2 |
| Cutlass | 16.6 | 71.7 | 4.4 | 12.4 | 80.4 | 6.8 | 12.6 | 79.6 | 10.7 |
| DS Bennett | 11.7 | 79.3 | 7.3 | 11.7 | 80.4 | 5.2 | 10.5[A] | 81.3[A] | 3.8[A] |
| EGA Wedgetail | 12.7 | 76.8 | 8.5 | 13.3 | 78.1 | 5.9 | 14.1 | 77.7 | 6.3 |
| Illabo | 14.1 | 75.3 | 7.0 | 12.9 | 77.4 | 9.6 | 13.6 | 78.2 | 8.1 |
| LongReach Kittyhawk | 12.3 | 81.2 | 11.5 | 12.2 | 82.0 | 9.7 | 13.4 | 81.7 | 7.7 |
| LongReach Lancer | 15.4 | 76.4 | 8.7 | 13.2 | 79.2 | 7.5 | 13.6 | 79.1 | 9.2 |
| LongReach Nighthawk | 11.2 | 79.8 | 6.2 | 12.0 | 80.2 | 6.5 | 14.3 | 80.7 | 6.1 |
| LongReach Trojan | 13.9 | 79.8 | 4.2 | 12.9 | 80.4 | 6.9 | 12.5 | 79.3 | 9.2 |
| Longsword | 15.4 | 76.0 | 1.5 | 13.8 | 80.0 | 2.1 | 13.5 | 79.8 | 2.6 |
| Manning | 11.6[A] | 75.7[A] | 5.7[A] | 12.2[A] | 77.9[A] | 3.6[A] | 11.5[A] | 77.1[A] | 4.1[A] |
| RGT Accroc | 13.7 | 75.2 | 15.1 | 11.6 | 78.8 | 10.8 | 14.6 | 77.1 | 9.1 |
| RGT Zanzibar | 13.1 | 76.6 | 15.6 | 12.9 | 78.1 | 11.8 | 12.6 | 78.8 | 15.0 |
| Sunlamb | 12.4 | 78.2 | 7.5 | 13.1 | 79.1 | 5.2 | 13.7 | 75.8 | 4.0 |
| Sunmax | 11.0 | 80.1 | 12.2 | 13.0 | 80.1 | 10.1 | 12.4 | 80.9 | 11.5 |
| l.s.d. genotype | 0.8 | 1.0 | 1.5 | | | | | | |
| l.s.d. SD | 0.4 | 0.4 | 0.7 | | | | | | |
| l.s.d. genotype × SD | 1.4 | 1.7 | 2.6 | | | | | | |

[A] harvested following 17 mm rain due to delayed maturity.

## Reference

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.

## Acknowledgements

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

We sincerely thank Cameron and Sarah Hazlett, Braeside, Wallendbeen for hosting the field experiment and acknowledge the technical support of Mary Matthews and Jordan Bathgate.

# Sowing date influence on wheat phenology and grain yield – Wagga Wagga 2018

Dr Felicity Harris, Hugh Kanaley, Cameron Copeland and Dean Maccallum (NSW DPI, Wagga Wagga); Hayden Petty (NSW DPI, Yanco)

## Key findings

- Frost and drought significantly influenced phenology and grain yield responses in 2018.
- Commercial cultivars were not broadly adapted across sowing dates from early April to late May.
- High grain yields were achieved from a range of genotype by sowing date combinations when phenology is considered.
- Whilst flowering time is important in maximising grain yield potential, timing of pre-flowering phases was also found to significantly influence grain yield.

## Introduction

In 2018, field experiments were conducted across 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 Wagga Wagga 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** | Wagga Wagga Agricultural Institute |
| **Soil type** | Red chromosol |
| **Previous crop** | Canola |
| **Sowing** | Direct drilled with DBS tynes spaced at 240 mm using a GPS auto-steer system<br>Target plant density: 140 plants/m$^2$ |
| **Soil pH$_{Ca}$** | 4.7 (0–10 cm); 4.9 (10–30 cm) |
| **Mineral nitrogen (N)** | 174 kg N/ha at sowing (1.8 m depth) |
| **Fertiliser** | 80 kg/ha mono-ammonium phosphate (MAP) (sowing) |
| **Weed control** | Knockdown: glyphosate (450 g/L) 1.2 L/ha<br>Pre-emergent: Sakura® 118 g/ha + Avadex® Xtra 1.6 L/ha + trifluralin (480 g/L) 0.8 L/ha<br>In-crop: Axial® 300 mL/ha + Precept® 2 L/ha (19 June) |
| **Disease management** | Seed treatment: Hombre® Ultra 200 mL/100 kg<br>Fertiliser treatment: Flutriafol (250 g/L) 400 mL/ha |
| **In-crop rainfall** | 179 mm (April–October); long-term average – 355 mm |

| | |
|---|---|
| **Severe temperature events** | |
| | Sixteen heat stress events (days >30 °C)<br>Thirty-six frosts (days <0 °C), 11 severe frosts (days <–2 °C) including –4.9 °C (28 August), –6.3 °C (29 August), –5.4 °C (30 August) and –3.9 °C (17 September) |
| **Harvest date** | 18 November 2018 (SD1, SD2)<br>19 December 2018 (SD3, SD4) |

## Treatments

Thirty-six wheat genotypes (Table 1), varying in phenology responses were sown on four sowing dates: SD1: 5 April, SD2: 20 April, SD3: 3 May and SD4: 21 May in 2018.
SD1, SD2 and SD4 were established with 15 mm irrigation via drippers.
SD3 established with 6.9 mm 4 May.

Table 1. Expected phenology responses of the 2018 experiment genotypes.

| Phenology type | Sub-category | Genotypes |
|---|---|---|
| Winter | Slow | Manning$^{\Phi}$, RGT Accroc |
| | Mid–slow | DS Bennett$^{\Phi}$ |
| | Mid | EGA Wedgetail$^{\Phi}$, LongReach Kittyhawk$^{\Phi}$ |
| | Fast | Longsword$^{\Phi}$ |
| Spring | Very slow | EGA Eaglehawk$^{\Phi}$, LongReach Nighthawk$^{\Phi}$ (LPB14-0392), RGT Zanzibar, Sunlamb$^{\Phi}$, Sunmax$^{\Phi}$ |
| | Slow | Cutlass$^{\Phi}$ |
| | Mid–slow | Coolah$^{\Phi}$, DS Pascal$^{\Phi}$, EGA Gregory$^{\Phi}$, LongReach Lancer$^{\Phi}$, LongReach Trojan$^{\Phi}$, Mitch$^{\Phi}$ |
| | Mid | Beckom$^{\Phi}$, Janz, Sunvale$^{\Phi}$ |
| | Mid–fast | LongReach Reliant$^{\Phi}$, Suntop$^{\Phi}$ |
| | Fast | Corack$^{\Phi}$, LongReach Mustang$^{\Phi}$, LongReach Hellfire$^{\Phi}$ (LPB14-3634), LongReach Spitfire$^{\Phi}$, Mace$^{\Phi}$, RAC2388, Scepter$^{\Phi}$, Sunprime$^{\Phi}$ |
| | Very fast | Condo$^{\Phi}$, H45$^{\Phi}$, LongReach Dart$^{\Phi}$, TenFour$^{\Phi}$, Vixen$^{\Phi}$ |

## Results

### Phasic development

In wheat, flowering time is a critical determinant of grain yield potential. Across the NGR environments, the optimal flowering period (OFP) is defined by decreasing frost risk and increasing risks of moisture and heat stress. Generally, flowering date is a strong predictor of yield, with genotype and sowing date combinations that flower in early–mid October at Wagga Wagga capable of achieving the highest grain yields. In 2018, the flowering window spanned from 11 August to 30 October, with significant variation in grain yields for genotype by sowing date combinations that flowered on the same day (Figure 1).

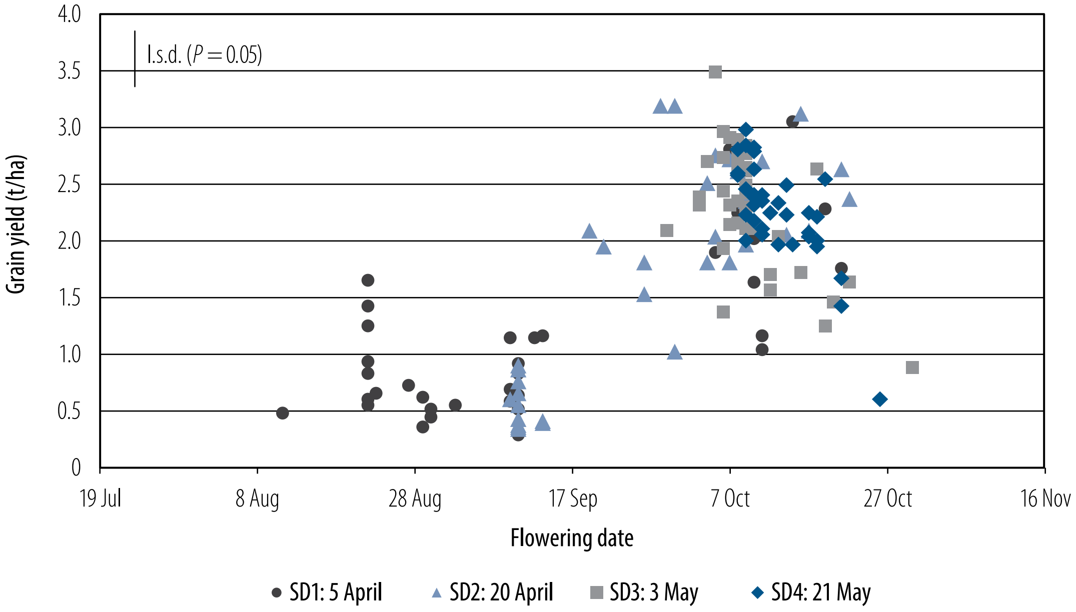

Figure 1. Relationship between flowering date and grain yield for 36 genotypes sown on 5 April, 20 April, 3 May and 21 May at Wagga Wagga, 2018; l.s.d., least significant difference.

Phasic development varied significantly among the genotypes with respect to sowing date (Figure 2), which influenced the flowering grain yield responses shown in Figure 1. Faster developing spring types (with minimal response to vernalisation), sown early (when temperatures were warmer and days longer), progressed quickly. For example, new release Vixen$^{\Phi}$ sown on SD1 at Wagga Wagga, started stem elongation (GS30) on 22 May and flowered on 27 August, a month earlier than the OFP, and achieved 0.72 t/ha. However, when sown on SD4, Vixen$^{\Phi}$ reached GS30 on 4 August, flowered on 9 October (within the OFP) and was able to achieve 2.99 t/ha, the highest grain yield recorded for SD4 (Table 2).

In contrast, the slower developing winter types, had prolonged vegetative phases from earlier sowing dates (largely due to their vernalisation requirement) and had more stable flowering dates. Mid winter types EGA Wedgetail$^{\Phi}$ and LongReach Kittyhawk$^{\Phi}$ recorded similar flowering dates for each sowing date, however, we observed differences in pre-flowering phases in response to sowing date. As observed at Wagga Wagga in 2017 (Harris et al. 2018), LongReach Kittyhawk$^{\Phi}$ reached GS30 eight and nine days faster than EGA Wedgetail$^{\Phi}$ in SD1 and SD2 respectively, while there were only one and three days difference in SD3 and SD4 respectively. DS Bennett$^{\Phi}$ was slower, reaching GS30 9–10 days later than EGA Wedgetail in SD1, SD2 and SD3, though had very stable flowering time across all sowing dates afforded by a strong photoperiod response. While it flowered slightly later than the OFP (Figure 2), it achieved relatively stable grain yields.

The winter types had minimal frost damage, and had relatively uniform maturity across all sowing dates, with the exception of fast winter type Longsword$^{\Phi}$ which, despite a prolonged vegetative phase, had hastened development thereafter, and had some stem frost damage (and later maturity) on SD1 and SD2 (Figure 2).

### Grain yield

Grain yields and genotype rankings varied significantly across all sowing dates (Table 2), which affirms that genotypes are not broadly adapted to sowing date.

In 2018, the highest grain yields were achieved by both winter type DS Bennett$^{\Phi}$ sown early–late April and the best performing spring types sown early May (e.g. Beckom$^{\Phi}$ sown 3 May).

Severe yield penalties occurred when:

- fast-developing spring wheats:

    - were sown before May
    - had advanced development
    - were exposed to severe frost (late August).
- slow winter genotypes, characterised as having a strong vernalisation and photoperiod response
    - flowered too late
    - grain-filling occurred under terminal drought conditions (Figure 2).

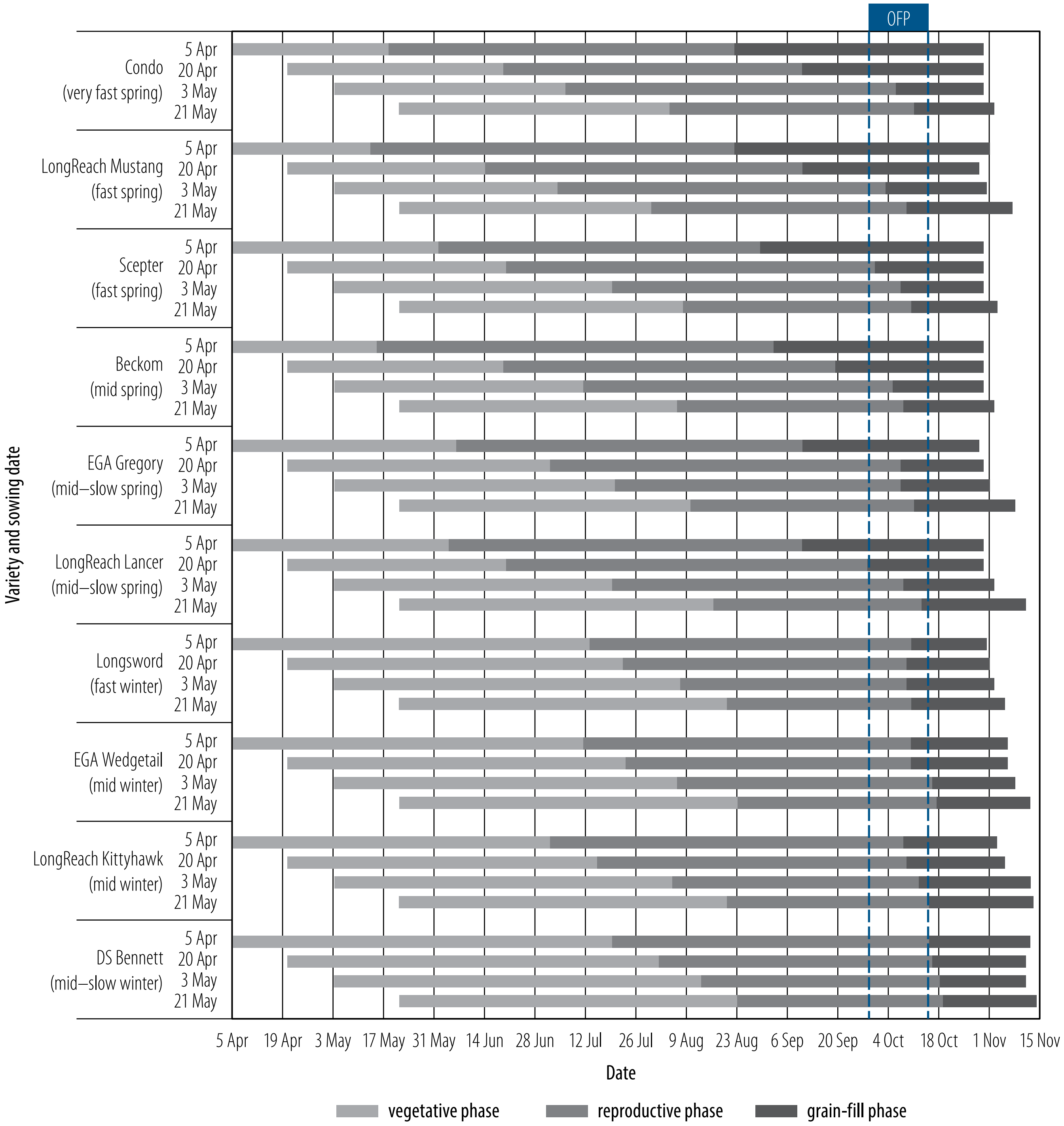

Figure 2. Influence of sowing date on phasic development of selected genotypes sown 5 April, 20 April, 3 May and 21 May at Wagga Wagga, 2018.
*Vegetative phase (sowing to GS30); reproductive phase (GS30 to flowering); grain-fill phase (flowering to maturity).*
*Blue dotted lines indicate optimal flowering period (OFP).*

Table 2. Grain yield of genotypes across four sowing dates at Wagga Wagga in 2018. Yield ranking according to sowing date (SD) treatment in parentheses.

| Genotype | Grain yield (t/ha) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | SD1: 5 April | | SD2: 20 April | | SD3: 3 May | | SD4: 21 May | |
| Beckom | 0.54 | (30) | 2.11 | (14) | 3.51 | (1) | 2.61 | (7) |
| Condo | 0.82 | (21) | 0.42 | (31) | 1.38 | (34) | 2.06 | (27) |
| Coolah | 0.83 | (20) | 2.76 | (5) | 2.31 | (21) | 2.24 | (21) |
| Corack | 0.66 | (24) | 0.40 | (33) | 2.69 | (10) | 2.84 | (3) |
| Cutlass | 0.64 | (25) | 1.53 | (23) | 2.63 | (13) | 2.34 | (17) |
| DS Bennett | 3.07 | (1) | 3.14 | (3) | 2.65 | (12) | 2.56 | (9) |
| DS Pascal | 1.17 | (13) | 2.71 | (7) | 2.51 | (14) | 2.25 | (20) |
| EGA Eaglehawk | 2.13 | (5) | 2.62 | (9) | 2.11 | (25) | 2.08 | (26) |
| EGA Gregory | 0.51 | (32) | 1.81 | (21) | 2.32 | (20) | 2.12 | (25) |
| EGA Wedgetail | 2.03 | (6) | 2.16 | (13) | 1.73 | (29) | 2.05 | (28) |
| H45 | 0.94 | (18) | 0.66 | (28) | 1.94 | (28) | 2.18 | (24) |
| Janz | 0.45 | (34) | 1.96 | (19) | 2.86 | (5) | 2.81 | (5) |
| LongReach Dart | 1.26 | (12) | 0.60 | (29) | 2.11 | (26) | 2.59 | (8) |
| LongReach Hellfire | 0.52 | (31) | 0.87 | (26) | 2.91 | (4) | 2.50 | (10) |
| LongReach Kittyhawk | 2.25 | (4) | 2.37 | (12) | 1.71 | (30) | 1.98 | (31) |
| LongReach Lancer | 0.92 | (19) | 3.21 | (1) | 2.36 | (18) | 1.97 | (32) |
| LongReach Mustang | 1.43 | (11) | 0.55 | (30) | 2.40 | (17) | 2.00 | (30) |
| LongReach Nighthawk | 2.82 | (2) | 2.72 | (6) | 1.25 | (35) | 2.02 | (29) |
| LongReach Reliant | 1.14 | (15) | 1.82 | (20) | 2.18 | (22) | 2.42 | (12) |
| LongReach Trojan | 0.28 | (36) | 1.81 | (22) | 2.72 | (9) | 2.33 | (18) |
| Longsword | 1.63 | (10) | 1.97 | (18) | 2.43 | (16) | 2.42 | (13) |
| Mace | 0.36 | (35) | 0.41 | (32) | 2.97 | (2) | 2.86 | (2) |
| Manning | 1.76 | (8) | 2.37 | (11) | 0.88 | (36) | 0.61 | (36) |
| Mitch | 0.58 | (28) | 2.04 | (17) | 2.05 | (27) | 2.22 | (23) |
| RAC2388 | 0.48 | (33) | 0.36 | (35) | 2.33 | (19) | 2.81 | (4) |
| RGT Accroc | 2.28 | (3) | 2.64 | (8) | 1.65 | (31) | 1.68 | (34) |
| RGT Zanzibar | 1.16 | (14) | 2.06 | (16) | 1.56 | (32) | 1.95 | (33) |
| Scepter | 0.62 | (26) | 1.03 | (24) | 2.92 | (3) | 2.40 | (15) |
| Spitfire | 0.56 | (29) | 0.75 | (27) | 2.67 | (11) | 2.65 | (6) |
| Sunlamb | 1.04 | (17) | 2.10 | (15) | 1.46 | (33) | 1.43 | (35) |
| Sunmax | 1.90 | (7) | 2.82 | (4) | 2.12 | (24) | 2.26 | (19) |
| Sunprime | 1.65 | (9) | 0.89 | (25) | 2.74 | (8) | 2.47 | (11) |
| Suntop | 1.14 | (16) | 2.52 | (10) | 2.45 | (15) | 2.37 | (16) |
| Sunvale | 0.69 | (23) | 3.20 | (2) | 2.79 | (7) | 2.41 | (14) |
| TenFour | 0.60 | (27) | 0.34 | (36) | 2.15 | (23) | 2.23 | (22) |
| Vixen | 0.72 | (22) | 0.38 | (34) | 2.79 | (6) | 2.99 | (1) |
| Mean | 1.15 | | 1.73 | | 2.28 | | 2.27 | |
| l.s.d genotype | 0.24 | | | | | | | |
| l.s.d. SD | 0.08 | | | | | | | |
| l.s.d genotype × SD | 0.49 | | | | | | | |

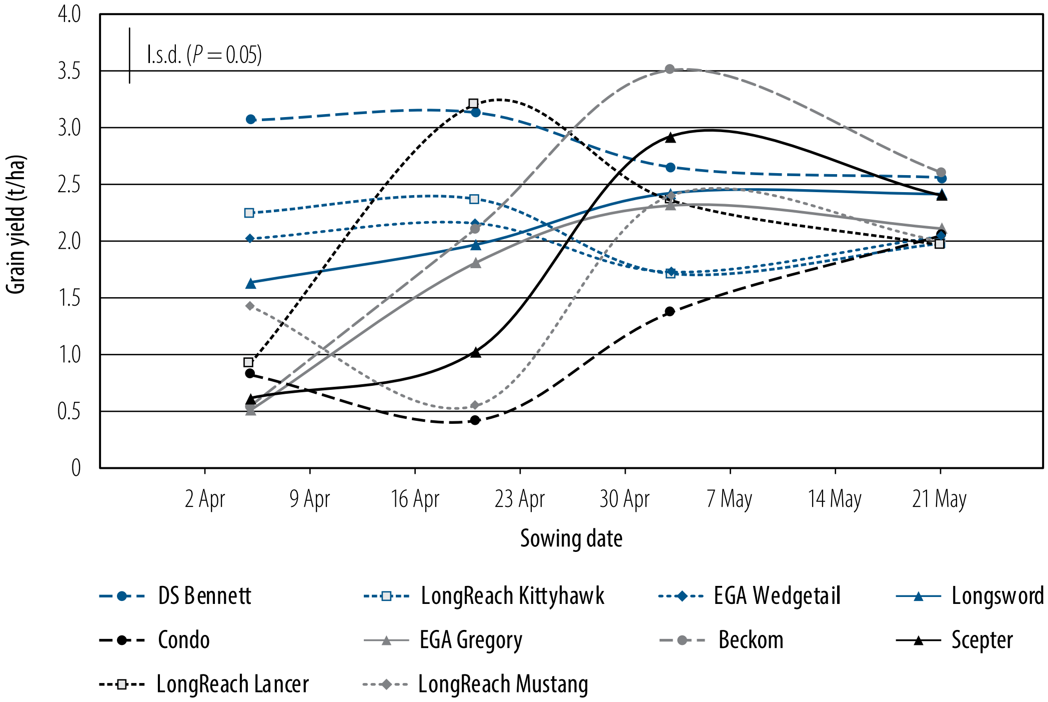

Figure 3. Grain yield responses of selected genotypes across four sowing dates: 5 April, 20 April, 3 May and 21 May at Wagga Wagga, 2018; l.s.d., least significant difference.

### Grain yield components

The timing and duration of specific development phases are directly related to forming the key grain yield components – grain number (per unit of area) and individual grain weight.

**Vegetative phase**: leaves and tillers are formed before the transition into the reproductive phase, which coincides with the start of spikelet development.

**Reproductive stage**: spikelet primordia continue to be initiated until early stem elongation.

**Stem elongation–flowering**: rapid growth (accumulating biomass), spike growth and differentiation occur, determining maximum grain number. This phase is the critical period for determining yield, which is very sensitive to stress. Any limitation to the crop at this time results in reduced grain numbers.

**After flowering, and during the grain-filling**: the embryo develops, producing viable seed for the subsequent generation. This phase coincides with grain weight establishment.

Figure 4 highlights the extent to which stress event timing influences yield formation, which illustrates the relationship between flowering time, grain number and grain weight at the Wagga Wagga site in 2018. Treatments that flowered earlier than the OFP and were exposed to frost had reduced grain numbers, while treatments that flowered later than the OFP, and were exposed to heat and moisture stress during grain-filling, had lower grain weights.

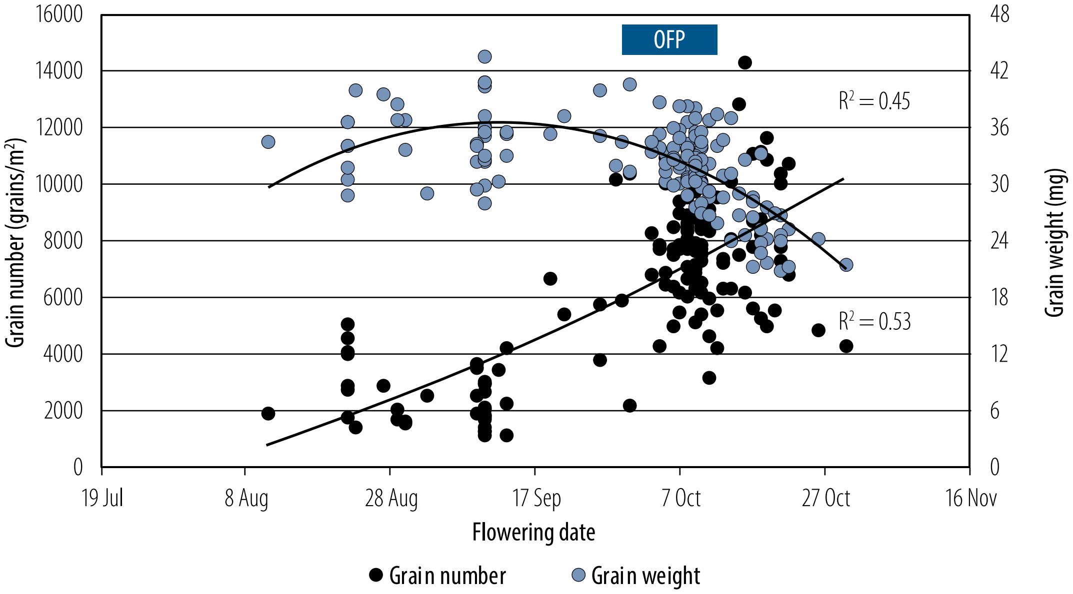

Figure 4. Relationship between flowering date, grain number and grain weight for genotypes with varied phenology patterns sown early April–late May at Wagga Wagga in 2018.
*Shaded bar indicates optimal flowering period (OFP) for Wagga Wagga site.*

Despite stress event timing being critical to the corresponding yield components, grain yield has been more closely associated with grain number than grain weight in cereals, and this relationship was maintained at Wagga Wagga in 2018, despite it being a low-yielding season, characterised by terminal drought (Figure 5).

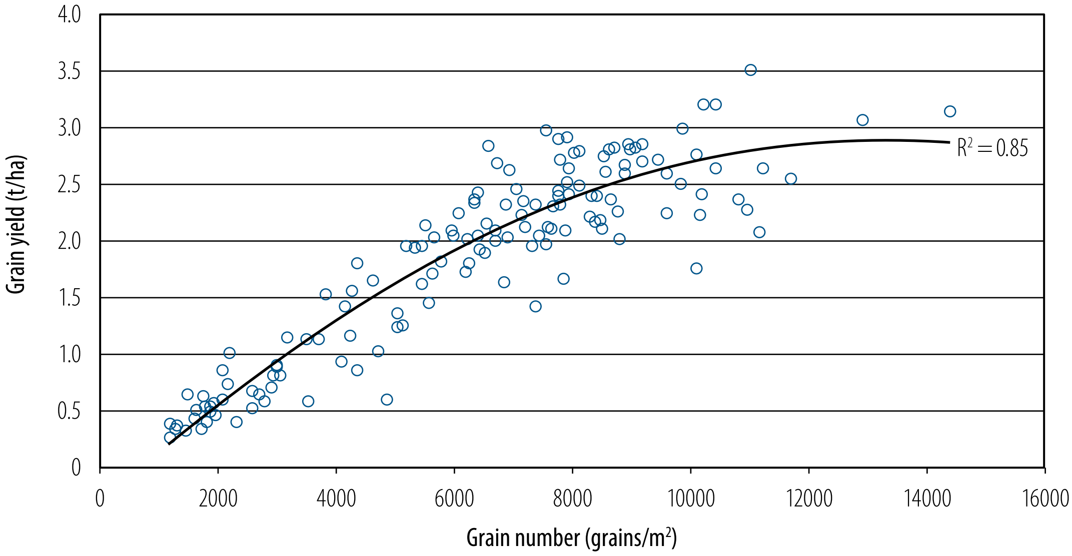

Figure 5. Relationship between grain yield and grain number for genotypes with varied phenology patterns sown early April–late May at Wagga Wagga 2018.

## Summary

We determined that the genotype by sowing date combinations that achieved the OFP generally achieved the highest grain yields. Despite below average rainfall, longer season winter wheats were able to achieve yields comparable with adapted spring types sown at the optimal time. We observed differences in phenology responses among genotypes with flowering dates, indicating that sowing date had a significant influence on pre-flowering development phases, which extreme frosts amplified in late August 2018. These findings indicate that the genotypes tested are not broadly adapted, and there is scope for growers to optimise grain yield through cultivar selection, and managing sowing date.

## Reference

Harris F, Kanaley H, McMahon G and Copeland C 2018. Influence of sowing date on wheat phenology and grain yield – Wagga Wagga 2017; D Slinger, T Moore and C Martin (eds). *Southern NSW research results 2018*, pp. 58–63. NSW Department of Primary Industries.

## Acknowledgements

This experiment was part of the 'Optimising grain yield potential of winter cereals in the Northern Grains Region' project, BLG104, 2017–20, a joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP). We acknowledge NSW DPI for their site cooperation at Wagga Wagga Agricultural Institute.

A sincere thank you to Mary Matthews and Jordan Bathgate for technical support.

# Sowing date influence on wheat phenology and grain yield – Cudal 2018

Dr Felicity Harris (NSW DPI, Wagga Wagga); Peter Matthews (NSW DPI, Orange); Peter Roberts and Jess Perry (NSW DPI, Cowra)

## Key findings

- Frost and drought had a significant influence on flowering date and grain yield responses in 2018.
- Commercial cultivars were not broadly adapted across sowing dates from mid April to late May.
- High grain yields were achieved from a range of genotype by sowing date combinations.
- While flowering time is important in maximising grain yield potential, timing and length of pre-flowering phases was also found to influence grain yield.

## Introduction

In 2018, field experiments were conducted across several sites in the Northern Grains Region (NGR) to determine how phenology influenced grain yield responses for a diverse set of wheat genotypes. This paper presents results from the Cudal site (central NSW) and discusses the sowing date (SD) influence on the phenology and grain yield responses from a core set of 36 wheat genotypes.

## Site details

| | |
|---|---|
| **Location** | Cranbury, Cudal NSW |
| **Soil type** | Red–brown chromosol |
| **Previous crop** | Canola |
| **Sowing** | Direct drilled with Horwood Bagshaw seeding units, spaced at 220 mm using a GPS auto-steer system<br>Target plant density: 160 plants/m$^2$ |
| **Soil pH$_{Ca}$** | 4.6 (0–10 cm); 5.5 (10–30 cm) |
| **Mineral nitrogen (N)** | 150 kg N/ha at sowing (1.2 m depth) |
| **Fertiliser** | 100 kg/ha mono-ammonium phosphate (MAP) (sowing)<br>150 kg/ha urea (sowing) |
| **Weed control** | Knockdown: glyphosate (450 g/L) 2 L/ha<br>Pre-emergent: Avadex® Xtra 2 L/ha + trifluralin (480 g/L) 1 L/ha<br>Post sow pre-emergent: Sakura® 118 g/ha<br>In-crop: Axial® 300 mL/ha + Decision® 1 L/ha + Precept® 2 L/ha (13 June) |
| **Disease management** | Seed treatment: Hombre® Ultra 200 mL/100 kg seed<br>Fertiliser treatment: Flutriafol (250 g/L) 400 mL/ha<br>In-crop: Prosaro® 300 mL/ha (1 September) |

| | |
|---|---|
| **Insect management** | Post sowing/pre-emergent: Talstar® 100 mL/ha<br>In-crop: Transform® 100 mL/ha (13 June)<br>In-crop: Aphidex® 250 g/ha (1 September) |
| **In-crop rainfall** | 154 mm (April–October); long-term average – 353 mm |
| **Severe temperature events** | Nine heat stress events (days >30 °C), which coincided with late-flowering to early grain-filling (18–31 October).<br>Twenty-two frosts (days <0 °C); six severe frosts (days <–2 °C) including –3.0 °C (14 July) –4.4 °C (15 July) and –3.1 °C (16 July). |
| **Harvest date** | 5 December 2018 |

## Treatments

Thirty-six wheat genotypes (Table 1), varying in phenology responses were sown on three sowing dates: SD1: 19 April, SD2: 3 May and SD3: 18 May in 2018.
SD2 was established with 13 mm irrigation via drippers.

Table 1. Expected phenology responses of the 2018 experiment genotypes.

| Phenology type | Sub-category | Genotypes |
|---|---|---|
| Winter | Slow | Manning$^{\phi}$, RGT Accroc |
| | Mid–slow | DS Bennett$^{\phi}$ |
| | Mid | EGA Wedgetail$^{\phi}$, LongReach Kittyhawk$^{\phi}$ |
| | Fast | Longsword$^{\phi}$ |
| Spring | Very slow | EGA Eaglehawk$^{\phi}$, LongReach Nighthawk$^{\phi}$ (LPB14-0392), RGT Zanzibar, Sunlamb$^{\phi}$, Sunmax$^{\phi}$ |
| | Slow | Cutlass$^{\phi}$ |
| | Mid–slow | Coolah$^{\phi}$, DS Pascal$^{\phi}$, EGA Gregory$^{\phi}$, LongReach Lancer$^{\phi}$, LongReach Trojan$^{\phi}$, Mitch$^{\phi}$ |
| | Mid | Beckom$^{\phi}$, Janz, Sunvale$^{\phi}$ |
| | Mid–fast | LongReach Reliant$^{\phi}$, Suntop$^{\phi}$ |
| | Fast | Corack$^{\phi}$, LongReach Hellfire$^{\phi}$ (LPB14-3634), LongReach Mustang$^{\phi}$, LongReach Spitfire$^{\phi}$, Mace$^{\phi}$, RAC2388 , Scepter$^{\phi}$, Sunprime$^{\phi}$ |
| | Very fast | Condo$^{\phi}$, H45, LongReach Dart$^{\phi}$, TenFour, Vixen$^{\phi}$ |

## Results

### Phasic development

The optimal flowering period (OFP) from long-term modelling for Cudal occurs in the second and third week of October, where the risk of frost, heat and moisture stress on grain yield potential can be minimised. In 2018, the flowering window for this experiment was from 20 September to 2 November. Early, severe frosts affected the faster spring types from SD1, where stem frosting was observed, delaying flowering. Some genotypes from SD1 flowered later than SD2. The dry conditions through September affected growth and development and thus flowering.

Genotypes that were later to flower were able to take advantage of the rain and milder conditions in October aiding grain set. The rain in late October and November was of little use to some genotypes that had already set grain numbers. Therefore, flowering time was not significantly associated with grain yield potential at the Cudal site in 2018; there was significant variation in grain yields for genotype by sowing date combinations that flowered within a similar window (Figure 1). For example, DS Bennett⟨ᶲ⟩ (slow winter type) sown on 19 April, flowered on 23 October and recorded 3.89 t/ha, while Spitfire (fast spring type) sown on 18 May flowered only two days earlier (21 October) and recorded 1.81 t/ha.

There is variation in development responses to vernalisation and photoperiod among the genotypes tested. Phasic development varied significantly with respect to sowing date (Figure 2), which influenced the flowering grain yield responses shown in Figure 1. Delayed sowing reduced the length of the growing season, with a reduced reproductive phase (GS30–GS65) being most affected. This corresponds to the period in which potential grain number is determined.

While the slower developing winter types had prolonged vegetative phases from earlier sowing dates (largely due to their vernalisation requirement) and had more stable flowering dates, we did observe differences in pre-flowering phases in response to sowing date. For example, LongReach Kittyhawk⟨ᶲ⟩ reached GS30 11 and 15 days faster than EGA Wedgetail⟨ᶲ⟩ in SD2 and SD3 respectively, despite similar flowering dates. DS Bennett⟨ᶲ⟩ was slower than EGA Wedgetail⟨ᶲ⟩ in SD1, reaching GS30 13 days later, though they were similar in SD2 and SD3. DS Bennett⟨ᶲ⟩ had a very stable flowering time across all sowing dates (2–3 days difference) afforded by a strong photoperiod response and, while it flowered slightly later than other EGA Wedgetail⟨ᶲ⟩ types (Figure 2), it was able to achieve relatively stable grain yields.

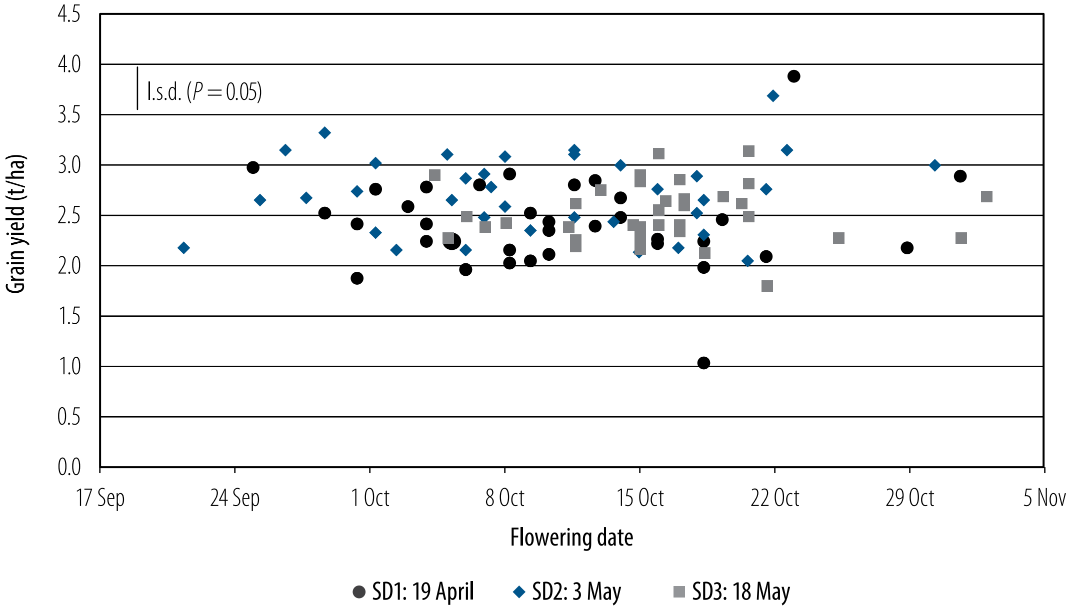

Figure 1. Relationship between flowering date and grain yield for 36 genotypes sown on 19 April, 3 May and 18 May at Cudal, 2018; l.s.d., least significant difference.

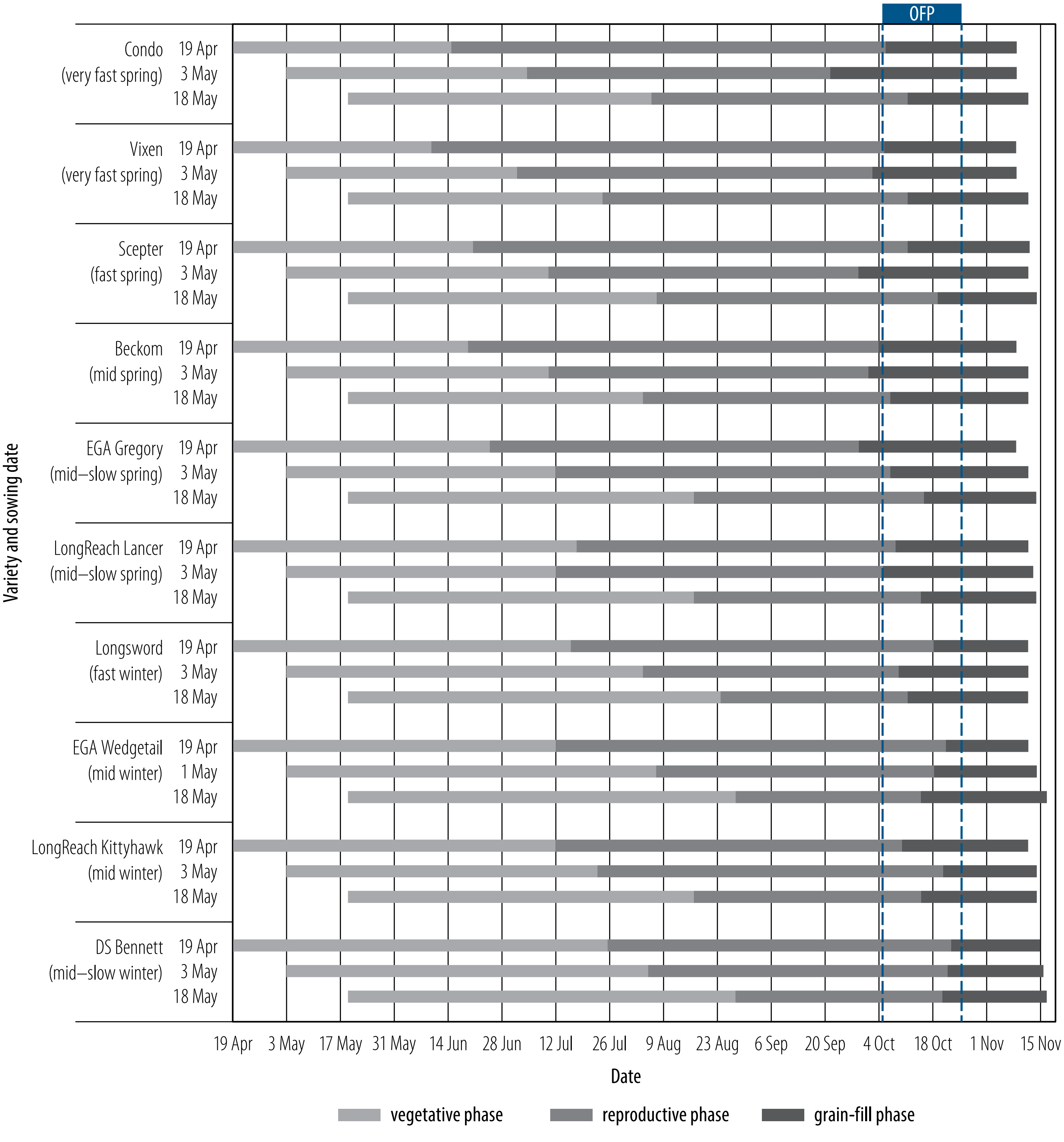

Figure 2. Influence of sowing date on phasic development of selected genotypes sown on 19 April, 3 May and 18 May at Cudal, 2018. *Vegetative phase (sowing to GS30); reproductive phase (GS30 to flowering); grain-fill phase (flowering to maturity). Blue dotted lines indicate optimal flowering period (OFP).*

### Grain yield

Despite the relatively flat response of grain yield to flowering date, genotype by grain yield rankings across the three sowing dates (late April to late May) varied significantly (Table 2). In 2018, the highest yielding treatment was winter type DS Bennett⦶ (SD1: 3.89 t/ha); the best performing spring type was Scepter⦶ (SD2: 3.33 t/ha) at the Cudal site (Figure 3).

Table 2. Grain yield of genotypes across three sowing dates at Cudal in 2018. Yield ranking according to sowing date (SD) treatment in parentheses.

| **Genotype** | **Grain yield (t/ha)** | | | | | |
|---|---|---|---|---|---|---|
| | **SD1: 19 April** | | **SD2: 3 May** | | **SD3: 19 May** | |
| Beckom | 2.25 | (22) | 3.02 | (9) | 2.40 | (23) |
| Condo | 1.97 | (33) | 2.18 | (32) | 2.20 | (33) |
| Coolah | 2.78 | (8) | 3.16 | (3) | 3.13 | (2) |
| Corack | 2.26 | (21) | 2.13 | (35) | 2.42 | (21) |
| Cutlass | 2.23 | (25) | 2.52 | (24) | 2.67 | (11) |
| Dart | 2.04 | (31) | 2.17 | (33) | 2.14 | (35) |
| DS Bennett | 3.89 | (1) | 3.70 | (1) | 2.83 | (7) |
| DS Pascal | 2.15 | (27) | 2.44 | (27) | 2.87 | (5) |
| EGA Eaglehawk | 2.82 | (6) | 2.91 | (12) | 2.84 | (6) |
| EGA Gregory | 2.53 | (12) | 2.48 | (26) | 2.56 | (16) |
| EGA Wedgetail | 2.08 | (29) | 2.31 | (30) | 2.25 | (32) |
| H45 | 1.88 | (35) | 2.66 | (20) | 2.30 | (28) |
| Janz | 2.44 | (16) | 2.59 | (23) | 2.43 | (19) |
| LongReach Hellfire | 2.25 | (23) | 2.89 | (13) | 2.28 | (30) |
| LongReach Kittyhawk | 2.11 | (28) | 2.04 | (36) | 2.39 | (25) |
| LongReach Lancer | 2.91 | (3) | 3.11 | (7) | 2.33 | (27) |
| LongReach Mustang | 2.52 | (13) | 2.66 | (21) | 2.42 | (20) |
| LongReach Nighthawk | 2.36 | (20) | 3.01 | (10) | 3.15 | (1) |
| LongReach Reliant | 2.97 | (2) | 3.09 | (8) | 2.92 | (4) |
| LongReach Trojan | 2.42 | (17) | 2.88 | (14) | 2.41 | (22) |
| Longsword | 1.99 | (32) | 2.35 | (28) | 2.27 | (31) |
| Mace | 2.04 | (30) | 2.68 | (19) | 2.36 | (26) |
| Manning | 2.17 | (26) | 3.00 | (11) | 2.29 | (29) |
| Mitch | 2.84 | (5) | 2.65 | (22) | 2.92 | (3) |
| RAC2388 | 2.47 | (14) | 2.73 | (18) | 2.62 | (15) |
| RGT Accroc | 2.89 | (4) | 3.16 | (4) | 2.69 | (10) |
| RGT Zanzibar | 2.67 | (10) | 2.77 | (16) | 2.65 | (12) |
| Scepter | 2.80 | (7) | 3.33 | (2) | 2.70 | (9) |
| Spitfire | 1.04 | (36) | 2.18 | (31) | 1.81 | (36) |
| Sunlamb | 2.46 | (15) | 2.75 | (17) | 2.62 | (14) |
| Sunmax | 2.58 | (11) | 3.12 | (6) | 2.51 | (17) |
| Sunprime | 2.41 | (18) | 3.15 | (5) | 2.49 | (18) |
| Suntop | 2.77 | (9) | 2.78 | (15) | 2.76 | (8) |
| Sunvale | 2.39 | (19) | 2.49 | (25) | 2.17 | (34) |
| TenFour | 1.96 | (34) | 2.33 | (29) | 2.40 | (24) |
| Vixen | 2.24 | (24) | 2.16 | (34) | 2.63 | (13) |
| Mean | 2.40 | | 2.71 | | 2.52 | |
| l.s.d. genotype | 0.23 | | | | | |
| l.s.d. SD | 0.07 | | | | | |
| l.s.d. genotype × SD | 0.40 | | | | | |

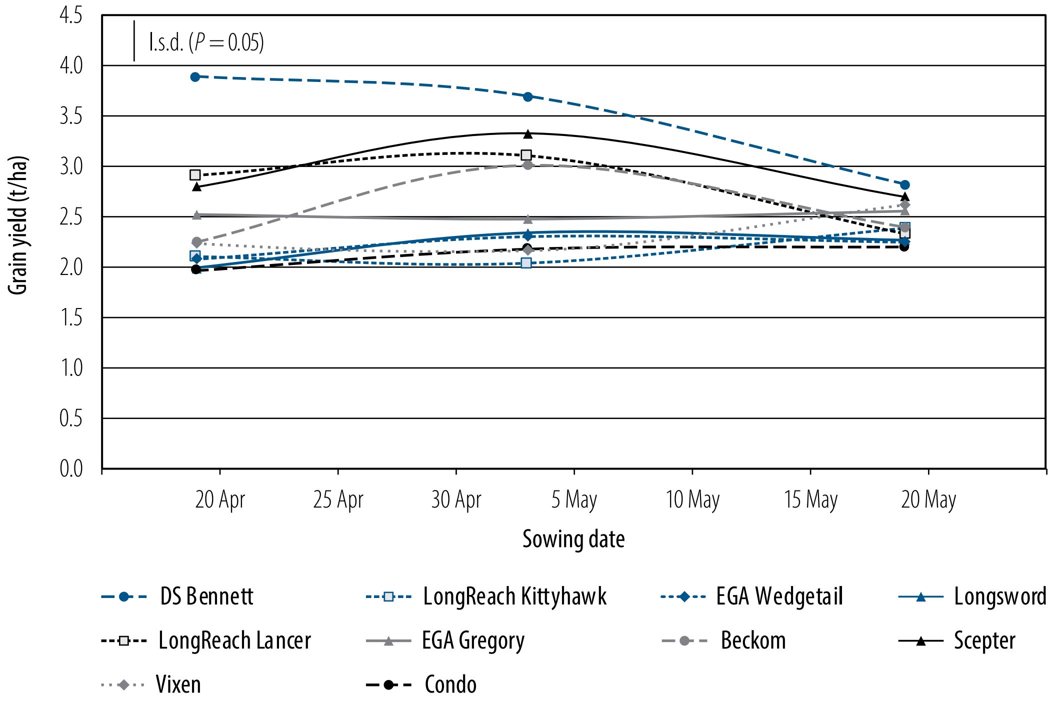

Figure 3. Grain yield responses of selected genotypes across three sowing dates: 19 April, 3 May and 18 May at Cudal, 2018; l.s.d., least significant difference.

### Grain quality

Genotype and sowing date significantly affected grain protein and test weight, while there was a significant effect of genotype only on screenings in 2018. There was also a significant interaction between genotype and sowing date for grain protein, test weight and screenings (Table 3). All treatment combinations achieved greater than 11.5% grain protein, with a significant reduction in grain protein as sowing was delayed. All genotype and sowing date combinations also achieved a test weight of >76 kg/hL and <5% screenings, with the exception of the longer season feed varieties Manning$^{\Phi}$ and RGT Accroc for all sowing dates and the very fast spring type TenFour in SD1 (Table 3).

Table 3. Protein (%), screenings (%) and test weight (kg/hL) of genotypes across three sowing dates at Cudal in 2018.

| Genotype | SD1: 19 April | | | SD2: 3 May | | | SD3: 19 May | | |
|---|---|---|---|---|---|---|---|---|---|
| | Protein (%) | Test weight (kg/hL) | Screenings (%) | Protein (%) | Test weight (kg/hL) | Screenings (%) | Protein (%) | Test weight (kg/hL) | Screenings (%) |
| Beckom | 14.3 | 78.8 | 4.4 | 14.2 | 79.3 | 4.5 | 13.6 | 79.5 | 4.5 |
| Condo | 16.1 | 80.3 | 0.8 | 15.3 | 80.5 | 0.1 | 15.2 | 81.8 | 0.1 |
| Coolah | 16.9 | 79.8 | 0.1 | 17.0 | 80.7 | 0.3 | 16.2 | 81.4 | 0.1 |
| Corack | 15.0 | 80.7 | 0.1 | 14.8 | 81.5 | 0.1 | 14.0 | 81.8 | 0.2 |
| Cutlass | 16.8 | 80.6 | 0.2 | 16.6 | 81.0 | 0.1 | 15.4 | 81.5 | 0.1 |
| Dart | 17.0 | 80.9 | 0.7 | 15.8 | 82.1 | 0.1 | 15.2 | 82.9 | 0.1 |
| DS Bennett | 16.1 | 80.2 | 0.4 | 16.2 | 81.1 | 0.4 | 15.6 | 82.6 | 0.1 |
| DS Pascal | 15.5 | 78.6 | 0.3 | 15.6 | 79.4 | 0.1 | 14.5 | 80.3 | 0.2 |
| EGA Eaglehawk | 16.5 | 80.5 | 0.6 | 16.5 | 81.2 | 0.1 | 16.3 | 81.7 | 0.8 |
| EGA Gregory | 16.4 | 80.7 | 0.1 | 16.1 | 81.3 | 0.1 | 15.3 | 81.7 | 0.1 |
| EGA Wedgetail | 17.8 | 76.5 | 0.1 | 17.4 | 77.7 | 0.1 | 16.5 | 77.6 | 0.1 |
| H45 | 16.8 | 79.8 | 1.0 | 15.8 | 80.8 | 1.2 | 15.5 | 81.1 | 0.2 |
| Janz | 16.5 | 78.7 | 0.3 | 17.0 | 78.6 | 0.5 | 15.2 | 80.1 | 0.2 |
| LongReach Hellfire | 18.6 | 81.3 | 0.1 | 17.5 | 82.3 | 0.1 | 18.0 | 82.6 | 0.1 |
| LongReach Kittyhawk | 16.3 | 81.0 | 0.1 | 15.9 | 81.9 | 0.1 | 15.9 | 82.0 | 0.1 |
| LongReach Lancer | 17.6 | 81.5 | 0.1 | 17.2 | 82.5 | 0.1 | 16.2 | 83.0 | 0.1 |
| LongReach Mustang | 16.2 | 80.1 | 0.1 | 16.5 | 80.4 | 0.1 | 16.7 | 80.6 | 0.1 |
| LongReach Nighthawk | 17.0 | 78.6 | 1.4 | 15.9 | 80.0 | 1.5 | 14.9 | 78.9 | 2.0 |
| LongReach Reliant | 15.5 | 82.1 | 0.1 | 15.6 | 82.2 | 0.1 | 15.3 | 82.9 | 0.1 |
| LongReach Trojan | 15.1 | 80.9 | 0.3 | 15.3 | 82.1 | 0.1 | 14.5 | 83.0 | 0.2 |
| Longsword | 18.0 | 77.1 | 0.1 | 17.2 | 78.1 | 0.1 | 16.4 | 79.4 | 0.2 |
| Mace | 17.0 | 79.5 | 0.3 | 16.2 | 80.5 | 0.1 | 15.7 | 80.6 | 0.1 |
| Manning | 15.7 | 72.8 | 7.0 | 15.3 | 73.7 | 7.4 | 14.7 | 74.0 | 8.7 |
| Mitch | 15.1 | 78.7 | 1.9 | 15.3 | 80.3 | 1.1 | 13.9 | 80.0 | 1.6 |
| RAC2388 | 15.7 | 79.3 | 1.0 | 15.6 | 79.8 | 0.4 | 14.5 | 80.6 | 0.1 |
| RGT Accroc | 16.7 | 73.4 | 5.6 | 16.2 | 74.6 | 5.4 | 15.6 | 74.5 | 5.2 |
| RGT Zanzibar | 16.4 | 78.3 | 0.2 | 15.8 | 78.9 | 0.1 | 15.3 | 79.5 | 0.4 |
| Scepter | 15.4 | 80.3 | 0.2 | 14.4 | 81.5 | 0.1 | 14.7 | 81.8 | 0.1 |
| Spitfire | 19.7 | 81.1 | 0.1 | 18.4 | 82.1 | 0.1 | 18.5 | 83.5 | 0.1 |
| Sunlamb | 15.4 | 79.1 | 0.6 | 15.1 | 80.7 | 0.1 | 15.6 | 80.1 | 0.1 |
| Sunmax | 17.7 | 79.2 | 1.7 | 16.9 | 80.0 | 2.2 | 15.9 | 80.1 | 3.3 |
| Sunprime | 17.1 | 79.2 | 0.1 | 17.0 | 80.1 | 0.1 | 16.8 | 81.4 | 0.1 |
| Suntop | 15.1 | 81.4 | 0.3 | 15.6 | 81.6 | 0.2 | 14.9 | 82.7 | 1.1 |
| Sunvale | 16.4 | 81.1 | 0.1 | 16.7 | 81.1 | 0.1 | 16.7 | 81.7 | 0.1 |
| TenFour | 17.4 | 75.7 | 0.3 | 16.8 | 78.1 | 0.2 | 16.1 | 79.1 | 0.1 |
| Vixen | 16.1 | 81.1 | 0.1 | 15.7 | 82.0 | 0.1 | 15.4 | 82.6 | 0.1 |
| Mean | 16.5 | 79.4 | 0.9 | 16.1 | 80.3 | 0.8 | 15.6 | 80.8 | 0.9 |
| l.s.d. genotype | 0.2 | 0.5 | 0.3 | | | | | | |
| l.s.d. SD | 0.1 | 0.1 | ns | | | | | | |
| l.s.d. genotype × SD | 0.4 | 0.9 | 0.5 | | | | | | |

## Summary

The 2018 seasonal conditions influenced the grain yield genotype response and the interaction between sowing date and genotypes. The impact of stem frosting on faster spring types, reduced growth and development of genotypes through a dry September and then late rain in October and November reduced the influence of flowering date on grain yield commonly observed. Despite this, economic grain yields were achieved, with the longer season winter wheats sown earlier still able to yield comparably with adapted spring types sown at the optimal time. These results highlight the interaction between phasic development and yield formation, and the importance of matching genotype and sowing time to achieve flowering at an appropriate time as an effective management strategy in optimising grain yields.

## Acknowledgements

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

We sincerely thank Doug and Adam Nash, Cranbury, Cudal for hosting the experiment and acknowledge the technical support of Jennifer Pumpa, Lorraine Thacker, Emma Angove, David Cupitt and Gabriel Brown.

# Sowing date effect on the phenology and grain yield of thirty-two wheat varieties – Condobolin 2018

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

## Key findings

- The central west of NSW had one of its driest winter growing seasons in 2018 resulting in lower than average grain yields.
- Optimum yield was obtained when varieties flowered in the third week of September.
- The most successful phenology type were the mid to slow varieties at all sowing dates, with fast varieties proving to be more competitive at the later sowing dates.

## Introduction

In 2018 a wheat experiment was conducted at Condobolin to examine the interaction between sowing date, flowering time and yield. Thirty-two wheat genotypes (Table 1) representing a number of phenology types were sown on three dates to simulate early, main season and late sowings representing farming practices in the central west of NSW. The following paper presents the findings of the experiment, discussing sowing date and genotype selection and its effect on optimising yield.

## Site details

| | |
|---|---|
| **Location** | Condobolin Agricultural Research and Advisory Station |
| **Soil type** | Red chromosol |
| **Previous crop** | 2017 wheat (stubble intact), 2016 field peas |
| **Fallow rainfall** | 220.6 mm (October–April) |
| **In-crop rainfall** | 63 mm (April–September) |
| **Soil nitrogen (kg N/ha)** | 24.7 (0–10 cm), 52.5 (10–60 cm), 18 (60–100 cm) |
| **Starter fertiliser** | 70 kg/ha mono-ammonium phosphate (MAP) (11% nitrogen [N], 22.7% phosphorus [P], 2% sulfur [S]) at sowing. |
| **Supplementary watering** | The site was treated with 25 mm of supplementary water at each sowing date in order to establish germination. A further 20 mm was applied on 20 September to ensure plant survival. |

## Treatments

| | |
|---|---|
| **Varieties** | 32 wheat genotypes with a range of phenology types (Table 1) |
| **Sowing date (SD)** | SD1: 20 April<br>SD2: 7 May<br>SD3: 21 May |

Table 1. Wheat genotypes and phenology types included in the experiment at Condobolin, 2018.

| Phenology type | Sub-category | Genotype |
|---|---|---|
| Winter | Mid–slow | DS Bennettᶲ |
| | Mid | EGA Wedgetailᶲ, LongReach Kittyhawkᶲ |
| | Fast | Longswordᶲ |
| Spring | Very slow | EGA Eaglehawkᶲ, Sunlambᶲ, Sunmaxᶲ |
| | Slow | Cutlassᶲ |
| | Mid–slow | Coolahᶲ, DS Pascalᶲ, EGA Gregoryᶲ, LongReach Lancerᶲ, LongReach Trojanᶲ, Mitchᶲ |
| | Mid | Beckomᶲ, Janz, Sunvaleᶲ |
| | Mid–fast | Suntopᶲ, LongReach Reliantᶲ |
| | Fast | Corackᶲ, LongReach Hellfireᶲ (LPB14-3634), LongReach Mustangᶲ, LongReach Spitfireᶲ, Maceᶲ, RAC2388, Scepterᶲ, Sunprimeᶲ |
| | Very fast | Condoᶲ, H45ᶲ, LongReach Dartᶲ, TenFour, Vixenᶲ |

## Results

### Grain yield and phenology

2018 was one of the lowest rainfall seasons on record, with an April–September rainfall of 63 mm. Fifty-three frosts (temperatures below 2 °C) were recorded throughout the growing period. There was no significant difference in yield between SD1 and SD2, but there was a significant increase in SD3 (Table 2). Overall, the mid–slow flowering phenotypes yielded the highest, with yield penalties for the fast and winter types. There was a significant yield difference between genotypes in all sowing dates, with the highest yielding variety being the very slow Sunmaxᶲ in SD1, and slow Cutlassᶲ in SD2 and SD3. It should be noted that sowing decisions should not be made based on one year of data alone, due to seasonal variability.

Peak yields were obtained when genotypes flowered in the third week of September, after major frosts had concluded (Figure 1). Later flowering dates, especially from winter varieties, had decreased yield possibly due to heat and moisture stress during grain fill.

Table 2. Grain yield and flowering dates of genotypes sown across three sowing dates at Condobolin, 2018. Figure in parentheses shows grain yield rank per sowing date.

| **Variety** | **SD1: 20 April** | | **SD2: 7 May** | | **SD3: 21 May** | |
|---|---|---|---|---|---|---|
| | **Yield (t/ha)** | **Flowering date (GS65)** | **Yield (t/ha)** | **Flowering date (GS65)** | **Yield (t/ha)** | **Flowering date (GS65)** |
| Beckom | 1.06 (14) | 14 Sep | 1.18 (8) | 19 Sep | 1.31 (16) | 19 Sep |
| Condo | 1.01 (16) | 15 Sep | 0.91 (26) | 15 Sep | 1.36 (11) | 18 Sep |
| Coolah | 1.39 (2) | 22 Sep | 1.20 (6) | 27 Sep | 1.13 (24) | 29 Sep |
| Corack | 1.03 (15) | 16 Sep | 0.98 (23) | 19 Sep | 1.16 (21) | 23 Sep |
| Cutlass | 1.32 (6) | 25 Sep | 1.41 (1) | 27 Sep | 1.58 (1) | 1 Oct |
| DS Bennett | 0.63 (32) | 7 Oct | 0.57 (32) | 6 Oct | 0.81 (32) | 7 Oct |
| DS Pascal | 1.15 (10) | 22 Sep | 0.95 (25) | 24 Sep | 1.11 (25) | 29 Sep |
| EGA Eaglehawk | 1.30 (7) | 29 Sep | 1.22 (5) | 1 Oct | 1.13 (23) | 2 Oct |
| EGA Gregory | 1.36 (3) | 20 Sep | 1.22 (4) | 23 Sep | 1.34 (13) | 27 Sep |
| EGA Wedgetail | 1.18 (9) | 29 Sep | 0.85 (27) | 1 Oct | 0.81 (31) | 4 Oct |
| H45 | 0.77 (30) | 10 Sep | 1.12 (12) | 13 Sep | 1.23 (19) | 17 Sep |
| Janz | 0.99 (18) | 16 Sep | 1.23 (3) | 21 Sep | 1.37 (10) | 25 Sep |
| LongReach Dart | 0.99 (17) | 15 Sep | 0.84 (28) | 15 Sep | 1.20 (20) | 17 Sep |
| LongReach Hellfire | 1.18 (8) | 18 Sep | 1.01 (21) | 26 Sep | 1.57 (2) | 29 Sep |
| LongReach Kittyhawk | 0.95 (22) | 26 Sep | 0.82 (30) | 1 Oct | 1.02 (29) | 2 Oct |
| LongReach Lancer | 1.11 (11) | 23 Sep | 0.99 (22) | 24 Sep | 1.11 (26) | 1 Oct |
| LongReach Mustang | 0.86 (26) | 15 Sep | 1.07 (15) | 15 Sep | 1.32 (14) | 20 Sep |
| LongReach Reliant | 0.98 (19) | 19 Sep | 1.12 (11) | 18 Sep | 1.47 (6) | 23 Sep |
| LongReach Spitfire | 0.85 (28) | 17 Sep | 1.04 (16) | 19 Sep | 1.41 (8) | 25 Sep |
| LongReach Trojan | 1.07 (13) | 17 Sep | 1.17 (9) | 23 Sep | 1.51 (4) | 25 Sep |
| Longsword | 0.96 (21) | 27 Sep | 1.33 (2) | 26 Sep | 1.45 (7) | 27 Sep |
| Mace | 0.86 (27) | 14 Sep | 1.03 (17) | 18 Sep | 1.35 (12) | 22 Sep |
| Mitch | 1.36 (4) | 19 Sep | 1.19 (7) | 22 Sep | 1.32 (15) | 27 Sep |
| RAC2388 | 0.89 (25) | 14 Sep | 0.84 (29) | 15 Sep | 1.29 (17) | 19 Sep |
| Scepter | 0.96 (20) | 18 Sep | 1.09 (13) | 19 Sep | 1.39 (9) | 23 Sep |
| Sunprime | 0.94 (23) | 12 Sep | 0.97 (24) | 14 Sep | 1.50 (5) | 16 Sep |
| Sunlamb | 0.76 (31) | 4 Oct | 0.75 (31) | 4 Oct | 0.90 (30) | 5 Oct |
| Sunmax | 1.40 (1) | 26 Sep | 1.07 (14) | 30 Sep | 1.15 (22) | 1 Oct |
| Suntop | 1.35 (5) | 21 Sep | 1.01 (20) | 22 Sep | 1.56 (3) | 25 Sep |
| Sunvale | 1.09 (12) | 22 Sep | 1.17 (10) | 23 Sep | 1.09 (28) | 1 Oct |
| TenFour | 0.77 (29) | 12 Sep | 1.03 (19) | 15 Sep | 1.24 (18) | 18 Sep |
| Vixen | 0.92 (24) | 12 Sep | 1.03 (18) | 15 Sep | 1.10 (27) | 15 Sep |
| Average | 1.04 | 21 Sep | 1.04 | 23 Sep | 1.26 | 27 Sep |

l.s.d. ($P = 0.05$) genotype 0.21 t/ha; sowing date 0.07 t/ha.

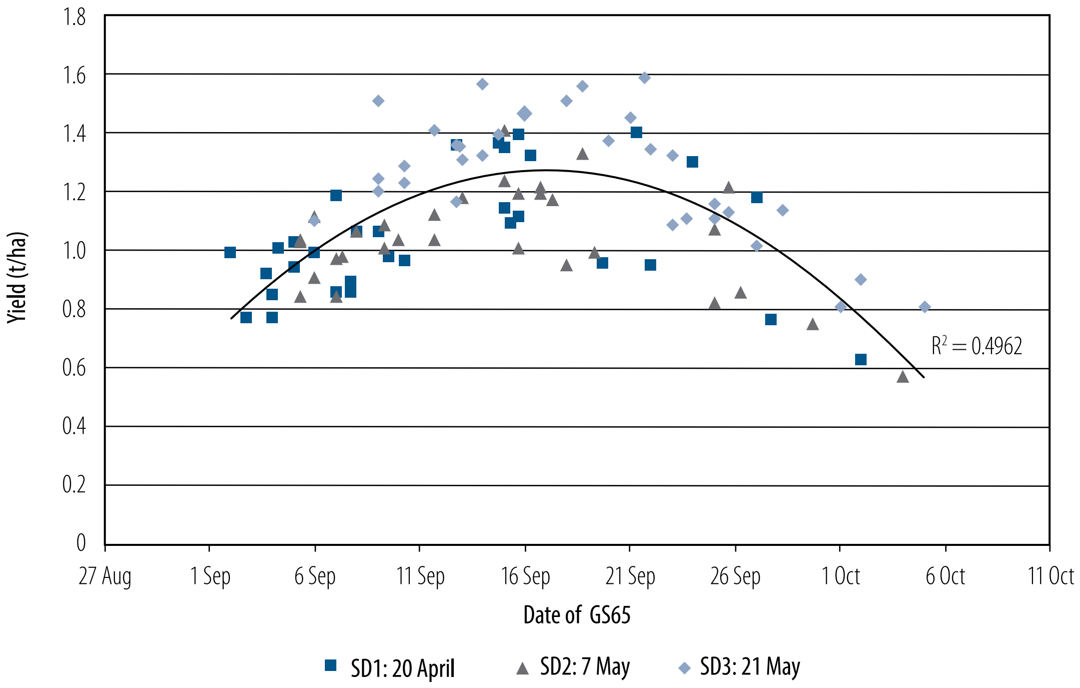

Figure 1. Grain yield vs GS65 dates for 32 varieties of wheat sown on three dates at Condobolin, 2018.

### Grain quality

Grain weight decreased significantly at SD3, while screenings (percentage <2 mm) increased. Genotype significantly affected both traits (Table 3). The only genotypes to exceed 5% screenings were Sunlamb$^{\text{Φ}}$ and DS Bennett$^{\text{Φ}}$ in SD3.

Protein significantly decreased from SD1 to SD2, and there was a significant genotype difference. The highest protein concentration was from Spitfire$^{\text{Φ}}$, with an average protein concentration of 12.6%. While genotype produced a significant difference in hectolitre weights, there was no difference from sowing dates. The harvest index significantly increased with sowing date.

Table 3. Grain quality of 32 wheat varieties sown at Condobolin, 2018. Values presented are from the highest yielding sowing date, SD3: 21 May.

| Variety | Protein (%) | Hectolitre weight (kg/hL) | Screenings (% <2 mm) | Harvest index |
|---|---|---|---|---|
| Beckom | 10.6 | 79.8 | 2.5 | 0.45 |
| Condo | 11.6 | 81.6 | 4.3 | 0.43 |
| Coolah | 10.1 | 78.2 | 4.5 | 0.40 |
| Corack | 11.6 | 81.7 | 2.4 | 0.35 |
| Cutlass | 10.1 | 82.4 | 2.0 | 0.46 |
| DS Bennett | 10.7 | 78.7 | 5.0 | 0.41 |
| DS Pascal | 10.8 | 78.4 | 2.7 | 0.39 |
| EGA Eaglehawk | 10.8 | 82.3 | 2.2 | 0.38 |
| EGA Gregory | 10.1 | 79.4 | 3.5 | 0.39 |
| EGA Wedgetail | 12.9 | 75.5 | 2.0 | 0.31 |
| H45 | 10.4 | 81.3 | 2.7 | 0.43 |
| Janz | 11.2 | 80.8 | 2.0 | 0.40 |
| LongReach Dart | 10.9 | 81.8 | 3.3 | 0.41 |
| LongReach Hellfire | 12.1 | 83.3 | 2.9 | 0.40 |
| LongReach Kittyhawk | 11.5 | 80.3 | 2.6 | 0.37 |
| LongReach Lancer | 11.5 | 82.0 | 2.3 | 0.46 |
| LongReach Mustang | 10.5 | 81.9 | 3.3 | 0.43 |
| LongReach Reliant | 9.7 | 81.1 | 3.6 | 0.45 |
| LongReach Spitfire | 11.9 | 84.2 | 3.6 | 0.42 |
| LongReach Trojan | 10.4 | 83.6 | 2.2 | 0.40 |
| Longsword | 10.6 | 81.3 | 2.0 | 0.47 |
| Mace | 9.9 | 81.6 | 2.7 | 0.45 |
| Mitch | 10.4 | 78.5 | 2.9 | 0.41 |
| RAC2388 | 9.9 | 80.4 | 2.9 | 0.43 |
| Scepter | 10.0 | 81.1 | 3.2 | 0.47 |
| Sunprime | 11.8 | 81.2 | 3.6 | 0.41 |
| Sunlamb | 12.0 | 79.2 | 5.6 | 0.37 |
| Sunmax | 11.6 | 81.4 | 3.5 | 0.43 |
| Suntop | 10.2 | 81.6 | 2.9 | 0.41 |
| Sunvale | 11.9 | 81.2 | 2.1 | 0.42 |
| TenFour | 11.0 | 78.3 | 2.8 | 0.45 |
| Vixen | 12.0 | 78.9 | 4.5 | 0.37 |
| Average | 11.0 | 80.7 | 3.1 | 0.41 |
| l.s.d. ($P = 0.05$) | 1.5 | 1.3 | 0.9 | 0.06 |

### Yield components

Yield is driven by tiller number (Table 4), number of grains per tiller and grain size. There was a significant difference in all three yield components for both genotype and sowing date, although there was no interaction. Grain size decreased in SD3, but an increase in the number of grains per tiller compensated. There was no relationship between grain yield, and any single yield component, although a relationship was observed between grain yield and the number of grains per square metre (Figure 2).

Table 4. Yield components of 32 wheat varieties sown at Condobolin, 2018. Data shown is from the highest yielding sowing date, SD3: 21 May.

| Genotype | Grain number (grains/ear) | Grain weight (mg/grain) | Tiller number (tillers/m$^2$) |
|---|---|---|---|
| Beckom | 73.4 | 31.5 | 303 |
| Condo | 76.9 | 41.3 | 259 |
| Coolah | 74.5 | 31.4 | 258 |
| Corack | 69.7 | 43.3 | 283 |
| Cutlass | 88.4 | 34.4 | 291 |
| DS Bennett | 103.4 | 29.6 | 258 |
| DS Pascal | 67.7 | 30.4 | 316 |
| EGA Eaglehawk | 74.4 | 33.9 | 271 |
| EGA Gregory | 85.4 | 33.3 | 270 |
| EGA Wedgetail | 70.2 | 34.0 | 264 |
| H45 | 99.7 | 31.3 | 220 |
| Janz | 68.7 | 32.6 | 291 |
| LongReach Dart | 88.9 | 34.3 | 248 |
| LongReach Hellfire | 60.3 | 39.4 | 329 |
| LongReach Kittyhawk | 78.7 | 36.1 | 264 |
| LongReach Lancer | 62.6 | 35.3 | 237 |
| LongReach Mustang | 71.5 | 35.3 | 286 |
| LongReach Reliant | 87.9 | 32.7 | 272 |
| LongReach Spitfire | 80.0 | 38.2 | 268 |
| LongReach Trojan | 63.7 | 38.0 | 331 |
| Longsword | 54.9 | 36.8 | 291 |
| Mace | 81.2 | 36.0 | 275 |
| Mitch | 81.5 | 32.6 | 269 |
| RAC2388 | 69.4 | 38.1 | 292 |
| Scepter | 79.8 | 36.8 | 213 |
| Sunlamb | 114.4 | 26.5 | 238 |
| Sunmax | 70.8 | 36.7 | 246 |
| Sunprime | 80.4 | 36.7 | 270 |
| Suntop | 76.1 | 35.9 | 294 |
| Sunvale | 62.2 | 32.5 | 315 |
| TenFour | 88.9 | 35.7 | 242 |
| Vixen | 63.7 | 45.0 | 273 |
| Average | 77.2 | 35.2 | 273 |
| l.s.d. ($P = 0.05$) | 10.9 | 1.9 | 44 |

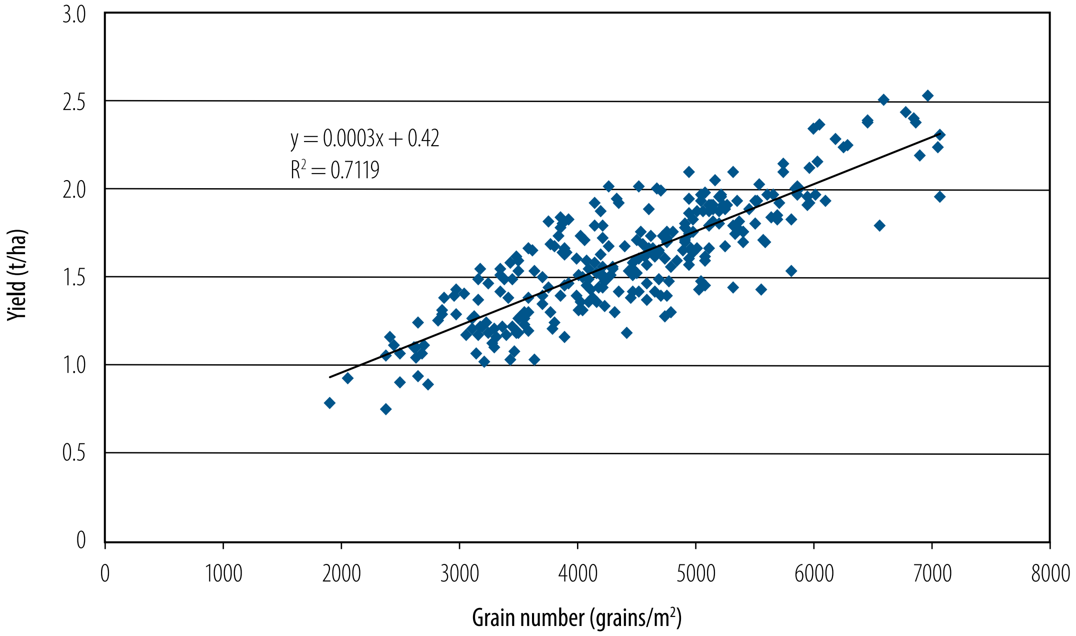

Figure 2. Relationship between grain yield and grain number/$m^2$ for 32 genotypes of wheat sown at Condobolin, 2018.

## Discussion

The 2018 growing season presented many challenges for growers in the central west of NSW. Genotypes flowering in the third week of September achieved the highest yield, with mid to slower varieties out-yielding fast and winter varieties. Frosts during August and the beginning of September coincided with stem elongation and early variety flowering, affecting their yield performance.

Fast-flowering genotypes are often favoured in the central west region of NSW in order to maximise the grain filling period in the event of terminal drought. In this experiment, however, mid to slow flowering varieties demonstrated a yield advantage over faster varieties due to frost affecting the early flowering types in SD1 and SD2. Of the varieties yielding above average in SD3, half were fast phenology types, while the top four varieties were mid to slow. Supplementary watering in the third week of September and the October rainfall might have provided a grain-filling advantage to the later flowering genotypes. While this experiment reports on a single year of results, it demonstrates the risk of early sowing, and the necessity to better match phenology type with sowing date.

## 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).

Many thanks to the technical assistance of Daryl Reardon and Leisl O'Halloran.

# Opportunities for early sown barley – Wagga Wagga and Wallendbeen 2018

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Dr Ben Trevaskis (CSIRO)

## Key findings

- New barley varieties such as RGT Planet⟨ɸ⟩ and Banks⟨ɸ⟩ offer alternative phenology patterns compared with benchmark fast spring type La Trobe⟨ɸ⟩.
- In southern NSW, most spring barley types are still suited to traditional May sowing dates, and earlier sowing options are limited by suitable winter varieties.

## Introduction

Matching varietal phenology and sowing date to achieve an optimal flowering time for each growing environment is the most effective management strategy to minimise the effects from abiotic stresses, while maximising grain yield, in all seasons. Recent yield improvements in barley varieties have been achieved through direct selection of yield, based on traditional May sowing dates and suitable flowering dates, achieved via indirect selection of phenology types with photoperiod sensitivity and without vernalisation responses. However, a recent trend towards sowing cereals (and canola) earlier, as well as European long-season spring barley introductions such as RGT Planet⟨ɸ⟩, has highlighted differences in barley phenology in southern NSW. This paper presents the phenology and grain yield responses of some diverse barley genotypes with respect to sowing date at Wagga Wagga and Wallendbeen in 2018, and discusses options for early sowing opportunities.

## Site details

| Site | Wagga Wagga, NSW | Wallendbeen, NSW |
|---|---|---|
| Location | Wagga Wagga Agricultural Institute | Braeside, Wallendbeen |
| Soil type | Red chromosol | Red kandasol |
| Previous crop | Canola | Canola |
| Sowing | Direct drilled with DBS tynes spaced at 240 mm using a GPS auto-steer system. Target plant density: 150 plants/m$^2$ | Direct drilled with DBS tynes spaced at 250 mm using a GPS auto-steer system. Target plant density: 150 plants/m$^2$ |
| Soil pH$_{Ca}$ | 4.7 (0–10 cm); 4.9 (10–30 cm) | 4.6 (0–10 cm); 5.4 (10–30 cm) |
| Mineral nitrogen (N) at sowing | 174 kg N/ha | 113 kg N/ha |
| Fertiliser | 80 kg/ha mono-ammonium phosphate (MAP) (sowing) | 82 kg/ha MAP (sowing)<br>Urea 87 kg/ha (spread 7 June) |
| Weed control | Knockdown: glyphosate (450 g/L) 1.2 L/ha<br>Pre-emergent: Boxer Gold® 2.5 L/ha + Avadex® Xtra 1.6 L/ha + Trifluralin (480 g/L) 0.8 L/ha<br>In-crop: Axial® 300 mL/ha + Precept® 2 L/ha (19 June) | Knockdown: glyphosate (450 g/L) 1.2 L/ha<br>Pre-emergent: Boxer Gold® 2.5 L/ha + Avadex® Xtra 1.6 L/ha + Trifluralin (480 g/L) 0.8 L/ha |

| Site | Wagga Wagga, NSW | Wallendbeen, NSW |
|---|---|---|
| Disease management | Seed treatment: Hombre® Ultra 200 mL/100 kg<br>Fertiliser treatment: Flutriafol (250 g/L) 400 mL/ha | Seed treatment: Hombre® Ultra 200 mL/100 kg<br>Fertiliser treatment: Flutriafol (250 g/L) 400 mL/ha<br>In-crop: Prosaro® 300 mL/ha (5 July) |
| In-crop rainfall | 179 mm (long-term average – 355 mm) | 219 mm (long-term average – 460 mm) |
| Severe temperature events | 16 heat stress events (days >30 °C)<br>36 frosts (days <0 °C)<br>11 severe frosts (days <–2 °C) including –4.9 °C (28 August), –6.3 °C (29 August), –5.4 (30 August), and –3.9 (17 September) | 2 heat stress events (days >30 °C)<br>10 frosts (days <0 °C)<br>3 severe frosts (days <–2 °C) including –2.4 °C (14 July), –2.3 °C (16 July), and –2.1 °C (17 September) |

## Treatments

A range of genotypes with different combinations of vernalisation and photoperiod genes were evaluated for early sowing opportunities at Wagga Wagga and Wallendbeen in 2018 (Table 1), including some novel genotypes: four lines derived from ultra-early barley genotype WI4441 (developed by Ben Trevaskis, CSIRO), three French winter genotypes (Secobra Research) and a European winter genotype (Syngenta).

Table 1. Sowing date and expected phenology types of genotypes included in field experiments at Wagga Wagga and Wallendbeen in 2018.

| Site | | Wagga Wagga, NSW | Wallendbeen, NSW |
|---|---|---|---|
| Sowing date (SD) | | SD1: 16 April*<br>SD2: 8 May<br>SD3: 28 May* | 13 April# |
| Winter genotypes | Slow | Cassiopée<br>Maltese<br>Salamadre | Cassiopée<br>Maltese<br>Salamadre<br>UK winter |
| | Fast | CSIRO B1<br>CSIRO B2<br>Urambie$^{\phi}$ | Urambie$^{\phi}$ |
| Spring genotypes | Slow | Banks$^{\phi}$<br>Oxford$^{\phi}$<br>Traveler$^{\phi}$<br>Westminster$^{\phi}$ | Oxford$^{\phi}$<br>Traveler$^{\phi}$<br>Westminster$^{\phi}$ |
| | Mid | Commander$^{\phi}$<br>RGT Planet$^{\phi}$<br>CSIRO B5<br>CSIRO B10 | Banks$^{\phi}$<br>Hacker<br>RGT Planet$^{\phi}$ |
| | Fast | Compass$^{\phi}$<br>Fathom$^{\phi}$<br>La Trobe$^{\phi}$<br>Rosalind$^{\phi}$ | La Trobe$^{\phi}$ |

* established with 15 mm irrigation via drippers.

# established with 10 mm irrigation via drippers.

## Results

### Phenology and grain yield

*Wagga Wagga, 2018*

Genotypes varied significantly in phasic development and flowering time at the Wagga Wagga site (Figure 1). Experiments conducted from 2014–18 indicate that many spring varieties achieve optimal flowering times and greatest grain yields when sown in mid May in southern NSW. Faster developing spring types (with minimal responses to vernalisation), sown early (when temperatures are warmer and days longer), progressed quickly, had a shorter vegetative phase, and flowered earlier compared with slower spring and winter types. For example, La Trobe$^{\phi}$ sown on SD1 at Wagga Wagga, started stem elongation (GS30) on 2 June. However, winter type Urambie$^{\phi}$ sown on the same day (16 April), had a prolonged vegetative phase due to its vernalisation requirement and reached GS30 four weeks later on 6 July. The variety had a relatively stable flowering response across all sowing dates.

The increased photoperiod requirements of Commander$^{\phi}$ and Banks$^{\phi}$ resulted in slightly slower development compared with La Trobe$^{\phi}$. Despite this, they still achieved the greatest grain yields from SD2 (Table 3). RGT Planet$^{\phi}$ is also a longer season spring genotype, though via a different phenology pattern (minimal vernalisation response coupled with weak photoperiod response), and is characterised as having only a slightly longer vegetative phase than La Trobe$^{\phi}$, with an extended reproductive phase. RGT Planet$^{\phi}$ has shown some flexibility across sowing dates, and is capable of being sown earlier in May than La Trobe$^{\phi}$. However, in frost-prone environments, due to its lack of vernalisation response, is not suited to April sowing dates.

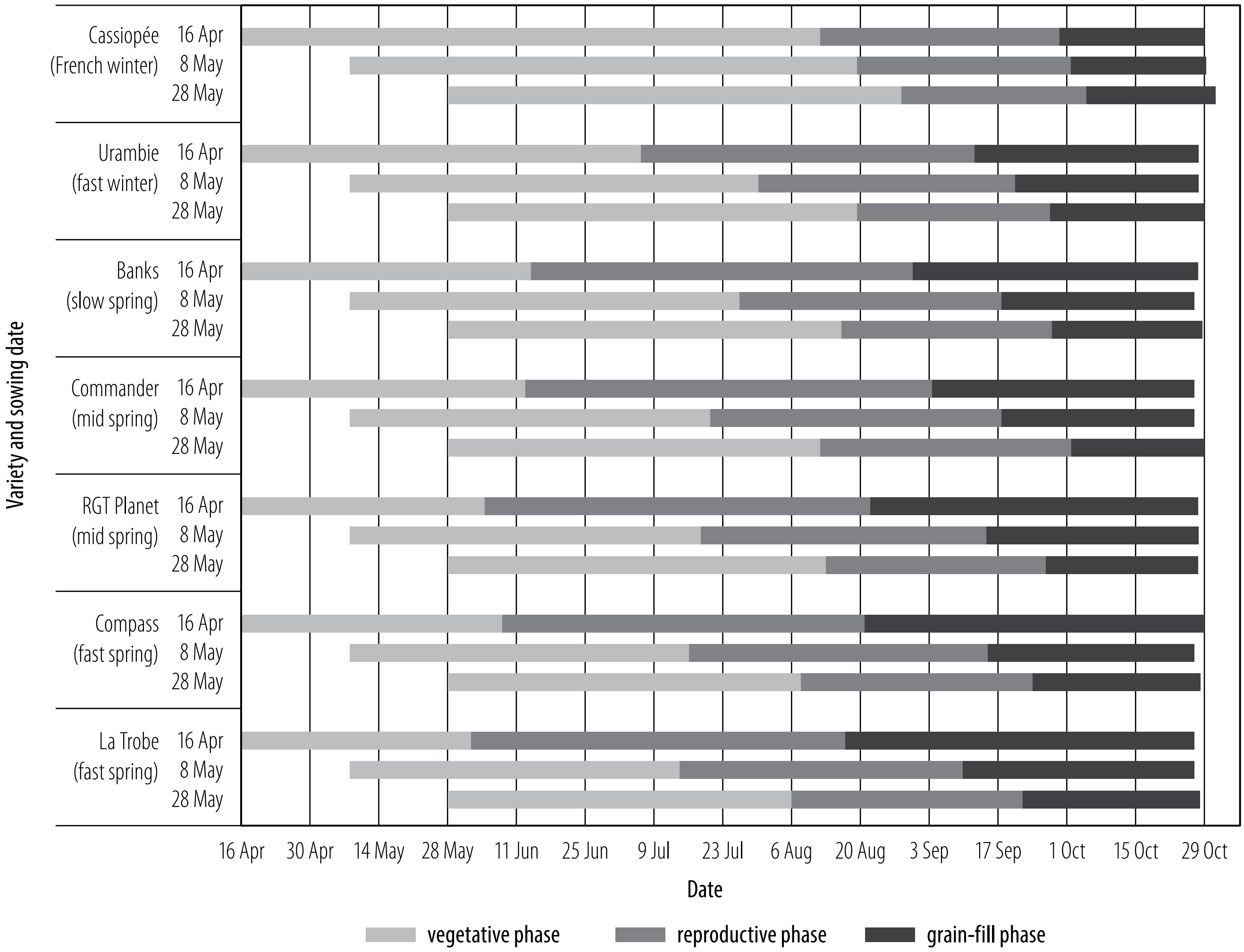

Figure 1. Sowing date influence on phasic development of selected genotypes sown on 16 April, 8 May and 28 May at Wagga Wagga in 2018.
*Vegetative phase: sowing to start of stem elongation (GS30); early reproductive phase: stem elongation (GS30) to awn peep (GS49); late reproductive: awn peep (GS49) to flowering (GS65).*

Generally, flowering date is a strong predictor of yield, with genotype and sowing date combinations that flower in late September–early October in Wagga Wagga capable of achieving the highest yields.

In 2018, there was significant variation in grain yields for genotype by sowing date combinations that flowered within the optimal period at Wagga Wagga (Figure 2). In 2018, optimal flowering time and similar grain yields were achieved by both fast winter type Urambie$^{\phi}$ sown mid–late April and the best performing spring types (e.g. RGT Planet$^{\phi}$) sown mid May. However, novel French winter genotypes, characterised as having a strong vernalisation and photoperiod response, flowered too late and suffered a significant yield penalty as grain filling occurred under terminal drought conditions (Table 2).

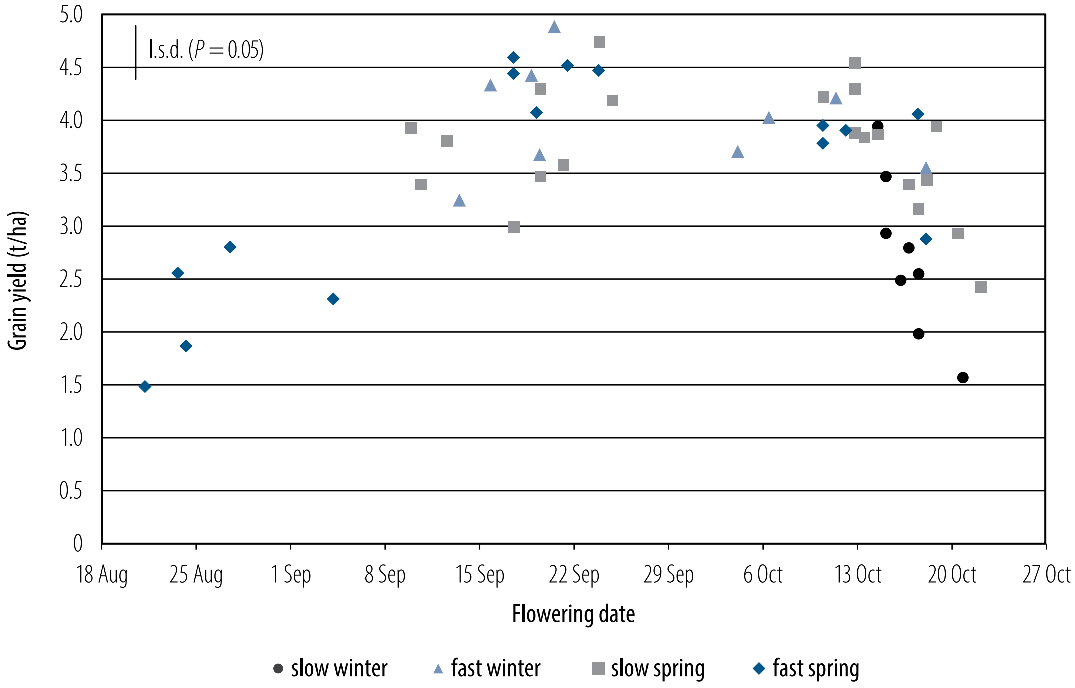

Figure 2. Relationship between flowering date and grain yield of genotypes sown on 16 April, 8 May and 28 May at Wagga Wagga in 2018; l.s.d., least significant difference.

Table 2. Grain yield responses to sowing date for genotypes sown 16 April, 8 May and 28 May at Wagga Wagga in 2018.

| Genotype | Grain yield (t/ha) | | |
|---|---|---|---|
| | SD1: 16 Apr | SD2: 8 May | SD3: 28 May |
| Banks | 3.57 | 4.53 | 3.94 |
| Cassiopée | 3.47 | 2.93 | 2.49 |
| Commander | 3.81 | 4.21 | 3.38 |
| Compass | 2.31 | 4.47 | 4.05 |
| CSIRO B1 | 3.24 | 3.66 | 3.7 |
| CSIRO B10 | 2.79 | 4.58 | 3.89 |
| CSIRO B2 | 4.33 | 4.42 | 4.01 |
| CSIRO B5 | 2.55 | 4.51 | 3.95 |
| Fathom | 3.39 | 4.18 | 3.86 |
| La Trobe | 1.86 | 4.43 | 3.77 |
| Maltesse | 3.89 | 2.55 | 1.57 |
| Oxford | 4.3 | 3.16 | 2.43 |
| RGT Planet | 3.92 | 4.73 | 3.83 |
| Rosalind | 1.48 | 4.06 | 2.87 |
| Salamandre | 3.94 | 2.79 | 1.98 |
| Traveler | 2.99 | 4.29 | 3.44 |
| Urambie | 4.88 | 4.19 | 3.54 |
| Westminster | 3.47 | 3.88 | 2.93 |
| Mean | 3.34 | 3.98 | 3.31 |
| l.s.d. genotype | 0.06 | | |
| l.s.d. SD | 0.12 | | |
| l.s.d. genotype × SD | 0.51 | | |

### *Wallendbeen, 2018*

A second field experiment was conducted at Wallendbeen to determine the suitability of novel winter genotypes for early sowing in a higher rainfall environment. Genotypes including Australian winter barley Urambie$^{\Phi}$ (fast winter), European winter types (strong vernalisation and photoperiod responses), and some spring types with varied development patterns were sown on 13 April 2018. In 2018, the Wallendbeen site also recorded below average rainfall, but recorded considerably less frost (number and severity), which influenced phenology and grain yield responses.

The highest yields were achieved by genotypes which flowered late September–early October, with a yield penalty associated with European winter types flowering after the optimal window (Figure 3). The yield penalty commonly experienced for early sowing fast-developing types (resulting in flowering earlier than optimal) was not as severe at Wallendbeen (Figure 3) as for Wagga Wagga (Figure 2) in 2018. This is likely to be due to reduced early frost risk, and timely grain-filling before slower winter types were exposed to significant moisture stress.

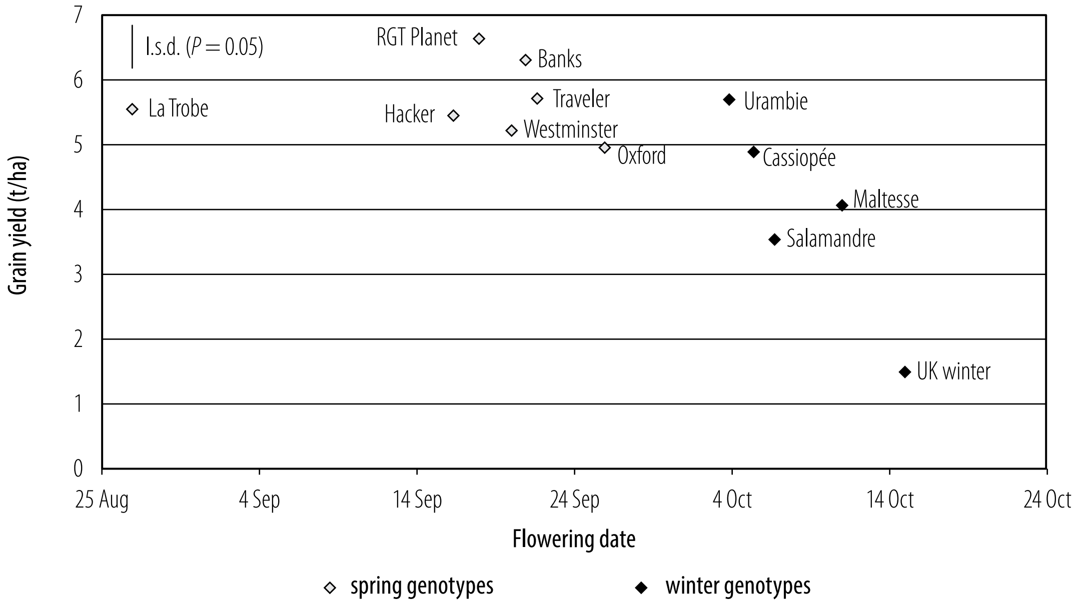

Figure 3. Relationship between flowering date and grain yield of genotypes sown on 13 April at Wallendbeen in 2018; l.s.d., least significant difference.

### *Opportunities for early-sown barley?*

An analysis comparing the best performing spring types (sown at the optimal time for each environment, typically traditional May dates), with the best performing fast winter and slow winter types was conducted across nine experiments in southern NSW and SA in 2017–18. This indicated that the fast winter types (typically Urambie⁽ᶦ⁾) were capable of comparably high yields when sown early, and both offered a constant significant yield advantage over slow winter types at seven out of nine sites (Figure 4). This suggests that a fast winter genotype is capable of achieving high yields when sown earlier than at the traditional May sowing dates. The strong vernalisation requirements of the European winter types consistently resulted in later than optimal flowering at all sites, and they were not able to maintain grain yield even in high rainfall environments. Further research investigating options for early sowing in southern NSW requires suitable germplasm that combines a vernalisation requirement capable of early sowing.

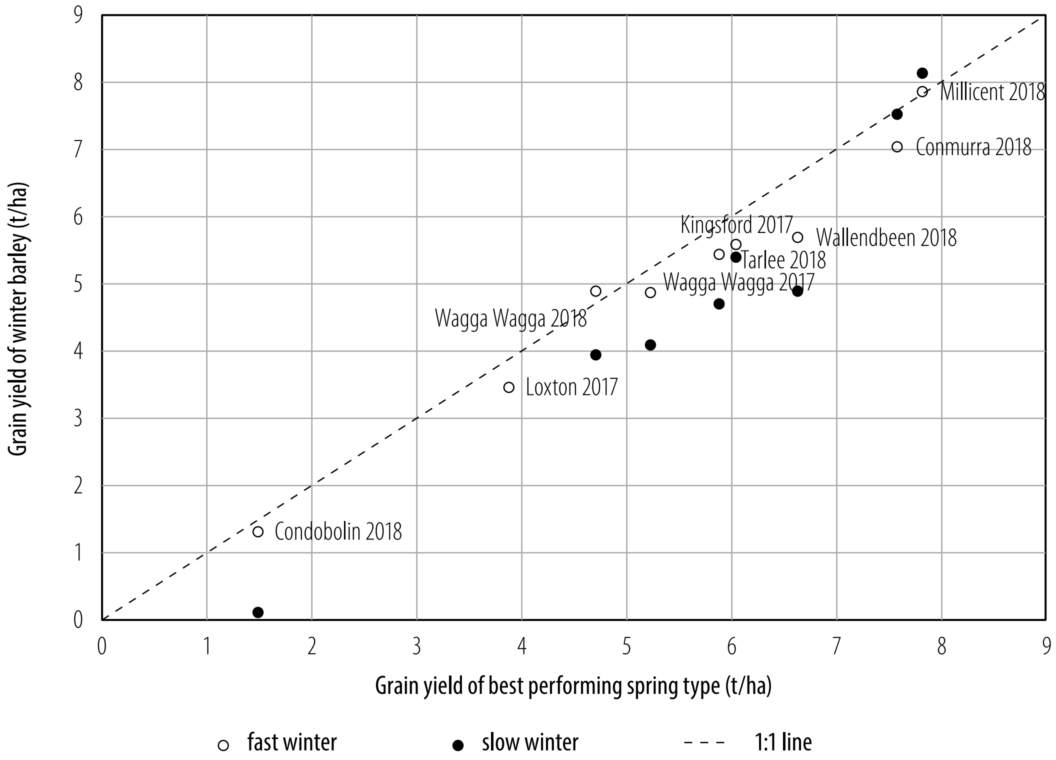

Figure 4. The relationship between the best performing spring barley types (sown at the optimal time) with fast winter and slow winter genotypes (sown mid–late April) at field experiments in NSW: Condobolin, 2018; Wagga Wagga 2017, 2018; Wallendbeen, 2018; and South Australia: Conmurra, 2018; Kingsford, 2017; Loxton, 2017; Millicent, 2018 and Tarlee, 2018.

## Summary

Despite the seasonal conditions experienced in 2018, high yields were achieved through varied genotype by sowing time combinations. However, in southern NSW, many barley varieties are still suited to traditional May sowing dates.

Recently introduced European longer season spring types such as RGT Planet$^{\text{\textcircled{D}}}$ and slower Australian spring types such as Banks$^{\text{\textcircled{D}}}$ and Commander$^{\text{\textcircled{D}}}$ offer opportunities for earlier sowing (early May) compared with the benchmark fast spring type La Trobe$^{\text{\textcircled{D}}}$. While new spring types have displayed some alternative phenology patterns, early sowing options in the frost-prone environments of southern NSW are currently limited by a lack of suitable winter genotypes.

Recent research has evaluated novel European winter types to provide options for early sowing, however, these did not offer a yield advantage over Australian fast winter types such as Urambie$^{\text{\textcircled{D}}}$.

## Acknowledgements

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

We acknowledge Cameron and Sarah Hazlett, Braeside, Wallendbeen for hosting the field experiment and acknowledge NSW DPI for their site cooperation at Wagga Wagga Agricultural Institute.

A sincere thank you to Mary Matthews and Jordan Bathgate for technical support.

# Sowing date effect on the phenology and grain yield of twenty-four barley varieties – Condobolin 2018

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

## Key findings

- Frost and low rainfall affected grain yield in the central west of NSW in 2018 resulting in below average yields.
- Fathom$^{\phi}$ and Compass$^{\phi}$ were the highest yielding barley genotypes, while late-flowering winter types incurred a severe yield penalty, due to terminal heat and moisture stress.
- There was no relationship between flowering date and yield in 2018 due to the interaction between frost and moisture stress that affected both early and late sowings.

## Introduction

Optimising barley's flowering window can be a major determinant of grain yield, through matching varietal selection with sowing in order to avoid frost damage during flowering while ensuring adequate time and moisture availability during grain fill. This experiment examines the effect of sowing date on 24 barley genotypes of differing phenology and physiology types at Condobolin, NSW in 2018.

## Site details

| | |
|---|---|
| **Location** | Condobolin Agricultural Research and Advisory Station |
| **Soil type** | Red chromosol |
| **Previous crop** | 2017 wheat (stubble intact), 2016 field peas |
| **Fallow rainfall** | 220.6 mm (October–April) |
| **In-crop rainfall** | 63 mm (April–September) |
| **Soil nitrogen (kg N/ha)** | 24.7 (0–10 cm), 52.5 (10–60 cm), 18 (60–100 cm) |
| **Starter fertiliser** | 70 kg/ha mono-ammonium phosphate (MAP) (11% nitrogen [N], 22.7% phosphorus [P], 2% sulfur [S]) at sowing. |
| **Supplementary watering** | The site was treated with 25 mm of supplementary water before each sowing. A following 20 mm of water was applied on 3 September. |

## Treatments

| | |
|---|---|
| **Varieties** | Banks$^{\phi}$, Biere$^{\phi}$, Bottler$^{\phi}$, Cassiopée, Commander$^{\phi}$, Compass$^{\phi}$, CSIRO B1, CSIRO B2, CSIRO B5, CSIRO B10, Fathom$^{\phi}$, La Trobe$^{\phi}$, Maltesse, Oxford$^{\phi}$, RGT Planet$^{\phi}$, Rosalind$^{\phi}$, Salamandre, Scope$^{\phi}$, Spartacus$^{\phi}$, Traveler$^{\phi}$, Urambie$^{\phi}$, Westminster$^{\phi}$, WI4896, WI4952.<br>The CSIRO lines are near-isogenic lines (NILs). They contain different combinations of vernalisation and photoperiod genes derived from ultra-early barley genotype WI4441 (developed by Dr Ben Trevaskis, CSIRO). Cassiopée, Maltese and Salamandre are French winter genotypes obtained from Secobra Research. WI4896 and WI4952 are unreleased experimental lines, with a similar genetic background to Compass$^{\phi}$. |

| | |
|---|---|
| **Sowing date (SD)** | SD1: 23 April<br>SD2: 10 May<br>SD3: 28 May |

## Results

### Grain yield and phenology

There were significant differences in yield by genotype, although no sowing date difference was observed (Table 1). The highest yielding variety was Fathom$^{\phi}$ in SD1, and Compass$^{\phi}$ in SD2 and SD3.

Table 1. Grain yield of 24 barley varieties sown on three dates at Condobolin, 2018. Figures in bold indicate highest yielding genotype per sowing date.

| Genotype | Grain yield (t/ha) | | |
|---|---|---|---|
| | SD1: 23 April | SD2: 10 May | SD3: 28 May |
| Banks | 1.27 | 0.87 | 0.95 |
| Biere | 0.76 | 1.14 | 0.88 |
| Bottler | 0.81 | 0.87 | 0.99 |
| Cassiopée | 0.06 | 0.13 | 0.08 |
| Commander | 0.97 | 0.67 | 0.46 |
| Compass | 0.94 | **1.42** | **1.34** |
| CSIRO B1 | 0.66 | 0.62 | 0.47 |
| CSIRO B10 | 0.79 | 1.13 | 0.74 |
| CSIRO B2 | 0.78 | 0.68 | 0.55 |
| CSIRO B5 | 1.06 | 0.65 | 0.68 |
| Fathom | **1.50** | 1.06 | 0.72 |
| La Trobe | 0.85 | 0.92 | 0.68 |
| Maltesse | 0.05 | 0.09 | 0.04 |
| Oxford | 0.68 | 0.64 | 0.44 |
| RGT Planet | 1.03 | 0.94 | 1.03 |
| Rosalind | 1.10 | 1.05 | 0.80 |
| Salamandre | 0.09 | 0.05 | 0.13 |
| Scope | 0.87 | 1.07 | 1.06 |
| Spartacus | 1.09 | 1.14 | 0.84 |
| Traveler | 1.02 | 1.02 | 0.79 |
| Urambie | 1.32 | 1.02 | 0.75 |
| Westminster | 0.72 | 1.04 | 0.80 |
| WI4896 | 1.10 | 1.06 | 0.67 |
| WI4952 | 1.09 | 0.94 | 1.02 |
| Average | 0.84 | 0.84 | 0.69 |

l.s.d ($P<0.05$) genotype 0.32 t/ha; sowing date 0.55 t/ha.

There were significant differences in flowering date by genotype and sowing date, although no interaction was observed. The date of awn peep (GS49) in each variety was recorded to indicate the onset of flowering. Due to the varying phenologies of the genotypes in the experiment, the period of awn peep differed from 29 August for the fastest, to 3 October for the slowest (Table 2). The fastest flowering variety was Biere$^{(D)}$, which flowered three days earlier than spring type La Trobe$^{(D)}$. Cassiopée, Maltesse and Salamandre are winter genotypes with similar or stronger vernalisation requirements than Urambie$^{(D)}$, currently the only winter barley commonly grown across NSW. All three French varieties had delayed flowering until late September or early October for all sowing dates, about two weeks after Urambie$^{(D)}$. Due to this late flowering, moisture stress severely affected their grain filling capacity and they yielded poorly. It should be noted that this experiment was conducted in a significantly low rainfall year, and sowing decisions should not be made on one year of results alone.

Table 2. Date of awn peep (GS49) for 24 barley varieties sown at Condobolin in 2018.

| **Variety** | **Date of awn peep** | | |
|---|---|---|---|
| | **SD1: 23 April** | **SD2: 10 May** | **SD3: 28 May** |
| Banks | 7 Sep | 10 Sep | 15 Sep |
| Biere | 29 Aug | 30 Aug | 1 Sep |
| Bottler | 5 Sep | 6 Sep | 10 Sep |
| Cassiopée | 29 Sep | 30 Sep | 2 Oct |
| Commander | 9 Sep | 13 Sep | 13 Sep |
| Compass | 3Sep | 7 Sep | 11 Sep |
| CSIRO B1 | 4 Sep | 3 Sep | 10 Sep |
| CSIRO B10 | 4 Sep | 5 Sep | 7 Sep |
| CSIRO B2 | 4 Sep | 6 Sep | 7 Sep |
| CSIRO B5 | 3 Sep | 7 Sep | 9 Sep |
| Fathom | 3 Sep | 5 Sep | 9 Sep |
| La Trobe | 1 Sep | 2 Sep | 8 Sep |
| Maltesse | 1 Oct | 30 Sep | 3 Oct |
| Oxford | 9 Sep | 12 Sep | 19 Sep |
| RGT Planet | 2 Sep | 3 Sep | 10 Sep |
| Rosalind | 2 Sep | 1 Sep | 7 Sep |
| Salamandre | 1 Oct | 1 Oct | 2 Oct |
| Scope | 6 Sep | 6 Sep | 9 Sep |
| Spartacus | 1 Sep | 3 Sep | 9 Sep |
| Traveler | 8 Sep | 10 Sep | 12 Sep |
| Urambie | 7 Sep | 9 Sep | 18 Sep |
| Westminster | 10 Sep | 12 Sep | 14 Sep |
| WI4896 | 4 Sep | 7 Sep | 10 Sep |
| WI4952 | 4 Sep | 9 Sep | 14 Sep |

l.s.d. ($P<0.05$) genotype 2.5 days; sowing date 0.89 days.

There was no relationship between flowering date and grain yield, which is atypical for central western NSW. The very late flowering French winter varieties were significantly lower yielding than other varieties, due to late flowering and terminal drought limiting grain fill (Figure 1).

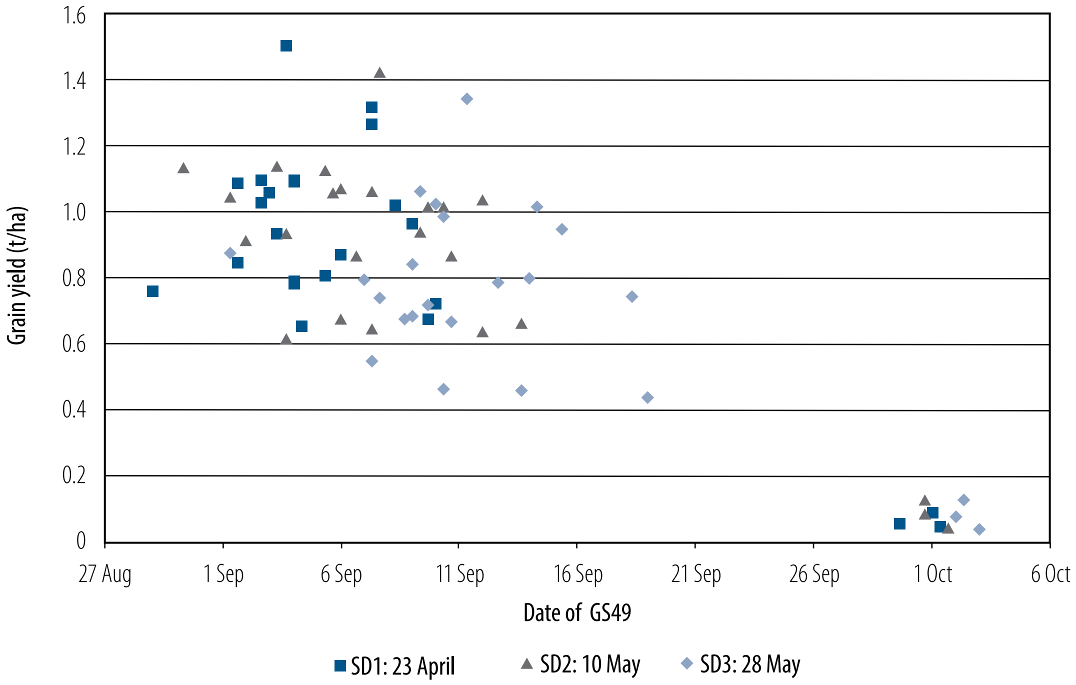

Figure 1. Relationship between grain yield and awn peep for 24 barley genotypes sown on three different dates at Condobolin, 2018.

### Grain quality and yield components

There were significant differences between genotypes and sowing dates for screenings (% <2 mm) and retention (% >2.5 mm) with an overall decrease in plumpness in SD2 and SD3. The highest screenings were in the late winter types, while Compass^(ḃ), La Trobe^(ḃ) and Biere^(ḃ) retained plumpness in SD2 and SD3. There was a significant difference between genotypes and sowing dates for hectolitre weights, with a slight reduction in the later sowing dates.

Grain protein concentration differed significantly by genotype, but sowing date produced no difference. Protein concentrations were greater than the malt specification of 12% in all varieties, except for Bottler^(ḃ), Compass^(ḃ), WI4896 and WI4952 (Table 3).

Table 3. Grain quality of 24 genotypes of barley sown at Condobolin, 2018. Data presented is from the main season sowing, SD2: 10 May.

| Genotype | Protein (%) | Screenings (% <2.2 mm) | Retention (% >2.5 mm) | Hectolitre weight (kg/hL) | Thousand grain weight (g) |
|---|---|---|---|---|---|
| Banks | 13.1 | 3.8 | 63.6 | 74.1 | 34.1 |
| Biere | 12.7 | 1.6 | 85.2 | 73.3 | 39.3 |
| Bottler | 12.0 | 4.9 | 66.3 | 71.6 | 33.0 |
| Cassiopée | 13.3 | 12.0 | 53.6 | * | 33.1 |
| Commander | 12.9 | 5.2 | 70.6 | 69.9 | 33.7 |
| Compass | 11.5 | 2.3 | 82.4 | 69.1 | 35.9 |
| CSIRO B1 | 12.6 | 4.1 | 68.7 | 67.4 | 36.8 |
| CSIRO B10 | 11.8 | 1.9 | 84.7 | 67.3 | 36.3 |
| CSIRO B2 | 13.2 | 3.8 | 58.0 | 68.3 | 35.2 |
| CSIRO B5 | 13.5 | 3.5 | 67.3 | 58.7 | 33.6 |
| Fathom | 12.1 | 2.4 | 82.5 | 67.2 | 40.0 |
| La Trobe | 13.7 | 0.9 | 87.2 | 72.6 | 36.3 |
| Maltesse | 13.0 | 12.4 | 55.8 | * | 31.7 |
| Oxford | 12.4 | 7.6 | 62.2 | 73.0 | 31.9 |
| Planet | 12.6 | 3.7 | 76.4 | 71.1 | 36.2 |
| Rosalind | 11.9 | 1.9 | 82.4 | 71.7 | 35.6 |
| Salamandre | * | * | * | * | 32.6 |
| Scope | 13.7 | 2.3 | 81.6 | 72.3 | 39.9 |
| Spartacus | 13.2 | 0.9 | 91.0 | 71.5 | 36.9 |
| Traveler | 12.3 | 4.5 | 74.3 | 68.8 | 35.8 |
| Urambie | 12.0 | 9.1 | 37.8 | 70.7 | 37.3 |
| Westminster | 13.2 | 2.9 | 76.1 | 73.1 | 36.0 |
| WI4896 | 12.3 | 2.3 | 82.6 | 68.9 | 35.4 |
| WI4952 | 12.1 | 3.8 | 74.6 | 69.6 | 32.3 |
| Average | 12.7 | 4.2 | 72.4 | 70.0 | 35.4 |

l.s.d. ($P<0.05$) protein 1.2 %; screenings 2.3%; retention 8.5%; hectolitre weight 0.5 kg/hL; thousand grain weight 1.4 g.
* indicates insufficient grain for results.

Grain yield is achieved through a combination of grain size, number of tillers per square metre, and number of grains per tiller. Number of tillers per square metre differed significantly between genotypes, with Compass$^{\phi}$ and Spartacus$^{\phi}$ having high numbers of tillers, while Fathom$^{\phi}$ and RGT Planet$^{\phi}$ have fewer tillers. Fathom$^{\phi}$ and RGT Planet$^{\phi}$ compensate for low tillering with large numbers of grains per tiller (tables 3 and 4). Spartacus$^{\phi}$ produced a high number of tillers in SD1, although decreased significantly in the later sowings. For genotypes reliant on tillering for grain yield, early season moisture is important for achieving maximum yield potential. Genotypes reliant on grains per tiller and grain size as major yield drivers are more reliant on moisture availability at grain fill.

Table 4. Final tiller number of 24 varieties of barley sown on three dates at Condobolin, NSW 2018.

| Variety | Tiller number (tillers/m$^2$) | | |
|---|---|---|---|
| | SD1: 23 April | SD2: 10 May | SD3: 28 May |
| Banks | 387 | 350 | 327 |
| Biere | 284 | 274 | 312 |
| Bottler | 387 | 286 | 361 |
| Cassiopée | 185 | 260 | 199 |
| Commander | 397 | 373 | 412 |
| Compass | 412 | 432 | 444 |
| CSIRO B1 | 308 | 389 | 305 |
| CSIRO B10 | 362 | 361 | 386 |
| CSIRO B2 | 418 | 416 | 431 |
| CSIRO B5 | 438 | 419 | 361 |
| Fathom | 315 | 304 | 304 |
| La Trobe | 384 | 393 | 375 |
| Maltesse | 246 | 272 | 212 |
| Oxford | 378 | 357 | 337 |
| Planet | 238 | 333 | 289 |
| Rosalind | 334 | 399 | 306 |
| Salamandre | 269 | 195 | 202 |
| Scope | 339 | 471 | 379 |
| Spartacus | 415 | 351 | 374 |
| Traveler | 409 | 297 | 359 |
| Urambie | 329 | 324 | 353 |
| Westminster | 301 | 315 | 258 |
| WI4896 | 409 | 493 | 366 |
| WI4952 | 339 | 382 | 374 |
| Average | 345 | 352 | 334 |

l.s.d. ($P = 0.05$) variety 59 tillers/m$^2$; sowing date 103 tillers/m$^2$.

## Discussion

Due to the interaction of frost affecting early flowering genotypes and terminal drought, there was no relationship between flowering date and yield, although very late flowering genotypes incurred a severe yield penalty in 2018. This is not typical of results for the central west of NSW, which generally exhibit a curvilinear relationship between yield and flowering, with an optimum flowering window of the second and third week of September.

## 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). Many thanks for technical assistance from Daryl Reardon and Leisl O'Halloran.

# Response to moisture stress of wheat near-isogenic lines varying at *Ppd* and *Vrn* genes – Yanco 2018

Dr Lance Maphosa and Kathryn Bechaz (NSW DPI, Yanco); Dr Felicity Harris (NSW DPI, Wagga Wagga)

## Key findings

- Under moisture stress conditions, early flowering and long grain-filling duration were advantageous in 2018.
- Short-season spring type near-isogenic lines (NILs) yielded better than winter types under moisture stress growing conditions at this site in 2018.
- The highest yielding line under moisture stress conditions had spring alleles in all *Vrn* genes and insensitive alleles in all *Ppd* genes.
- Under irrigated conditions the highest yielding lines had at least one spring *Vrn* allele and one *Ppd* insensitive allele.

## Introduction

Plant development is affected by genotype × environment × management interactions. At the genetic level, it is mainly affected by three groups of genes:

1. Photoperiod (*Ppd*): day-length response, with the insensitive types able to switch from the vegetative to reproductive phase regardless of day length.
2. Vernalisation (*Vrn*): cold temperature requirement, with the sensitive (winter) types requiring a minimum threshold to be met before switching from the vegetative to the reproductive phase.
3. Earliness: the residual genetic control when all the photoperiod and vernalisation requirements have been met (Fischer 2011).

This experiment aimed to look at the response to moisture stress of lines differing at the *Ppd* and *Vrn* genes.

## Site details

| | |
|---|---|
| **Location** | Yanco Agricultural Institute |
| **Soil type** | Merungle loam to Merungle sand |
| **Previous crop** | Field peas |
| **Sowing** | Irrigated and moisture stressed experiments were both sown on 18 May 2018 |
| **Target plant density** | 135 plants/m$^2$ |
| **In-crop rainfall** | 123 mm (1 May–30 November 2018) |
| **Supplementary watering** | 158 mm pre-sowing watering<br>223 mm for the irrigated experiment<br>98 mm for the moisture stressed experiment |
| **Soil nitrogen (N)** | Available nitrate N to 180 cm depth 455 kg N/ha (155 kg N/ha available to 30 cm) |

| | |
|---|---|
| **Starter fertiliser** | Mono-ammonium phosphate (MAP) fertiliser at 100 kg/ha, treated with Intake® |
| **Weed management** | Post-emergent weed control: Boxer Gold® (800 g/L prosulfocarb and 120 g/L S-metolachlor) at 2.5 L/ha (13 June); Precept® (125 g/L MCPA as 2-ethylhexyl ester and 25 g/L pyrasulfotole) at 1 L/ha and Lontrel® (600 g/L clopyralid) at 60 mL/ha (25 June) |
| **Disease management** | Stripe rust application: Prosaro® (210 g/L prothioconazole and 210 g/L tebuconazole) at 150 mL/ha (24 July) and at 300 mL/ha (24 August) |
| **Insect management** | Aphid control: Transform® (500 g/kg sulfoxatlor) at 50 g/ha (24 July); Dominex Duo® (100 g/L alpha-cypermethrin) at 125 mL/ha (24 August) |

## Treatments

A set of 32 NILs on a Sunstate$^{\phi}$ (wheat variety) background with allelic variation at the *Ppd* and *Vrn* genes was used to understand how the different moisture conditions affected wheat development and yield. Check varieties (Sunstate Delta ft mutant, Sunstate1006 mutant, Suntop$^{\phi}$ and WinterSuntop3_12) were also included in the experiment.

The experiments were sown on 18 May 2018. Due to the dry conditions in 2018, pre-sowing watering was needed to ensure successful establishment – 158 mm was applied. The experiments were treated the same way until flowering when watering was stopped on the moisture stressed experiment. However, the lines had different flowering dates, so an average peak flowering date of 2 September was used. The irrigated experiment received a further 125 mm of water during grain filling.

## Results

### Phenology

There was substantial variation in phenological development of the NILs measured as days to stem elongation (Z31), flowering (Z65) and physiological maturity (Z90). Vegetative growth phase conditions were identical and moisture stress was imposed at flowering and therefore did not have an effect on phasic development up to Z65. NILs with both winter type growth habits requiring vernalisation and photoperiod sensitivity were the slowest to reach Z31, Z65 and Z90.

### Yield

Moisture stress after flowering significantly reduced grain yield for all the NILs and check varieties (Figure 1). Yield also varied within the NILs for both the irrigated and moisture stressed experiments, probably driven by differences in development rate.

Under moisture stress conditions there was a high correlation between days to flowering and grain yield ($r^2 = 0.79$), with the early flowering lines having higher yields. However, under irrigated conditions there was no linear correlation between days to flowering and yield (Figure 2). At Yanco, the optimum flowering period is generally considered to be late September, once the risk of frost damage has reduced for irrigated wheat. This corresponded with some of the highest yielding lines in this experiment, which flowered 129–136 days after sowing (21–28 September).

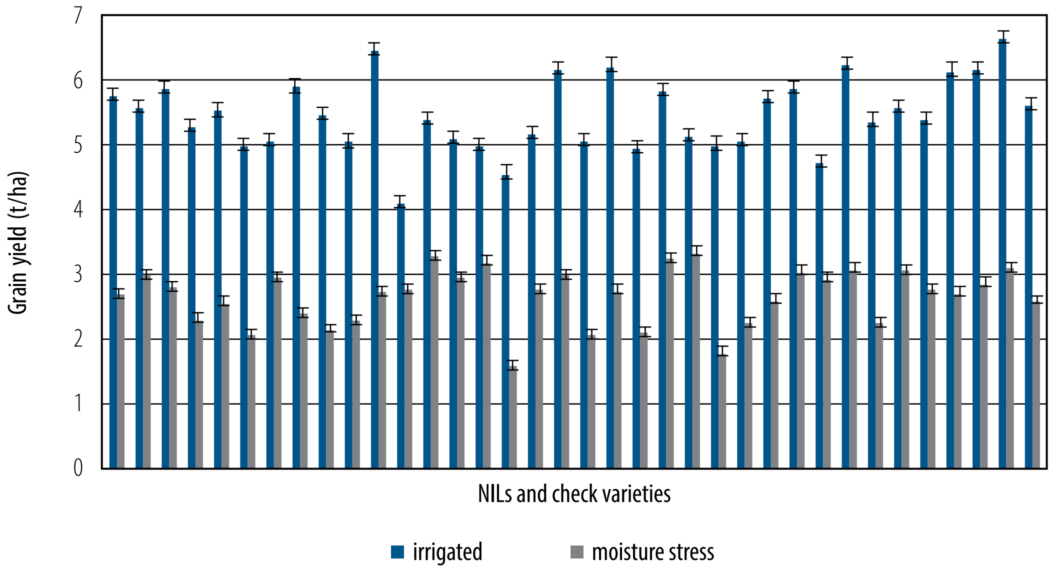

Figure 1. Grain yield for the 32 NILs and check varieties (last four on the right, Sunstate Delta ft mutant, Sunstate1006 mutant, Suntop$^{\Phi}$, and WinterSuntop3_12) under irrigated and moisture stress conditions.

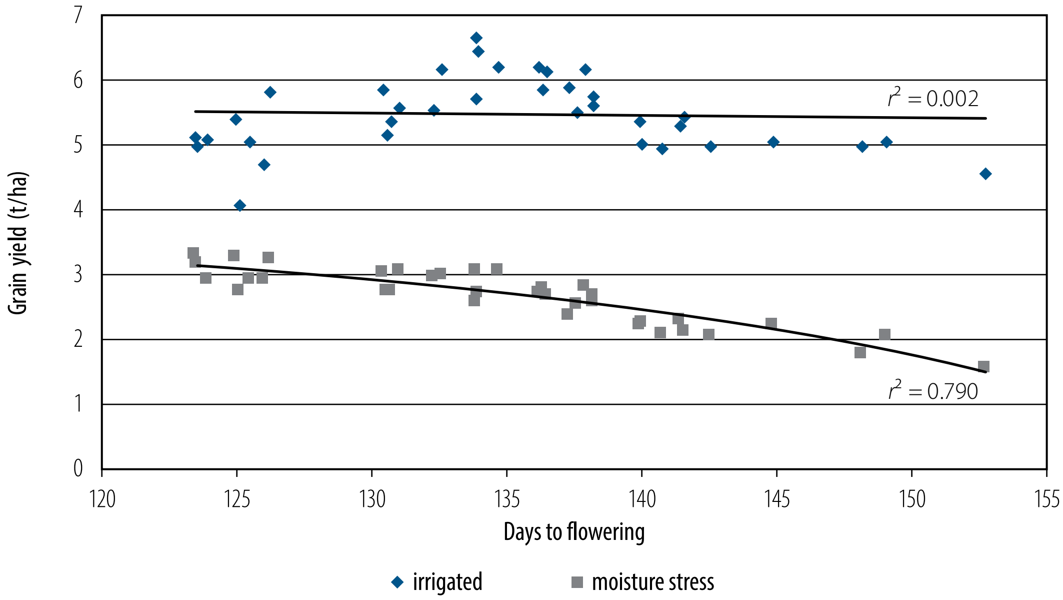

Figure 2. Relationship between days to flowering and grain yield of 32 NILs and check varieties grown under irrigated and moisture stress conditions.

A similar trend was observed for the relationship between yield and days to physiological maturity. Under moisture stress there was a high correlation ($r^2 = 0.72$) with the early-maturing lines yielding better than the late-maturing lines, but under favourable conditions there was no correlation. At Yanco, the optimum time for maturity for irrigated wheat is generally considered to be mid November. After this date, late season heat stress increases the risk of decreased yield. This window corresponded with some of the highest yielding irrigated lines in this experiment, which matured around 180 days after sowing (11 November). The irrigated experiment matured later, and time to maturity for all the lines spanned 10 days (175–185 days), compared with the moisture stressed treatment, which ranged from 155 days to 175 days (spanned 20 days).

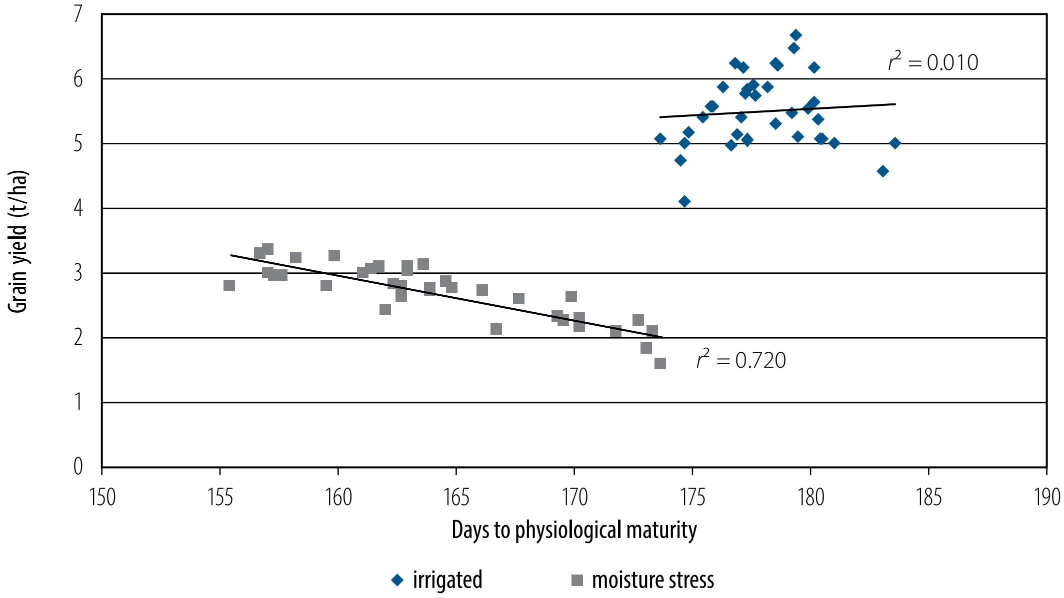

Figure 3. Relationship between physiological maturity and grain yield of the 32 NILs and check cultivars grown under irrigated and moisture stress conditions.

### Grain filling characteristics

There was a correlation between the grain filling duration, defined as time from heading to physiological maturity, and grain yield ($r^2 = 0.79$) under moisture stress conditions (Figure 4). Under moisture stress conditions the longer the grain filling period the higher the yield, a pattern that was not observed under irrigated conditions.

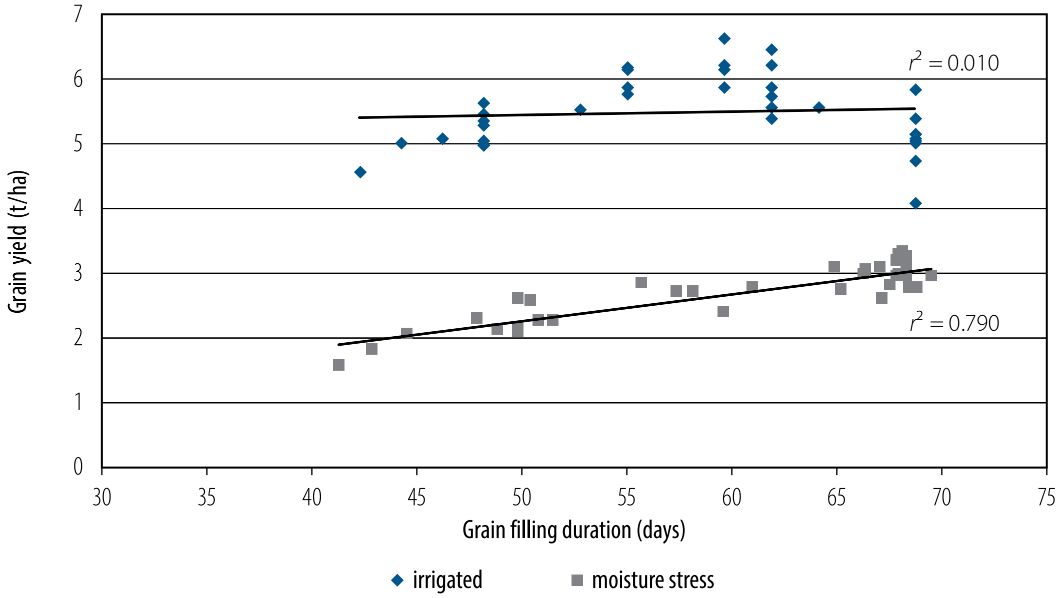

Figure 4. Relationship between grain filling duration and grain yield of the 32 NILs and check cultivars grown under irrigated and moisture stress conditions.

However, under both moisture stress and irrigated conditions there was no linear correlation between grain filling rate and yield (Figure 5).

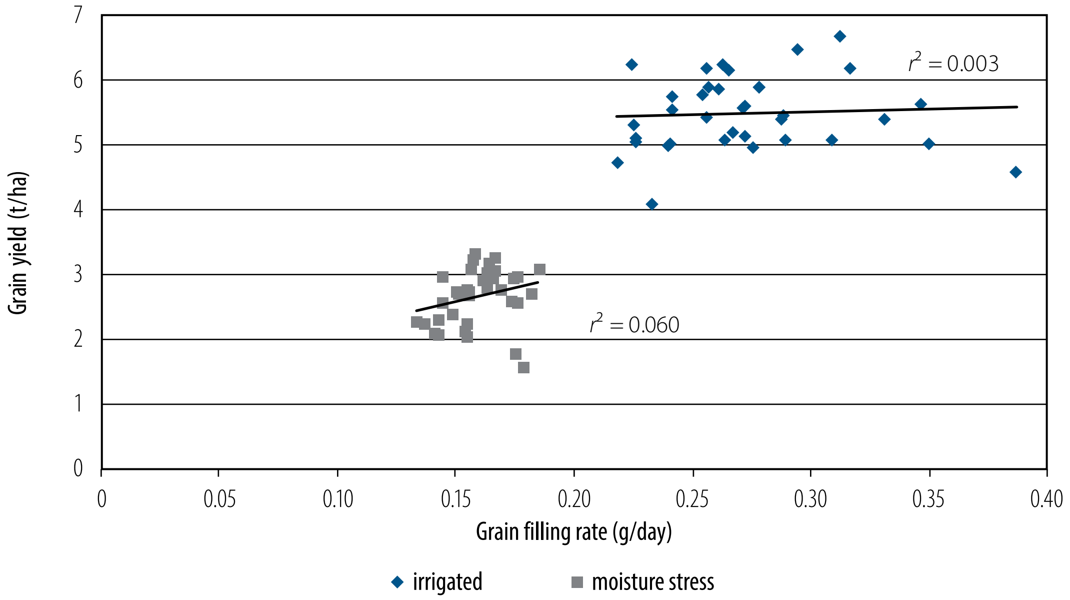

Figure 5. Relationship between grain filling rate and grain yield of the 32 NILs and check cultivars grown under irrigated and moisture stress conditions.

### Grain quality

There was a moderate to high linear correlation between percentage screenings and thousand grain weight under both moisture stress ($r^2 = 0.62$) and irrigated ($r^2 = 0.70$) conditions (Figure 6). Screenings were higher and grain weight was lower under moisture stress conditions than under irrigated conditions.

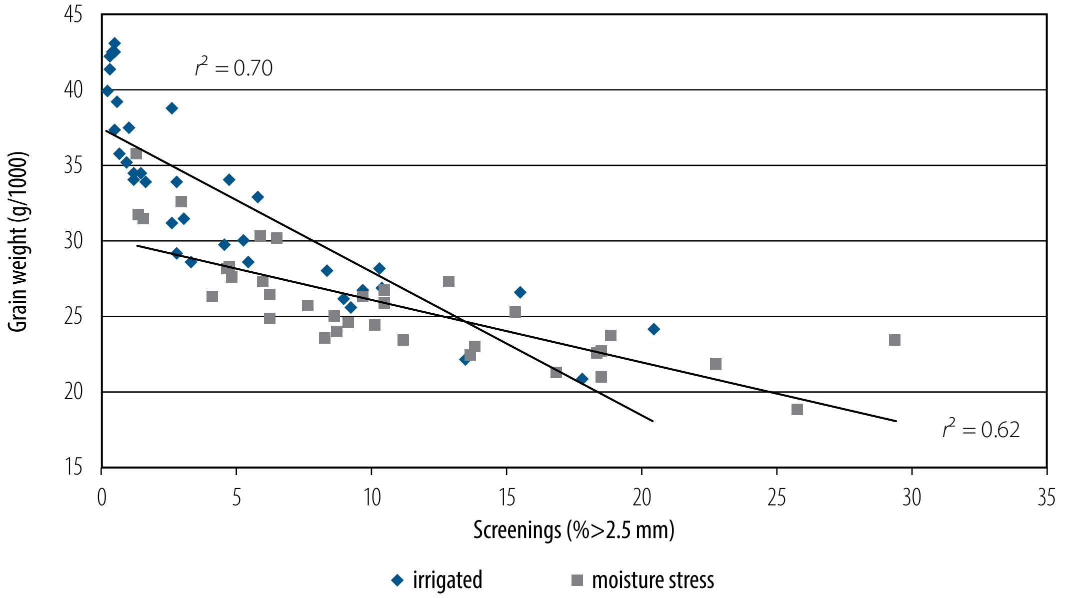

Figure 6. Relationship between percentage screenings and thousand grain weight of the 32 NILs and check cultivars grown under irrigated and moisture stress conditions.

## Conclusion

The NILs varied widely in phasic development such as time to stem elongation, flowering and physiological maturity. Under terminal moisture stress conditions, as is often experienced in the Australian wheat belt, early maturing, short-season lines were the highest yielding in 2018. Terminal moisture stress affects grain filling duration leading to a higher percentage of screenings, decreased grain weight and yield compared with irrigated conditions. This highlights the importance of correct sowing time (Harris et al. 2018), especially if there is frequent terminal moisture stress affecting the growing environment. However, under irrigated conditions, the NILs yielded well regardless of the developmental differences between the lines.

## References

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## Acknowledgements

This experiment was part of the 'Optimising grain yield potential of winter cereals in the Northern Grains Region' project, BLG104, 1 July 2017–30 June 2020, with joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

Thank you to Dionne Wornes, Peter Davidson and Glenn Morris for technical support.

# Agronomy – canola

## Early sowing of hybrid canola proves successful in a dry season

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

### Key findings

- Sowing slow-developing hybrid canola in early April achieved the highest yield in sowing date by variety type experiments at Ganmain and Wagga Wagga in 2018.
- Early sowing extended the crop vegetative period allowing more time for roots to access deep water stored in the soil from summer rain.

### Introduction

In the past, there have been industry concerns around the 'aggressive' canola management strategy of early sowing of hybrids with high nitrogen availability. A particular concern is that in a dry winter, the strategy would exhaust soil water on vegetative growth resulting in haying-off and a low grain yield. With above average summer rain leading to high starting water supply followed by very low in-crop rainfall, 2018 was a season for testing the aggressive strategy in southern NSW at two sites: Ganmain (site 1) and Wagga Wagga (site 2).

### Site details – 1

| | |
|---|---|
| **Location** | Ganmain, 60 km north-west of Wagga Wagga |
| **Soil type** | Brown chromosol |
| **Previous crop** | Barley |
| **Fallow rainfall** | 253 mm (November 2017–March 2018) |
| **In-crop rainfall** | 145 mm (April 2018–October 2018) (long-term average – 300 mm) |
| **Soil nitrogen** | 186 kg/ha (0–180 cm, 27 March) |

### Site details – 2

| | |
|---|---|
| **Location** | Wagga Wagga Agricultural Institute |
| **Soil type** | Red dermosol |
| **Previous crop** | Wheat |
| **Fallow rainfall** | 310 mm (November 2017–March 2018) |
| **In-crop rainfall** | 162 mm (April 2018–October 2018) (long-term average – 330 mm) |
| **Soil nitrogen** | 227 kg/ha (0–180 cm, 27 March) |

## Treatments

| | | |
|---|---|---|
| **Varieties** | Nuseed Diamond | Fast spring, hybrid conventional herbicide |
| | ATR Stingray$^{\phi}$ | Fast spring, open-pollinated triazine tolerant (OP TT) |
| | Pioneer® 44Y90 (CL) | Mid–fast spring, hybrid Clearfield (CLF) |
| | ATR Bonito$^{\phi}$ | Mid–fast spring, OP TT |
| | Pioneer® 45Y91 (CL) | Mid–slow spring, hybrid CLF |
| | Pioneer® 45Y25 (RR) | Mid–slow spring, hybrid Roundup Ready (RR) |
| | ATR Wahoo$^{\phi}$ | Slow spring, OP TT |
| | Archer | Slow spring, hybrid CLF |
| **Sowing date (SD)** | SD1: | 5 April – Ganmain |
| | | 4 April – Wagga Wagga |
| | SD2: | 26 April – Ganmain |
| | | 27 April – Wagga Wagga |
| **Nitrogen rate** | Low: | 30 kg/ha – Ganmain |
| | | 45 kg/ha – Wagga Wagga |
| | High: | 180 kg/ha – Ganmain |
| | | 195 kg/ha – Wagga Wagga |

## Results

### Seasonal conditions

Both sites had above average summer rainfall (2017–18) followed by below average autumn, winter and spring rainfall, with each month from April to October (with the exception of June) recording well below average rainfall. Ten millimetres of water was applied on both sowing dates at both sites to germinate the experiments on time due to the very low autumn rainfall. There were severe frosts at both sites in late August, with a minimum temperature of –6.2 °C at Ganmain and –4.0 °C at Wagga Wagga, both on 29 August.

### Phenology

Nuseed Diamond and ATR Stingray$^{\phi}$ were the fastest to flower from early sowing at both sites, with flowering starting in late July. Archer, Pioneer® 45Y25 (RR), Pioneer® 45Y91 (CL) and ATR Wahoo$^{\phi}$ all flowered in mid–late August, just before the most severe frost of the season on 29 August. Nuseed Diamond and ATR Stingray$^{\phi}$ flowered in mid–late August from SD2 at both sites, with the slow varieties flowering in late August to early September from the later sowing date.

### Grain yield

Sowing slow developing hybrids early achieved the highest yield in 2018 at both Ganmain and Wagga Wagga. Pioneer® 45Y91 (CL) was the highest yielding variety at both sites, yielding 2.2 t/ha and 2.6 t/ha at Ganmain and Wagga Wagga respectively (Figure 1). Early sown Archer yielded consistently well at both sites while sowing Pioneer® 44Y90 (CL) early yielded very well at Wagga Wagga (2.5 t/ha) but was penalised by frost at Ganmain (1.7 t/ha) compared with the slower varieties. From SD1, the fast variety Nuseed Diamond produced similar biomass as the slower developing varieties (13 t/ha at Ganmain and 11 t/ha at Wagga Wagga), but its harvest index was low because of frost damage (0.1 at Ganmain and 0.15 at Wagga Wagga). Pioneer® 44Y90 (CL) and Pioneer® 45Y91 (CL) were the only varieties to yield above 1.5 t/ha from both sowing dates at both sites. Sowing the OP TT variety ATR Wahoo$^{\phi}$ early yielded above the experiment mean (mean = 1.4 t/ha at Ganmain and 1.7 t/ha at Wagga Wagga) by 0.35 t/ha and 0.2 t/ha at Ganmain and Wagga respectively, but was heavily penalised from delayed sowing.

There was a positive response to applied nitrogen at Ganmain of 0.23 t/ha (averaged across all treatments). At Wagga Wagga, nitrogen had no effect on the early sown treatments, but a negative effect of 0.25 t/ha on the late sown treatments.

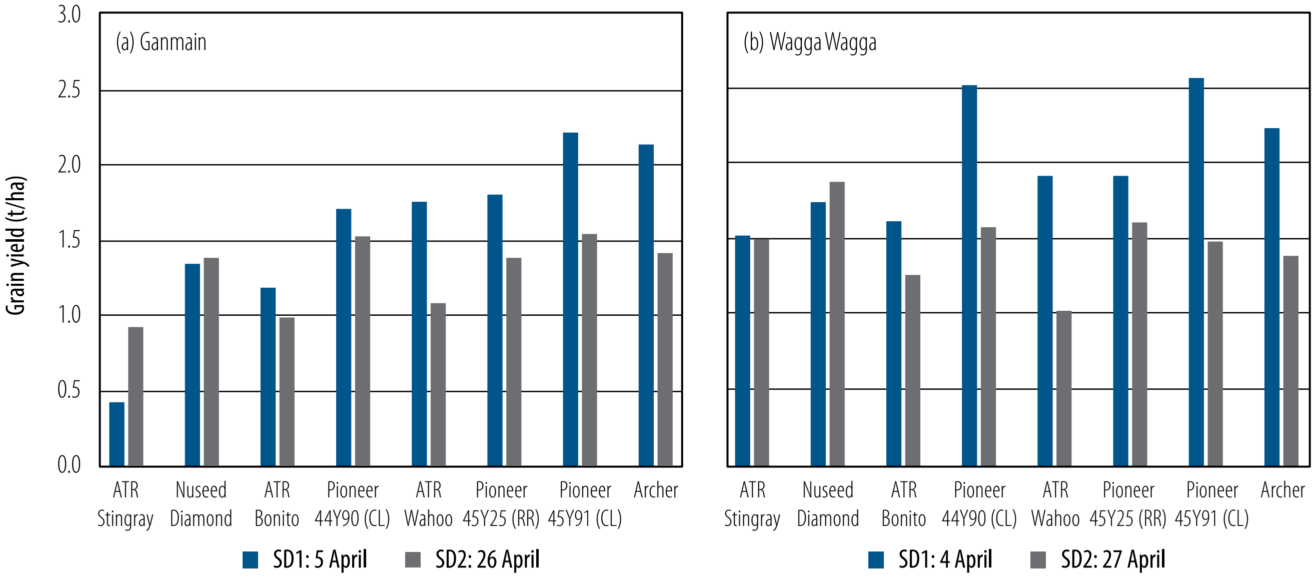

Figure 1. Grain yield (t/ha) of eight canola varieties sown in early and late April at (a) Ganmain and (b) Wagga Wagga, 2018; l.s.d. (*P* = 0.05) = 0.36 at Ganmain and 0.32 at Wagga Wagga.

### Oil concentration

The higher nitrogen rate reduced the average oil concentration by 2% at Ganmain (41.3% to 39.3%) and 2.1% at Wagga Wagga (40.4% to 38.3%). Frost also affected oil concentration, with Nuseed Diamond and ATR Stingray^{Φ} having low oil (<38%) from early sowing at both sites. There was only about 1% oil difference between all other varieties at Ganmain (41% to 42%) with no clear management trend (nitrogen rate and sowing date). At Wagga Wagga oil was reduced from 41% to 39% with delayed sowing for all varieties except the early flowering Nuseed Diamond and ATR Stingray^{Φ}.

## Conclusion

Early sown hybrid canola performed extremely well in 2018 and allayed fears that the aggressive management strategy would lead to canola haying-off. With more time in the ground and more vigorous growth, we hypothesise that slow hybrid varieties sown early effectively accessed water stored from the major rain events in December 2017. Just as importantly, these varieties also had the right phenology so that flowering did not start until mid–late August, avoiding severe frosts on developing pods. Pioneer® 45Y91 (CL) was the stand-out variety across the two experiments, achieving the highest yield at both sites, but also yielding slightly above the overall experiment mean when sown late. For a low-risk canola option, early sown ATR Wahoo^{Φ} had solid performance and provides a low seed cost option to have available should there be an early season break.

## Acknowledgements

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

# The effect of sowing date, soil moisture and nitrogen rate on flowering and grain yield of hybrid and open-pollinated canola

Ewan Leighton and Daryl Reardon (NSW DPI, Condobolin)

## Key findings

- Hybrid canola varieties Archer, Nuseed Diamond and Clearfield (CL) Pioneer® 44Y90 (CL) out-yielded open-pollinated (OP) triazine tolerant (TT) varieties ATR Stingray$^{\phi}$ and ATR Bonito$^{\phi}$ across all sowing dates. Hybrids generally had more growth and better recovery from frost damage.
- ATR Wahoo$^{\phi}$ was competitive with hybrid varieties as its slower phenology helped avoid frost damage.
- The highest yield resulted from planting early–mid developing (Pioneer® 44Y90 (CL)) and slow-developing (Archer) varieties on either sowing date, and fast-developing (Nuseed Diamond) on a later sowing date.
- Full irrigation led to an earlier flowering date and average yield increases of 109% over partial irrigation.

## Introduction

Recent experiments in the 'Optimised canola profitability' (OCP) project have emphasised the importance of matching sowing date with phenology in order to reduce crop exposure to stress during critical growth periods (Brill et al. 2017). This experiment was designed to further evaluate previous findings in the context of different seasonal conditions and altering water availability to change yield potential. Six varieties with diverse phenology and breeding (hybrid or OP) were sown on two sowing dates with two nitrogen (N) rates across full and partial irrigation. A partial irrigation treatment was required due to the low, decile one, rainfall conditions throughout the season.

This experiment formed part of a larger network of national canola experiments evaluating varietal response to sowing times in a range of climatic zones. Experiments were sown from South Australia's Eyre Peninsula to southern Queensland.

## Site details

| | |
|---|---|
| **Location** | Condobolin Agricultural Research and Advisory Station |
| **Soil type** | Red–brown chromosol, $pH_{Ca}$ 4.7 (0–10 cm) |
| **Previous crops** | Wheat 2014, wheat 2015, field peas 2016, wheat 2017 |
| **Fertiliser** | 70 kg/ha mono-ammonium phosphate (MAP) at sowing + Jubilee (flutriafol 500 g/L) at 580 mL/100 kg MAP (fungicide on fertiliser) |
| **Soil available N** | 95.2 kg/ha (0–120 cm) soil test conducted in February 2018 |
| **Growing season rainfall** | 86.8 mm (1 April–30 September 2018) |
| **Fallow rainfall** | 159.4 mm (1 November 2017–31 March 2018) |
| **Harvest** | Harvested by hand as varieties reached maturity |

## Treatments

| | | |
|---|---|---|
| **Canola varieties** | Nuseed Diamond | Fast, hybrid, conventional |
| | ATR Stingray$^{\phi}$ | Fast, open-pollinated triazine tolerant (OP TT) |
| | Pioneer® 44Y90 (CL) | Mid–fast, hybrid, Clearfield (CL) |
| | ATR Bonito$^{\phi}$ | Mid–fast, OP TT |
| | ATR Wahoo$^{\phi}$ | Slow, OP TT |
| | Archer | Slow, hybrid, CL |
| **Sowing date (SD)** | SD1: 5 April<br>SD2: 26 April | |
| **Supplementary watering** | Full: 234 mm (applied regularly with an overhead lateral irrigator)<br>Partial: 93 mm (applied intermittently with an overhead lateral irrigator) | |
| **Nitrogen rate** | Decile 3 yield target: no additional fertiliser<br>Decile 9 yield target: 75 kg N/ha (pre-sowing) + 75 kg N/ha at the 6 to 8-leaf growth stage | |

## Seasonal conditions

Growing season and pre-season fallow rainfall were both below average for the region, with 86.8 mm of rain falling from 1 April to 31 October. The long-term average (LTA) growing season rainfall is 227.5 mm. Rainfall was below the LTA in all growing season months. There were 30.6 mm in June and 31.8 mm in October, while the remaining five months received a combined 27.2 mm.

Monthly minimum temperatures were lower than average, with 28 days below 0 °C. There were seven major frosts during the growing season (≤–3.0 °C); –3.3 °C (26 June), –4.3 °C (14 July), –4.5 °C (15 July), –4.1 °C (16 July), –3.3 °C (22 July), –3.7 °C (23 July) and –4.0 °C (29 August).

## Irrigation

Irrigation was applied at regular intervals within the fully irrigated treatment to target a high yield potential, while intermittent applications were made within the partially irrigated treatment area. Dry conditions throughout the season allowed for a large difference in water treatments. Intermittent irrigation was applied to partially irrigated plots to ensure crops remained alive throughout the season. Fully irrigated plots received enough water to minimise soil moisture limitations.

There was a 40 mm irrigation applied to the partially irrigated blocks in the month preceding SD1, while the fully irrigated blocks received 70 mm over this period. An additional 18 mm was applied to the partially irrigated blocks between SD1 and SD2, while the fully irrigated blocks received 36 mm over the same period. Table 1 shows the irrigation dates and water quantity applied from SD1.

Table 1. Water applied across the partial and fully irrigated treatments at Condobolin, 2018.

| Date | 7 Mar | 19 Mar | 20 Mar | 21 Apr | 22 Apr | 22 May | 24 May | 7 Jun | 25 Jul | 8 Aug | 24 Aug | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Full irrigation (mm) | 20 | 30 | 20 | 18 | 18 | 15 | 15 | 20 | 38 | 20 | 20 | 234 |
| Partial irrigation (mm) | 20 | – | 20 | 18 | – | 15 | – | – | – | 20 | – | 93 |

## Results

### Flowering

From SD1, the fast-developing variety Nuseed Diamond started flowering in late June and early July (Figure 1). ATR Stingray$^{\phi}$ flowered one week later in early July where moisture was not limiting and up to eight days earlier in partially irrigated plots where moisture stress was evident (Figure 1). The slowest two varieties, Archer and ATR Wahoo$^{\phi}$, started flowering in early–mid August, up to six weeks later than Nuseed Diamond.

From SD2, ATR Stingray$^{\phi}$ flowered in mid July where fully irrigated, and up to three weeks later in early August where partially irrigated. Nuseed Diamond began flowering two weeks later than ATR StingrayΦ, on 28 July in fully irrigated plots. There was little difference in flowering date between Nuseed Diamond and ATR StingrayΦ where plots were partially irrigated. ATR BonitoΦ, Pioneer® 44Y90 (CL) and ATR WahooΦ all flowered between 10 August and 16 August regardless of irrigation. The slow-developing variety Archer flowered in late August, with fully irrigated plots flowering eight days earlier (21 August) than those partially irrigated (29 August).

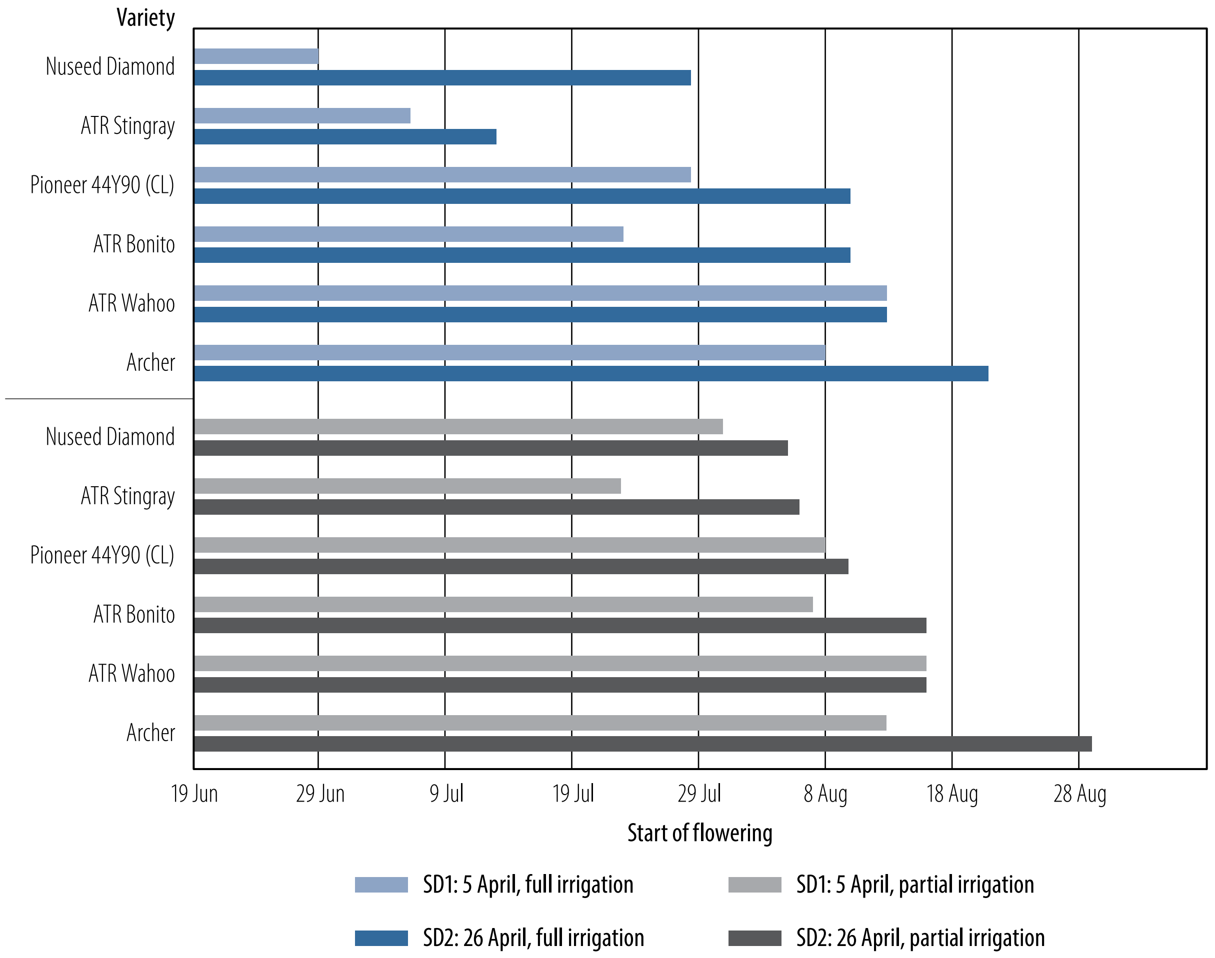

Figure 1. Start of flowering (50% of plants with at least one flower open) for six canola varieties fully irrigated and partially irrigated, sown on two sowing dates at Condobolin, 2018.

### Grain yield

There was no significant yield difference recorded on average between SD1 and SD2 across either irrigation treatment. Grain yields within fully irrigated treatments were 109% greater than in partially irrigated treatments, or 1.12 t/ha on average.

Hybrid varieties Archer and Pioneer® 44Y90 (CL) recorded grain yields around 2.5 t/ha across both sowing dates under full irrigation (Figure 2). These treatments flowered in the optimum window with fewer extreme frosts and a mild start to spring, so pods were not exposed to significant periods of environmental stress (Condon 2018).

Sowing date did not significantly affect the ATR WahooΦ grain yield under full irrigation, nor under the limited irrigation treatment.

ATR BonitoΦ, ATR StingrayΦ and Nuseed Diamond recorded 0.6 t/ha, 0.4 t/ha and 0.3 t/ha yield increases in SD2 compared with SD1 respectively, in the fully irrigated plots. These varieties at SD1 had flowered in mid-winter, increasing exposure to frost during a sensitive development phase, limiting grain yield.

In partially irrigated plots, ATR StingrayΦ produced a 0.3 t/ha yield increase at SD1 compared with SD2.

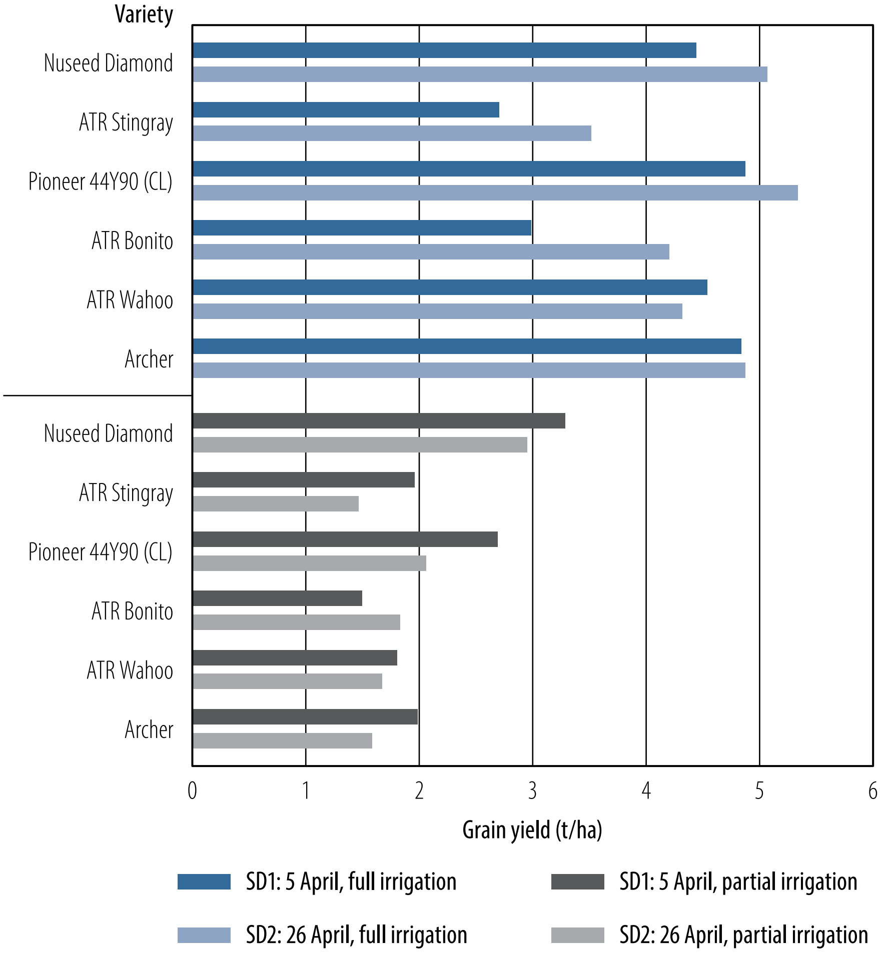

Figure 2. Grain yield of three OP and three hybrid canola varieties sown on two sowing dates (SD1 and SD2) with two irrigation treatments (full and partial) at Condobolin, 2018; l.s.d. ($P<0.05$) = 0.29 t/ha.

Nitrogen treatment had no significant effect on grain yield within varieties.

All three fully irrigated hybrid varieties recorded significantly higher grain yields than the OP varieties ATR Bonito$^{\Phi}$ and ATR Stingray$^{\Phi}$ regardless of sowing date (Figure 2).

There was no significant difference in grain yield between ATR Wahoo$^{\Phi}$ and the hybrid varieties at SD2 when fully irrigated, while Pioneer® 44Y90 (CL) and Nuseed Diamond both out-yielded ATR Wahoo$^{\Phi}$ at SD1 by 0.5 t/ha and 0.37 t/ha respectively.

Under partial irrigation, the fast-developing hybrid Nuseed Diamond and mid–fast-developing hybrid Pioneer® 44Y90 (CL) recorded significantly higher yields than the remaining four varieties.

Overall, the hybrid varieties under full irrigation recorded an average 0.65 t/ha yield increase in SD1 and an average 0.53 t/ha increase in SD2.

## Summary

The outcomes from this experiment support previous research underlining the importance of matching variety phenology with sowing date to limit exposure to environmental stress during key growth stages.

Sowing faster developing varieties early exposed the crop to frost during the sensitive flowering/podding phase. Sowing slower developing varieties early is favourable as the crop remains vegetative at the time when frost risks are high. By implementing sound agronomic practices (variety choice and nitrogen management) in conjunction with matching phenology and sowing date, yields can be significantly improved.

This experiment also underlined the important role plant available water can play in mitigating yield losses related to frost damage, particularly amongst hybrid varieties. Crops affected by frost have the ability to recover and re-establish a profitable yield with increased plant available moisture. While this demonstrates the frost recovery and associated yield benefits observed when water is non-limiting, it also reinforces that current agronomy principles regarding sowing date and phenology are relevant regardless of water availability.

## References

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## Acknowledgements

This experiment was a joint investment by GRDC and NSW DPI as part of the collaborative project 'Optimised canola profitability', CSP00187, 2014–19; a partnership also including CSIRO and SARDI.

Thanks to the operational staff at Condobolin Agricultural Research and Advisory Station for assistance throughout this experiment.

# Sowing date effect on flowering and grain yield of twelve canola varieties – Leeton 2018

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

## Key findings

- The second sowing date of 11 April had the highest average grain yield for the spring varieties. Grain yield was significantly reduced in these varieties (except Nuseed Diamond) when sowing date was delayed from 11 April to 1 May.
- Nuseed Diamond maintained a high grain yield when the sowing date was delayed to 1 May with a reduced risk of frost damage from flowering starting later.
- The first sowing date of 27 March had the highest average grain yield for the winter varieties, with a general yield decline as sowing time was delayed.
- Spring varieties were generally higher yielding than the winter varieties.
- Triazine tolerant varieties were generally lower yielding compared with other varieties with a similar phenology.

## Introduction

This experiment was designed to help improve understanding of the:

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

Better understanding about variety specific sowing times will help growers to select 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.

Twelve canola varieties with differing phenology were evaluated on three sowing dates from late March to early May.

## Site details

| | |
|---|---|
| **Location** | Leeton Field Station |
| **Soil type** | Brown clay with a $pH_{Ca}$ of 6.4 |
| **Previous crop** | Barley (irrigated) |
| **In-crop rainfall** | 124 mm (1.24 ML) (April 2018–October 2018) |
| **Supplementary watering** | 470 mm (estimation) (4.7 ML) |
| **Soil nitrogen** | 76 kg/ha (0–60 cm) |
| **Nitrogen (N) applied** | 20 March, urea at 220 kg/ha = 100 kg N/ha<br>20 March, Gran-Am at 80 kg/ha = 16 kg N/ha<br>At sowing, di-ammonium phosphate (DAP) at 130 kg/ha = 23 kg N/ha<br>First topdressing (8-leaf) at 175 kg urea/ha = 80 kg N/ha<br>Second topdressing (visible bud) at 175 kg urea/ha = 80 kg N/ha |

## Treatments

### Varieties

| | |
|---|---|
| Nuseed Diamond | Fast developing, conventional hybrid variety (spring type) |
| Pioneer® 44Y90 (CL) | Mid–fast developing, Clearfield (CL) hybrid variety (spring type) |
| ATR Bonito$^{\phi}$ | Mid–fast developing, triazine tolerant (TT) open-pollinated (OP) variety (spring type) |
| Pioneer® 45Y91 (CL) | Mid–slow developing, CL hybrid variety (spring type) |
| Pioneer® 45Y25 (RR) | Mid–slow developing, Roundup Ready (RR) variety (spring type) |
| Bayer RR | Mid–slow developing, experimental line from Bayer, RR variety (spring type) |
| Archer | Mid–slow developing, CL hybrid variety (spring type) |
| ATR Wahoo$^{\phi}$ | Mid–slow developing, TT OP variety (spring type) |
| Victory® V7001CL | Slow developing, CL hybrid (spring type) |
| SF Edimax CL | Very slow developing, CL variety (winter type) |
| Phoenix CL | Very slow developing, CL variety (winter type) |
| Hyola® 970CL | Very slow developing, CL variety (winter type) |

### Sowing date (SD)

SD1: 27 March 2018
SD2: 11 April 2018
SD3: 1 May 2018

## Results

### Phenology

Nuseed Diamond was the fastest developing variety from SD1 and started flowering on 23 June, 88 days after sowing (Figure 1). Nuseed Diamond development is primarily driven by temperature, (no vernalisation requirement) therefore warmer temperatures hastened its development. Hyola® 970CL was the slowest variety to start flowering from SD1, taking 191 days from sowing. Hyola® 970CL is a winter variety and has a strong vernalisation requirement, therefore it will not start flowering until after winter finishes. Victory® V7001CL was the slowest spring variety to start flowering from SD1, taking 144 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 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.

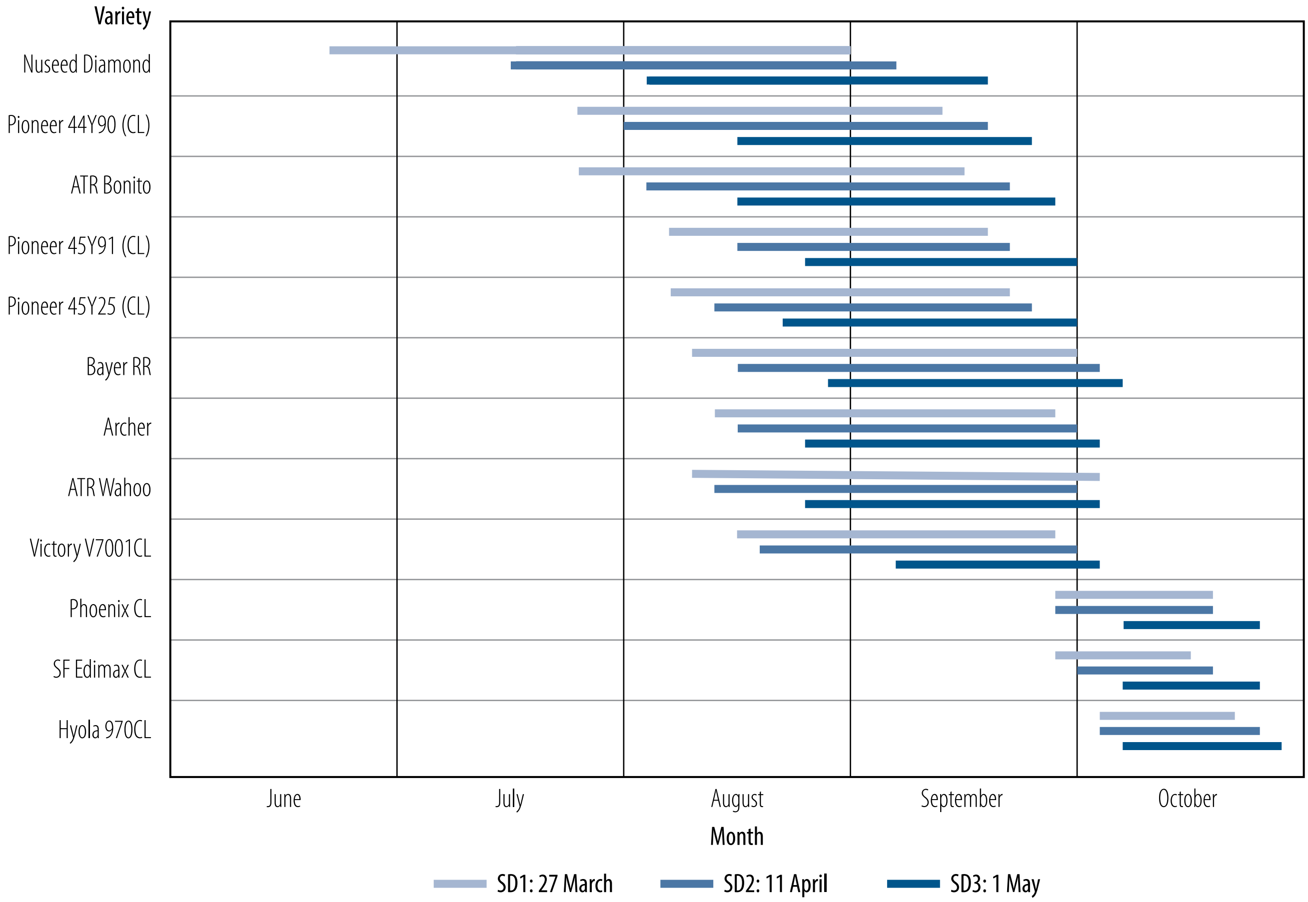

Figure 1. Flowering period of 12 canola varieties sown on three sowing dates at Leeton, 2018.

### Grain yield

Bayer RR (SD2) had the highest grain yield at 5.57 t/ha and was statistically similar to Nuseed Diamond (SD2 and SD3), Pioneer® 44Y90 CL (SD2), Pioneer® 45Y91 CL (SD1 and SD2), Pioneer® 45Y25 RR (SD2), Bayer RR (SD1) and Archer (SD1 and SD2).

ATR Bonito$^{\text{ⴰ}}$ (SD2) was the highest yielding TT variety at 4.19 t/ha, but was significantly lower yielding than the non-TT varieties of Nuseed Diamond (SD2 and SD3), Pioneer® 45Y91 CL (SD1), Pioneer® 45Y25 RR (SD2), Bayer RR (SD1 and SD2) and Archer (SD1 and SD2).

The highest yield for the spring varieties was from SD2, with an average of 4.91 t/ha; SD1 had 4.52 t/ha; SD3 had the lowest average yield with 3.86 t/ha. All spring varieties showed a strong response to sowing date. The fastest maturing variety, Nuseed Diamond, yielded significantly higher from SD2 and SD3, compared with SD1. All other spring varieties yielded less from SD3 compared with SD2.

Phoenix CL (SD3) had the lowest grain yield at 2.13 t/ha and was similar in yield to the two other winter varieties SF Edimax CL and Hyola® 970CL for the same sowing date. All three winter varieties also showed a strong response to sowing date, yielding significantly less as sowing date was delayed.

### Oil content

Bayer RR (SD1) had the highest oil concentration at 43.08% and was statistically similar to Nuseed Diamond (SD3), Pioneer® 44Y90 CL (SD3), ATR Bonito$^{\text{ⴰ}}$ (SD1, SD2 and SD3), Pioneer® 45Y91 CL (SD2), Pioneer® 45Y25 RR (SD2) and Bayer RR (SD1). Hyola® 970CL (SD1) had the lowest oil concentration at 36.60% and was similar to SF Edimax CL (SD2 and SD3), Phoenix CL (SD3) and the fast maturing spring variety Nuseed Diamond (SD1). Hyola® 970CL also had similar low oils at SD2 and SD3.

ATR Bonito$^{\text{ⴰ}}$ had the highest oil concentration over the three sowing dates with an average of 42.32% and was statistically similar to Bayer RR. Hyola® 970CL had the lowest oil concentration over the three sowing dates with an average of 36.72% – significantly lower than all other varieties. The three winter varieties of Hyola® 970CL, SF Edimax CL and Phoenix CL had a significantly lower oil concentration than all the spring varieties.

There was a significant interaction between variety oil concentration and sowing date. Both Nuseed Diamond and ATR Wahoo$^{\phi}$ had a significantly lower oil concentration in SD1 compared with SD2 and SD3. This result was unexpected as normally oil is reduced with delayed sowing. The varieties Pioneer® 45Y91 CL, Bayer RR and Archer had reduced oil concentration as sowing date was delayed.

Table 1. Grain yield (t/ha) and oil content (%) of 12 canola varieties sown on three sowing dates at Leeton, 2018.

| Variety | Grain yield (t/ha) | | | Oil content (%) | | | |
|---|---|---|---|---|---|---|---|
| | SD1: 27 March | SD2: 11 April | SD3: 1 May | SD1: 27 March | SD2: 11 April | SD3: 1 May | Average |
| Nuseed Diamond | 4.48 | 5.21 | 5.25 | 37.08 | 38.98 | 42.43 | 39.49 |
| Pioneer 44Y90 CL | 4.38 | 4.83 | 3.91 | 41.20 | 41.35 | 41.95 | 41.50 |
| ATR Bonito | 3.88 | 4.19 | 3.40 | 41.93 | 43.03 | 42.00 | **42.32** |
| Pioneer 45Y91 CL | 5.55 | 4.94 | 3.76 | 41.73 | 41.88 | 39.30 | 40.97 |
| Pioneer 45Y25 RR | 4.71 | 5.37 | 4.44 | 41.43 | 41.90 | 40.73 | 41.35 |
| Bayer RR | 5.24 | **5.57** | 3.55 | **43.08** | 42.18 | 40.70 | 41.98 |
| Archer | 5.09 | 5.37 | 4.12 | 40.83 | 40.23 | 39.08 | 40.04 |
| ATR Wahoo | 3.31 | 4.05 | 3.29 | 38.15 | 40.75 | 39.93 | 39.61 |
| Victory® 7001CL | 4.07 | 4.69 | 3.00 | 41.25 | 40.85 | 38.40 | 40.17 |
| Phoenix CL | 3.21 | 3.22 | 2.13 | 38.80 | 38.45 | 37.68 | 38.31 |
| SF Edimax CL | 3.56 | 2.98 | 2.18 | 38.50 | 36.95 | 37.25 | 37.57 |
| Hyola® 970CL | 3.45 | 3.50 | 2.27 | 36.60 | 36.75 | 36.80 | 36.72 |
| l.s.d ($P<0.05$) | 0.81 | | | 1.36 | | | 0.80 |

Values in bold indicate the highest value and underlined values indicate the lowest for each group.

## Conclusion

This research shows that the recommended sowing time of mid April for irrigated canola in the Riverina is optimum for most spring varieties. Grain yield was maximised from SD2 for the spring varieties with very little penalty in oil concentration. For the fastest maturing variety, Nuseed Diamond, sowing is best delayed to early May to minimise the risk of frost damage during flowering.

The three winter varieties performed best from SD1 with grain yield and oil concentration generally declining as sowing date was delayed. The overall winter varieties' performance was poor compared with the spring varieties. Both grain yield and oil concentration was significantly lower than all the spring varieties and showed little potential for adoption as a grain only crop in the irrigated production areas of southern NSW.

Growers should only consider growing TT varieties where specific weed control is needed, as they are consistently the lowest yielding.

## Acknowledgements

This experiment is 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 Michael Hately and Gabby Napier for their technical support.

# Agronomy – pulses

## Chickpea phenology and grain yield response to sowing date – Yanco 2018

Tony Napier, Dr Lance Maphosa and Daniel Johnston (NSW DPI, Yanco); Mark Richards (NSW DPI, Wagga Wagga)

### Key findings

- The low mean yield averaged across sowing dates and varieties (1.23 t/ha) at this site was largely attributed to limited pre-sowing moisture and low (87 mm) in-crop rainfall.
- Genesis™ 090 showed more signs of susceptibility to drought stress than other varieties.
- Late April and mid May sowing dates produced higher yields overall.
- There was an interaction between sowing date and variety for phenological development and harvest index, but not for grain yield.
- Growing degree days affected time to emergence, with delayed time to emergence as sowing date was delayed into late autumn, but there was no effect on plant density.

### Introduction

Identifying the optimum sowing date maximises yield potential by ensuring that critical growth phases such as flowering and podding do not coincide with abiotic stresses such as frost, drought and heat. The aim of this experiment was to determine the optimum sowing date for chickpea by identifying the phenological drivers of crop development and grain yield. The experiment was conducted at Yanco, NSW under dryland conditions, but water was applied to ensure crop establishment, and later in the season to maintain the experiment during extreme drought conditions.

This experiment was part of a series of ongoing experiments sown in central and southern NSW aiming to:

- identify the phenological drivers of chickpea in central and southern NSW
- determine variety response to sowing date across varying climatic zones
- determine optimal genotype and sowing date combinations.

This paper presents results from the Yanco site in 2018.

### Site details

| | |
|---|---|
| **Location** | Yanco Agricultural Institute |
| **Soil type** | Brown chromosol |
| **Soil $pH_{Ca}$** | 6.0 (0–10 cm) |
| **Previous crop** | Fallow |
| **Target plant density** | 40 plants/$m^2$ |

| | |
|---|---|
| **Mineral nitrogen (N)** | 109 kg N/ha (0–60 cm) |
| **Fertiliser** | Energiser Plus at 80 kg/ha (N 13.5: phosphorus [P] 13.5: potassium [K] 0.0: sulfur [S] 9.5) |
| **Pre-sowing watering** | 77 mm applied with overhead sprinklers from 20 March 2018 to 19 April 2018 |
| **In-crop watering** | 10 mm applied with dripper tubes immediately after sowing<br>64 mm applied with overhead sprinklers from 23 August 2018 to 24 September 2018 |
| **Growing season rainfall** | 87 mm (1 April 2018–31 October 2018) |
| **Pre-emergent herbicides** | 2 L/ha of Rifle® (440 g/L pendimethalin), 1.8 L/ha of Avadex® (500 g/L tri-allate) and 0.6 kg/ha of Terbyne Xtreme® (875 g/kg terbuthylazine) immediately before each sowing date |
| **Post emergent herbicides** | Two applications of Verdict® (520 g/L haloxyfop) at 100 mL/ha (25 May and 3 June)<br>One application of Status® (240 g/L clethodim) at 500 mL/ha (3 June) |
| **Fungicides** | Three applications of Dithane® (750 g/kg mancozeb) at 2.2 kg/ha (7 June, 5 July and 28 August)<br>Two applications of Bravo® (720 g/L chlorothalonil) at 1 L/ha (23 July and 2 August)<br>One application of Cheers® (720 g/L chlorothalonil) at 1.4 L/ha (10 September) |
| **Insecticides** | One application of Decis® (27.5 g/L deltamethrin) at 500 mL/ha (4 October) |

## Treatments

Eight chickpea varieties comprising five desi and three kabuli varieties were sown on four sowing dates.

| | |
|---|---|
| **Varieties** | Desi varieties: PBA Boundary$^{\phi}$, PBA Striker$^{\phi}$, PBA Slasher$^{\phi}$, CICA1521, Neelam$^{\phi}$<br>Kabuli varieties: Genesis™ 079, Genesis™ 090, Kalkee |
| **Sowing date (SD)** | SD1: 16 April 2018<br>SD2: 30 April 2018<br>SD3: 14 May 2018<br>SD4: 28 May 2018 |

## Results

### Growth phase duration

Time to emergence, ranged from eight days to 27 days and was longer when sowing was delayed (Figure 1). Chickpea requires a minimum threshold of approximately 115 growing degree days (GDD) to emerge, and this took longer to satisfy in the experiments at later sowing dates as temperatures dropped in late autumn (Whish 2016; GRDC GrowNotes™ 2017).

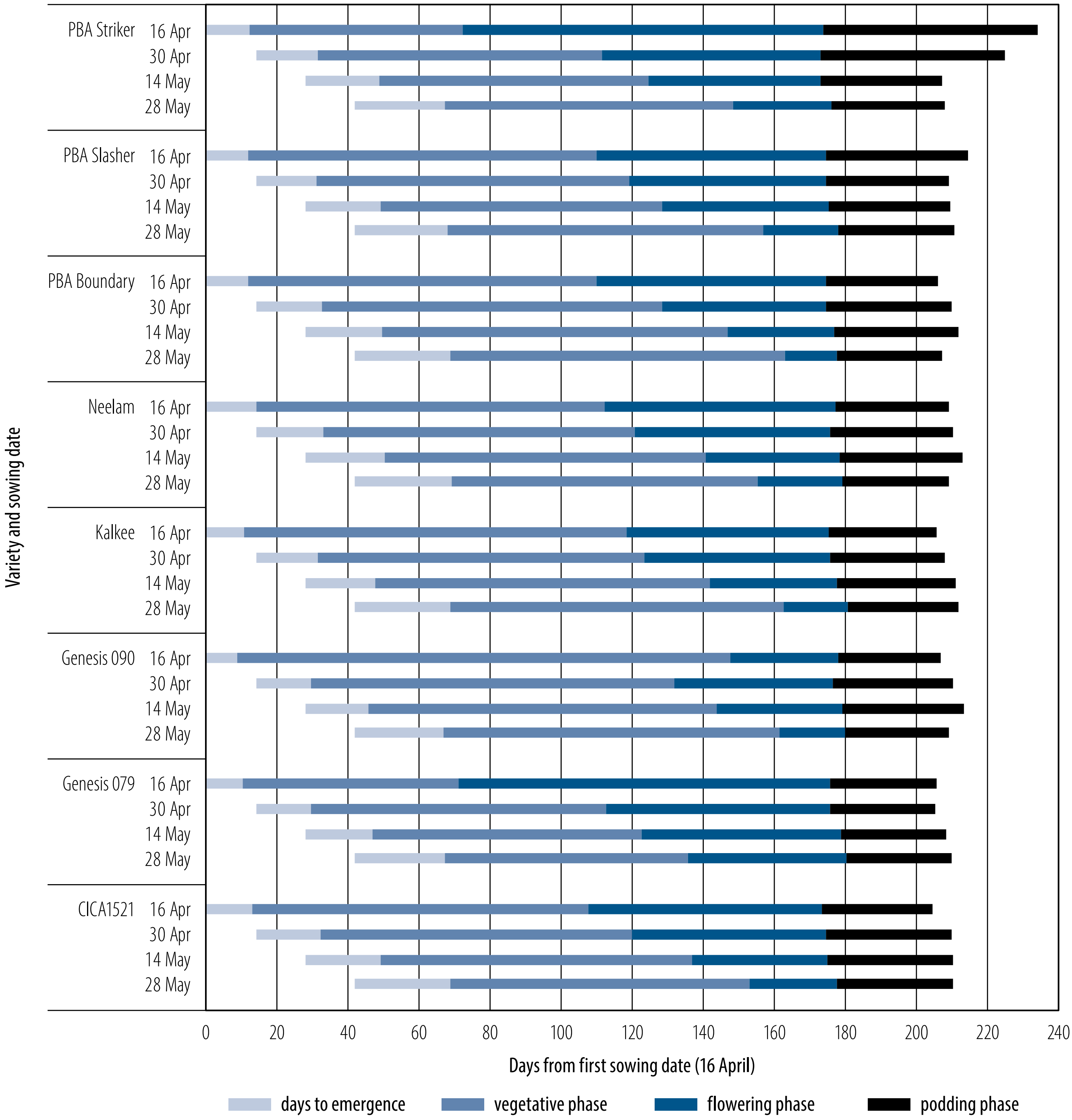

Figure 1. Duration of growth stages of eight chickpea varieties sown on four dates at Yanco, 2018.

Moisture stress induced varietal responses to flowering time and flowering duration, with PBA Striker$^{\Phi}$ and Genesis™ 079 flowering very early (72 days and 71 days after sowing respectively) (Figure 1). Vegetative, flowering and podding phase duration were longest in SD1 and decreased as sowing date was delayed. The longer flowering and podding phases meant that the early-sown treatments had a higher exposure to frosts than those sown later.

### Grain yield, yield components, harvest index and harvest biomass

Mean grain yield of varieties ranged from 0.87 t/ha for SD1 to 1.44 t/ha for SD3 (Figure 2), while across sowing time it ranged from 0.99 t/ha for Genesis™ 090 to 1.49 t/ha for PBA Striker$^{\text{\textphi}}$ (Figure 3). Across all sowing times, Genesis™ 090 showed signs of drought stress earlier than other varieties, but recovered after watering. This could have reduced its yield potential. The highest yields came from SD3, with a corresponding flowering time of around 90 days after sowing (Figure 4). There were different varietal yield responses to sowing date. High grain yield was mainly due to a larger number of seeds and pods per plant, and a larger seed size.

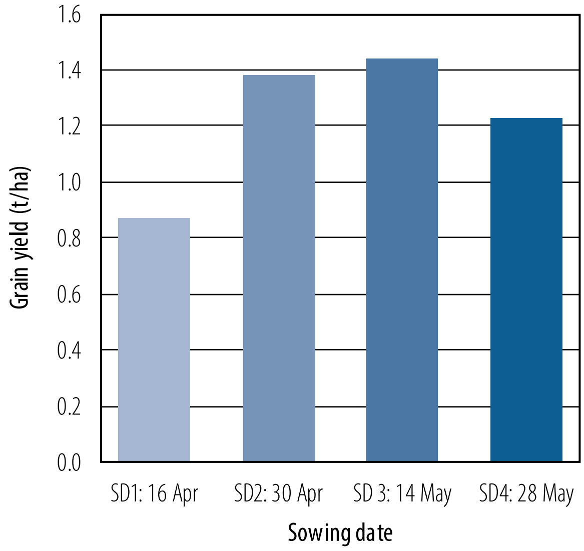

Figure 2. Grain yield of chickpeas sown on four dates meaned over eight varieties at Yanco, 2018; l.s.d. ($P<0.001$) = 0.18 t/ha.

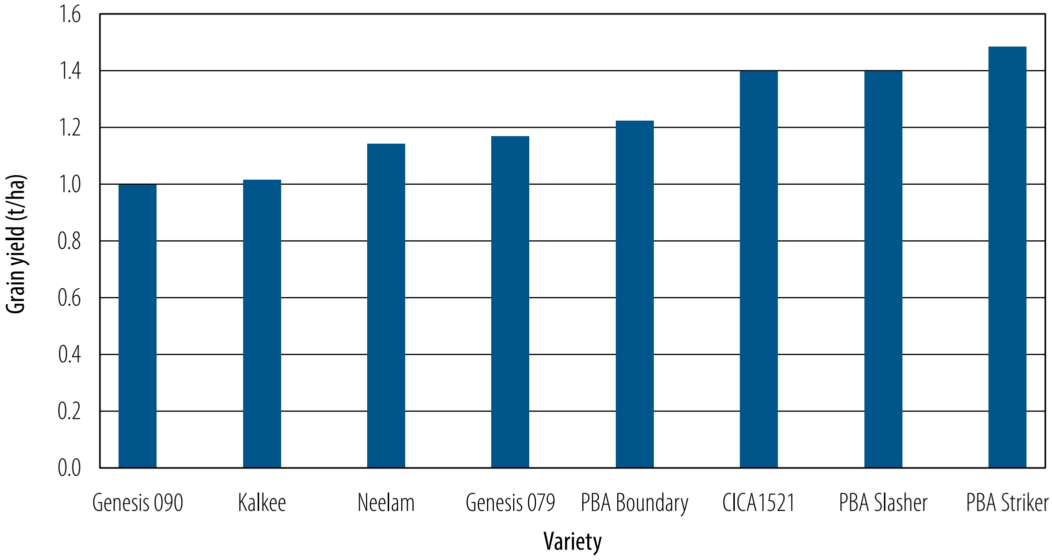

Figure 3. Grain yield of eight chickpea varieties meaned over four sowing dates at Yanco, 2018; l.s.d. ($P<0.001$) = 0.21 t/ha.

Averaged across sowing dates, the mean harvest index increased from 0.29 for Genesis™ 090 to 0.38 for PBA Striker$^{\text{\textphi}}$; mean of final harvest biomass ranged from 3.14 t/ha for Neelam$^{\text{\textphi}}$ to 4.16 t/ha for PBA Slasher$^{\text{\textphi}}$ (Table 1).

Table 1. Harvest index and harvest biomass of eight chickpea varieties across four sowing dates at Yanco in 2018.

| Variety | Harvest index (%) | Harvest biomass (t/ha) |
|---|---|---|
| CICA1521 | 0.36 | 4.04 |
| Genesis 079 | 0.35 | 3.50 |
| Genesis 090 | 0.29 | 3.56 |
| Kalkee | 0.31 | 3.44 |
| Neelam | 0.37 | 3.14 |
| PBA Boundary | 0.31 | 3.92 |
| PBA Slasher | 0.36 | 4.16 |
| PBA Striker | 0.38 | 3.93 |
| Mean | 0.34 | 3.71 |
| l.s.d ($P<0.05$) | | |
| Sowing date | 0.04 | 0.40 |
| Variety | 0.04 | 0.50 |
| Interaction (sowing date × variety) | 0.07 | n.s. |

Note: n.s. indicates not significant.

### Effect of temperature on flowering and podding

Temperatures during flowering and podding affected flower and pod abortion and ultimately yield. Figure 4 details the mean temperatures during the flowering and podding phases and the phase durations. SD1 and SD2 had more days with temperatures below 0 °C during flowering and podding than SD3 and SD4. Chickpea tends to abort pods at mean daily temperatures below 15 °C. Mean temperature rose above this threshold on 30 August. However, the early cultivar PBA Striker⁽ᵇ sown on SD1, which reached flowering on 28 June, reached peak podding on 29 August which is before the date when the threshold was met. After 30 August there were periods of low temperatures that did not appear to have affected PBA Striker⁽ᵇ from SD1, as it was the second highest yielding variety across all sowing dates. All other varieties, averaged across sowing dates, reached podding around 21 September in response to rising mean temperatures.

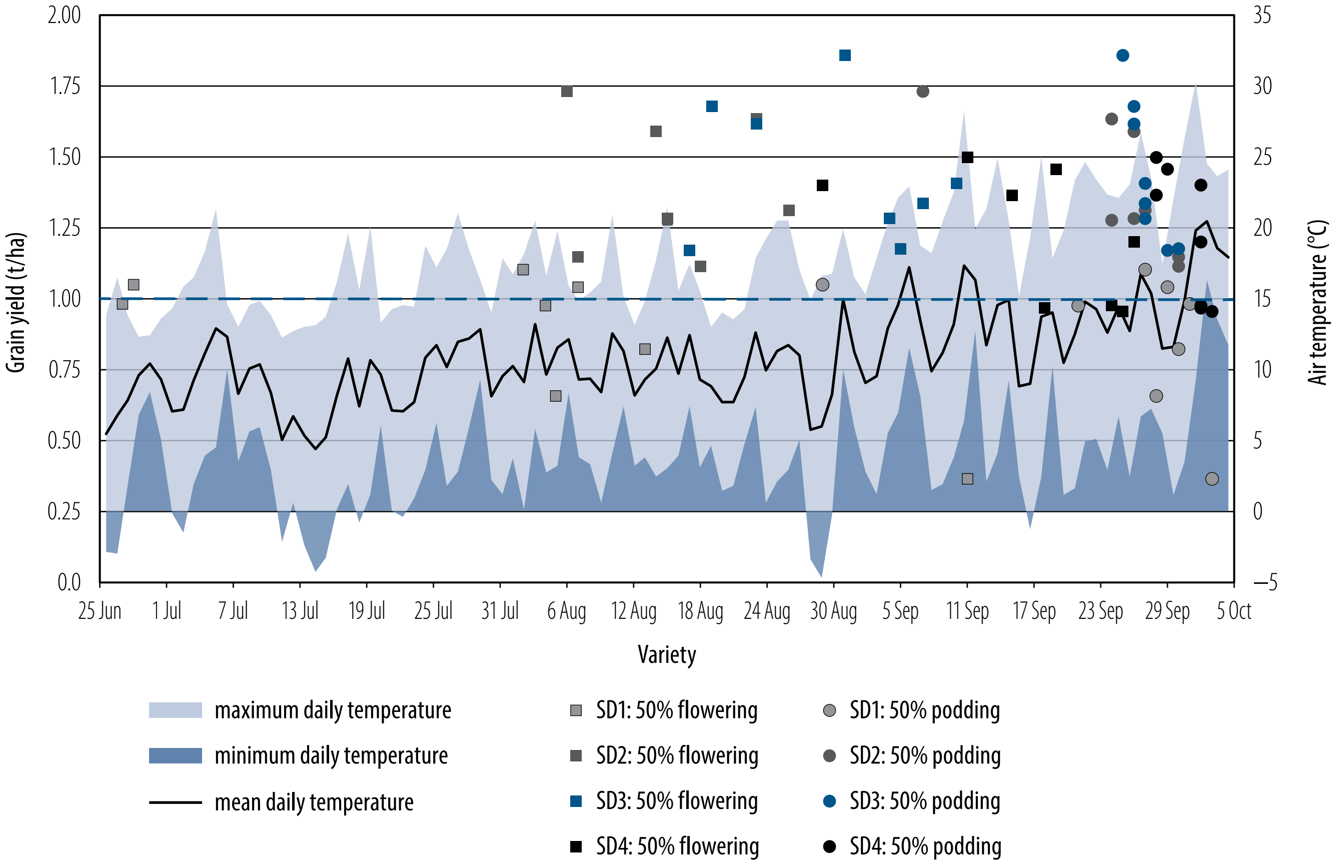

Figure 4. Chickpea grain yield, flowering and podding response to temperature and sowing date at Yanco 2018. *Same colour denotes the same SD, and squares denote flowering phase while circles denote podding phase. Dashed line indicates pod set threshold (15 °C).*

## Conclusion

Limited pre-sowing moisture affected plant growth, biomass accumulation and final grain yield at Yanco in 2018. The late April (SD2) and mid May (SD3) sowing dates produced the highest yields (1.38 t/ha and 1.44 t/ha respectively) when averaged across varieties. Yield was related to a number of yield components: number of pods, filled and unfilled pods, seed number and seed weight. The low mean grain yield (0.87 t/ha) observed from SD1 could be partly attributed to the high number of unfilled pods from frost damage during flowering and podding. Lack of soil moisture shortened the growing season and caused some varieties such as PBA Striker$^{\text{(}}$ and Genesis™ 079 to flower and pod earlier than normal. There are differing optimum sowing dates for different varieties, with the late April (SD2) and mid May (SD3) sowing dates producing higher yields overall.

## References

GRDC GrowNotes™ 2017. *Plant growth and physiology*. Grains Research and Development Corporation, https://grdc.com.au/__data/assets/pdf_file/0020/301646/GRDC-GrowNotes-Chickpeas-WESTERN.pdf, viewed on 4 March 2019.

Whish J 2016. *Accessing and using day degrees in field crops as a tool to assist crop management*. GRDC Update Paper. Grains Research and Development Corporation, https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/accessing-and-using-day-degrees-in-field-crops-as-a-tool-to-assist-crop-management, viewed on 4 March 2019.

## 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 Michael Hately and Gabby Napier for field assessments and data collection.

# Chickpea phenology and grain yield response to sowing date – Leeton 2018

Dr Lance Maphosa, Tony Napier and Daniel Johnston (NSW DPI, Yanco); Mark Richards (NSW DPI, Wagga Wagga)

## Key findings

- Sowing time in this pre-watered site had no effect on overall yield.
- There was an interaction between sowing date and variety for phenological development, grain yield and harvest index.
- Growing degree days affected time to emergence; later sowing dates delayed emergence, but there was no effect on plant density.

## Introduction

Identifying the optimum sowing date maximises yield potential by ensuring that critical growth phases such as flowering and podding do not coincide with abiotic stresses such as frost, drought and heat. This experiment aimed to determine the optimum sowing date for chickpea by identifying the phenological drivers of crop development and grain yield. The experiment site, located at Leeton NSW, was watered before sowing to ensure good establishment and to fill the soil profile. It was watered later in the season to maintain the experiment in extreme drought conditions.

This experiment was part of a series of ongoing experiments sown in central and southern NSW aiming to:

- identify the phenological drivers of chickpea in central and southern NSW
- determine variety response to sowing date across varying climatic zones
- determine optimal genotype and sowing date combinations.

This paper presents results from the Leeton site in 2018.

## Site details

| | |
|---|---|
| **Location** | Leeton Field Station |
| **Soil type** | Brown chromosol |
| **Soil $pH_{Ca}$** | 6.4 (0–10 cm) |
| **Previous crop** | Barley |
| **Target plant density** | 40 plants/$m^2$ |
| **Mineral nitrogen (N)** | 65 kg N/ha (0–60 cm) |
| **Fertiliser** | No base fertiliser applied |
| **Pre-sowing watering** | 220 mm applied with flood irrigation on 13 March 2018 |
| **In-crop watering** | 10 mm applied with dripper tubes immediately after sowing<br>24 mm applied with overhead sprinklers, 13 September 2018 to 9 October 2018 |
| **Growing season rainfall** | 87 mm (1 April 2018–31 October 2018) |

| | |
|---|---|
| **Weed management** | Pre-emergent: 2 L/ha of Rifle® (440 g/L pendimethalin), 1.8 L/ha of Avadex® (500 g/L tri-allate) and 0.6 kg/ha of Terbyne Xtreme® (875 g/kg terbuthylazine) immediately before each sowing date<br>Post-emergent: two applications of Verdict® (520 g/L haloxyfop) at 100 mL/ha (25 May and 3 June)<br>One application of Status® (240 g/L clethodim) at 500 mL/ha (3 June) |
| **Disease management** | Three applications of Dithane® (750 g/kg mancozeb) at 2.2 kg/ha (7 June, 5 July and 28 August)<br>Two applications of Bravo® (720 g/L chlorothalonil) at 1 L/ha (23 July and 2 August)<br>One application of Cheers® (720 g/L chlorothalonil) at 1.4 L/ha (10 September) |
| **Insect management** | One application of Decis® (27.5 g/L deltamethrin) at 500 mL/ha (4 October) |

## Treatments

Eight chickpea varieties comprising five desi and three kabuli were sown on four sowing dates.

| | |
|---|---|
| **Desi varieties** | PBA Boundary$^{\phi}$, PBA Striker$^{\phi}$, PBA Slasher$^{\phi}$, CICA1521 and Neelam$^{\phi}$ |
| **Kabuli varieties** | Genesis™ 079, Genesis™ 090 and Kalkee |
| **Sowing date (SD)** | SD1: 16 April 2018<br>SD2: 30 April 2018<br>SD3: 14 May 2018<br>SD4: 28 May 2018 |

## Results

### Growth phase duration

Time to emergence ranged from 7 days to 26 days; as sowing date was delayed, the time to emergence took longer (Figure 1). Chickpea requires a minimum threshold of approximately 115 growing degree days (GDD) to emerge. This took longer to satisfy at the later sowing date (SD4) as temperatures dropped in late autumn (Whish 2016; GRDC GrowNotes™ 2017).

Vegetative, flowering and podding phase duration were longest in the early-sown treatment (SD1) and decreased as sowing date was delayed. The longer flowering and podding phases meant that the early-sown treatment (SD1) had a higher exposure to frosts than those sown later. The low yield observed from SD1 can be partly attributed to the high number of unfilled pods resulting from frost exposure.

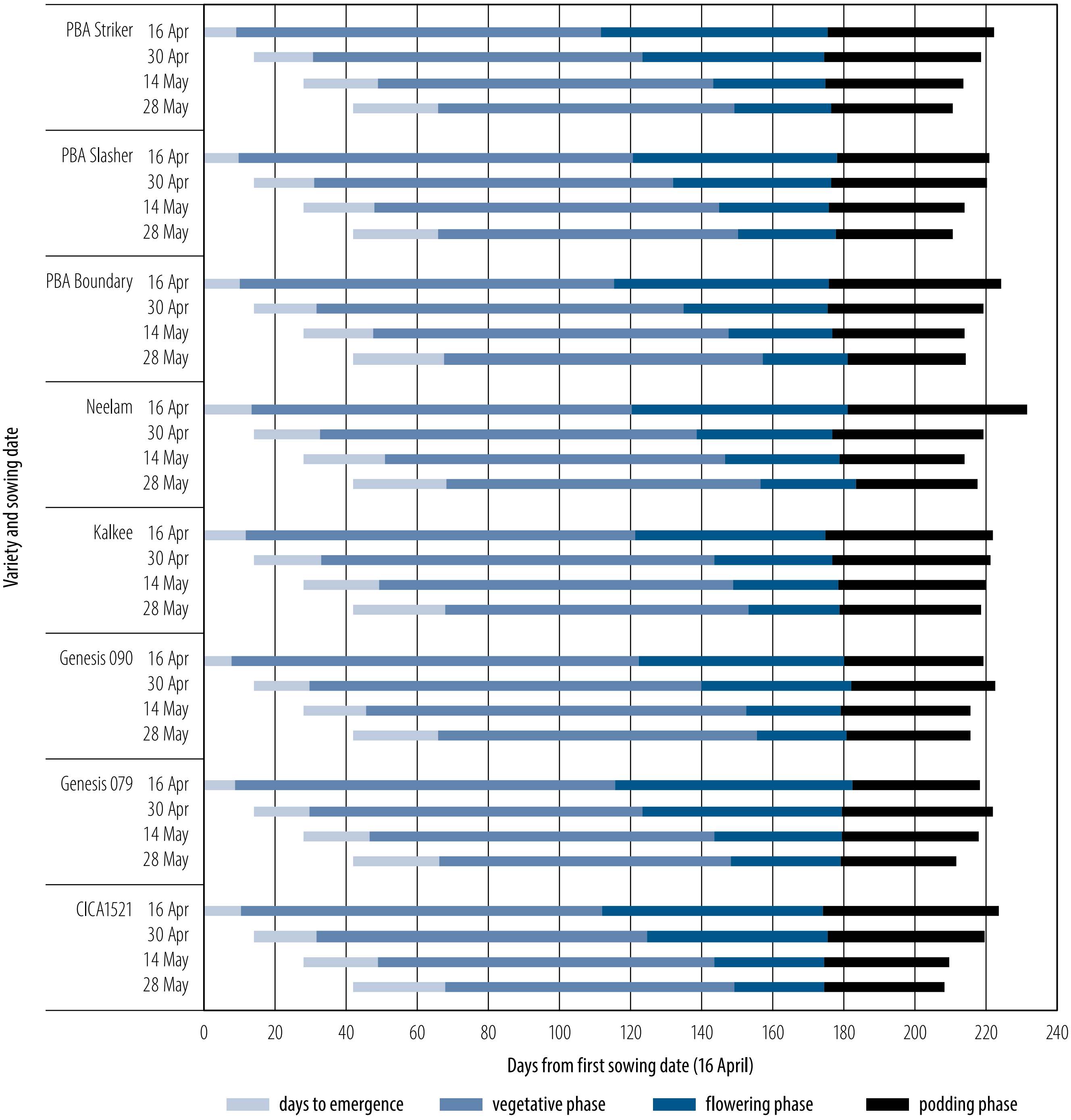

Figure 1. Chickpea variety growth stage duration; sown in 2018 at Leeton.

### Yield, yield components, harvest index and harvest biomass

- Yield ranged from 1.52 t/ha for Genesis™ 090 (SD2) to 2.85 t/ha for Genesis™ 079 (SD3) (Figure 2).
- The highest average yields came from the mid May sowing (SD3), with a corresponding flowering time of around 115 days after sowing (Figure 3).
- There were different varietal yield responses and interactions with sowing date.
- High grain yield was mainly due to a larger number of seeds and pods per plant, and a larger seed size. High seed number was due to a high proportion of filled pods, or fewer unfilled pods per plant.

Harvest index ranged from 0.25 for PBA Boundary$^{\phi}$ (SD1) to 0.50 for PBA Striker$^{\phi}$ and Genesis™ 079 (SD4). For all varieties, SD1 had the highest harvest biomass and PBA Boundary$^{\phi}$ had the highest biomass averaged across sowing times (Table 1).

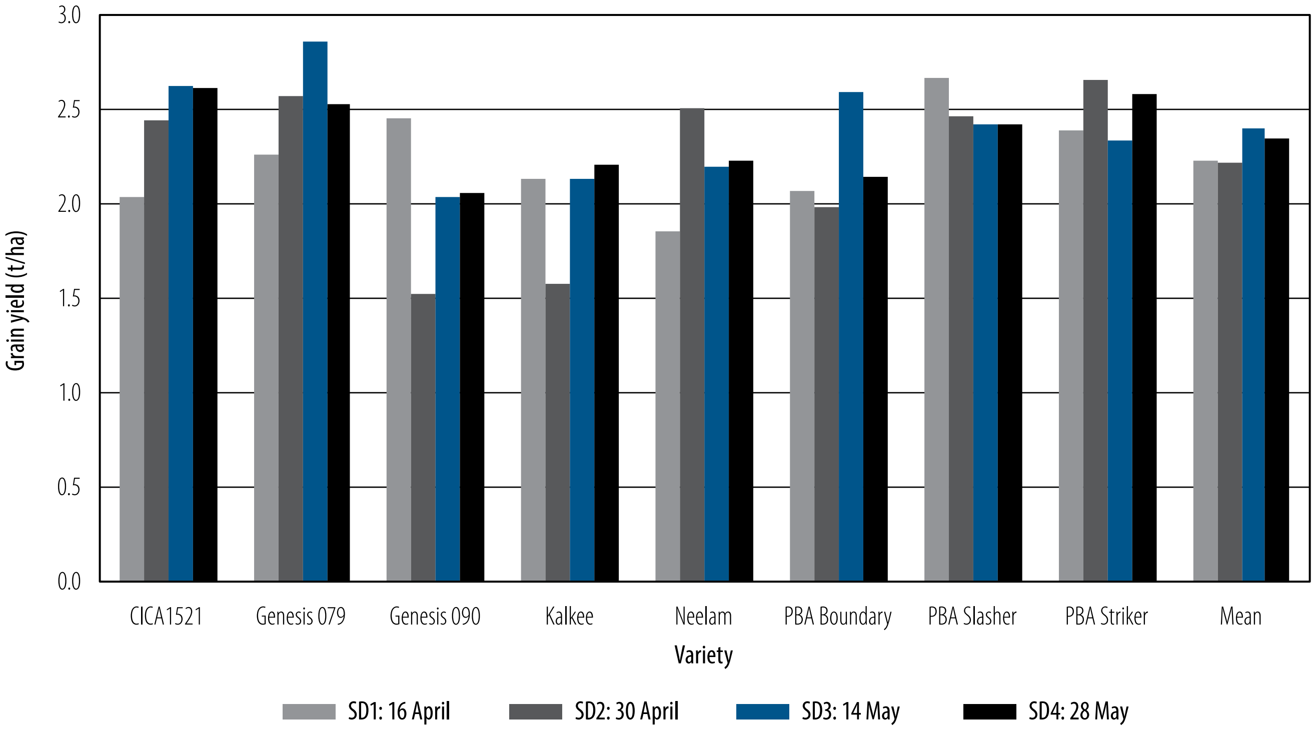

Figure 2. Grain yield of eight chickpea varieties across four sowing dates at Leeton in 2018; l.s.d. ($P = 0.05$) = 0.54 t/ha.

Table 1. Harvest index and biomass at harvest for the four sowing dates at Leeton in 2018.

| Variety | Harvest index (%) | | | | | Harvest biomass (t/ha) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SD1 | SD2 | SD3 | SD4 | Mean | SD1 | SD2 | SD3 | SD4 | Mean |
| CICA1521 | 0.28 | 0.41 | 0.46 | 0.48 | 0.41 | 7.28 | 5.93 | 5.75 | 5.40 | 6.09 |
| Genesis 079 | 0.32 | 0.45 | 0.46 | 0.50 | 0.43 | 7.07 | 5.67 | 6.17 | 4.99 | 5.98 |
| Genesis 090 | 0.33 | 0.34 | 0.40 | 0.44 | 0.38 | 7.39 | 4.41 | 5.12 | 4.60 | 5.38 |
| Kalkee | 0.29 | 0.36 | 0.42 | 0.46 | 0.38 | 7.45 | 4.44 | 5.07 | 4.83 | 5.44 |
| Neelam | 0.29 | 0.43 | 0.45 | 0.48 | 0.41 | 6.59 | 5.78 | 5.01 | 4.58 | 5.49 |
| PBA Boundary | 0.25 | 0.35 | 0.43 | 0.39 | 0.36 | 8.17 | 5.66 | 6.05 | 5.50 | 6.34 |
| PBA Slasher | 0.34 | 0.39 | 0.45 | 0.46 | 0.41 | 7.89 | 6.14 | 5.49 | 5.35 | 6.22 |
| PBA Striker | 0.32 | 0.42 | 0.48 | 0.50 | 0.43 | 7.43 | 6.26 | 4.92 | 5.14 | 5.94 |
| Mean | 0.30 | 0.39 | 0.44 | 0.46 | 0.40 | 7.41 | 5.54 | 5.45 | 5.05 | 5.86 |
| l.s.d ($P<0.05$) | | | | | | | | | | |
| Sowing date | 0.04 | | | | | 1.02 | | | | |
| Variety | 0.03 | | | | | 0.53 | | | | |
| Interaction (sowing date × variety) | n.s. | | | | | n.s. | | | | |

Note: n.s. indicates not significant.

### Effect of temperature on flowering and podding

Low temperatures during flowering and podding affected flower and pod abortion and ultimately yield (Figure 3). Chickpea tends to abort pods at mean daily temperatures below 15 °C.

SD1 had a large number of days with temperatures below 0 °C during flowering and podding. SD2 also had temperatures below 0 °C during the same period.

The influence of mean temperature at the onset of podding is clearly visible in that, regardless of sowing date, all the lines started podding after 31 August when the mean temperature had reached 15 °C.

There were few instances after this date when the mean temperature dropped below this value. This could have led to pod abortion and the observed low yields for Genesis™ 090 (SD2) for example (Figure 3). Thus it is also the effect of individual days with low temperatures, not only the mean temperature that affected flower and pod viability.

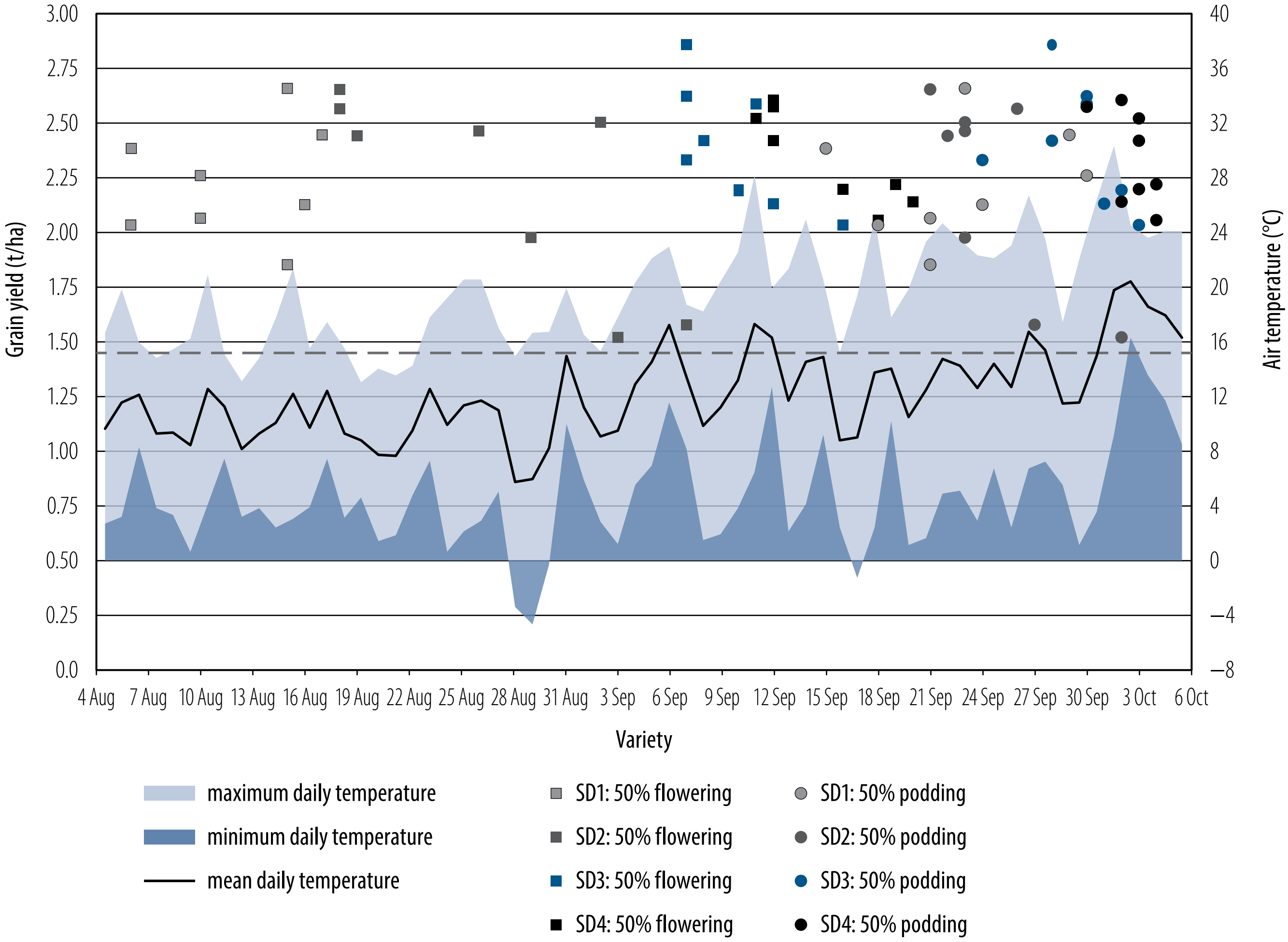

Figure 3. Chickpea yield, flowering and podding response to temperature and sowing date at Leeton 2018. *Note: Same colour denotes the same SD, and squares denote flowering phase while circles denote podding phase. Dashed line indicates pod set threshold (15 °C).*

## Conclusion

While sowing date affected time to emergence, it did not affect plant establishment at Leeton in 2018. Sowing date did not affect yield, but variety did affect yield and there was an interaction between variety and sowing time (genotype by environment). This was driven, to a large extent, by temperatures during flowering and podding, with lower temperatures resulting in flower and pod abortion. However, yield differences between varieties were related to a number of the yield components: number of pods, filled and unfilled pods, seed number and seed weight. Exposure to chilling temperatures for long periods would have led to a high proportion of unfilled pods as seen with SD1.

## References

GRDC GrowNotes™ 2017. *Plant growth and physiology*. Grains Research and Development Corporation, https://grdc.com.au/__data/assets/pdf_file/0020/301646/GRDC-GrowNotes-Chickpeas-WESTERN.pdf, viewed on 4 March 2019.

Whish J 2016. *Accessing and using day degrees in field crops as a tool to assist crop management*. GRDC Update Paper. Grains Research and Development Corporation, https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/accessing-and-using-day-degrees-in-field-crops-as-a-tool-to-assist-crop-management, viewed on 4 March 2019.

## Acknowledgements

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Thank you to Michael Hately and Gabby Napier for field assessments and data collection.

# Chickpea phenology and grain yield response to sowing date – Wagga Wagga 2018

Mark Richards (NSW DPI, Wagga Wagga); Dr Lance Maphosa (NSW DPI, Yanco); Karl Moore and Scott Clark (NSW DPI, Wagga Wagga)

## Key findings

- Varieties have differing optimum sowing dates, with the late April and mid May sowing dates producing higher yields overall.
- Identified sowing date and variety interactions for phenological development, grain yield and harvest index.
- Growing degree days affected time to emergence, with delayed time to emergence as the sowing date was delayed into late autumn.
- Sowing date had no effect on plant establishment.

## Introduction

Identifying the optimum sowing date maximises yield potential by ensuring that critical growth phases such as flowering and podding do not coincide with abiotic stresses such as frost, drought and heat. This experiment aimed to determine the optimum sowing date for chickpea by identifying the phenological drivers of crop development and grain yield. The experiment was conducted at Wagga Wagga, NSW under dryland conditions, but water was applied to ensure crop establishment for the first three sowing dates.

This experiment was part of a series of ongoing experiments sown in central and southern NSW aiming to:

- identify the phenological drivers of chickpea in central and southern NSW
- determine variety response to sowing dates across varying climatic zones
- determine optimal genotype and sowing date combinations.

This paper presents results from the Wagga Wagga site in 2018.

## Site details

| | |
|---|---|
| **Location** | Wagga Wagga Agricultural Institute |
| **Soil type** | Red chromosol |
| **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) |
| **Previous crop** | Barley |
| **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: 5.1 mm – 18 April; 10.5 mm – 26 April<br>SD2: 10.6 mm – 1 May<br>SD3: 7.9 mm – 24 May |
| **Growing season rainfall** | 152.6 mm (1 April 2018–31 October 2018) |

| | |
|---|---|
| **Target plant density** | 40 plants/$m^2$ |
| **Weed management** | Pre-emergent: 900 g/ha Terbyne® Xtreme (875 g/kg terbuthylazine),<br>1.6 L/ha Avadex® Xtra (500 g/L tri-allate), 1.7 L/ha TriflurX® (480 g/L trifluralin), incorporated by sowing (IBS)<br>Post emergent: 300 mL/ha Select® Xtra (360 g/L clethodim),<br>500 mL/ha Uptake™ spraying oil (582 g/L paraffinic oil) |
| **Disease management** | Dithane® (750 g/kg mancozeb) 2.2 kg/ha – 27 June<br>Aviator® Xpro (150 g/L prothioconazole) 600 mL/ha – 14 August |
| **Insect management** | Astound® (100 g/L alpha–cypermethrin) 300 mL/ha – 23 May, 21 September<br>Astral 250EC (250 g/L bifenthrin) 40 mL/ha – 29 September |
| **Harvest date** | Harvest index cuts were taken as varieties reached maturity and machine harvested on 19 November 2018 |

## Treatments

Eight chickpea varieties comprising five desi and three kabuli varieties were sown on four sowing dates.

| | |
|---|---|
| **Desi varieties** | PBA Boundaryⓟ, PBA Strikerⓟ, PBA Slasherⓟ, CICA1521 and Neelamⓟ |
| **Kabuli varieties** | Genesis™ 079, Genesis™ 090 and Kalkee |
| **Sowing date (SD)** | SD1: 16 April 2018<br>SD2: 30 April 2018<br>SD3: 14 May 2018<br>SD4: 28 May 2018 |

## Results

### Growth phase duration

Time to emergence ranged from six days to 27 days and was longer when sowing was delayed (Figure 1). Chickpea requires a minimum threshold of approximately 115 growing degree days (GDD) to emerge (Whish 2016; GRDC GrowNotes™ 2017). The progressive delay in sowing time from SD1 to SD4 ensured that as temperatures dropped during autumn and accumulation of GDD decreased, crop emergence was delayed.

Significant interaction was observed between variety and sowing date for vegetative, flowering and podding phase durations. Vegetative, flowering and podding phase durations decreased significantly as sowing date was delayed from SD1 to SD4 (Figure 1). Earlier flowering time for SD1 and SD2 treatments resulted in more exposure to frosts and therefore flower abortion than SD3 and SD4. Lower yield observed in SD1 can be partly attributed to the high number of unfilled pods resulting from frost exposure. Days to flowering ranged from 111 days to 150 days.

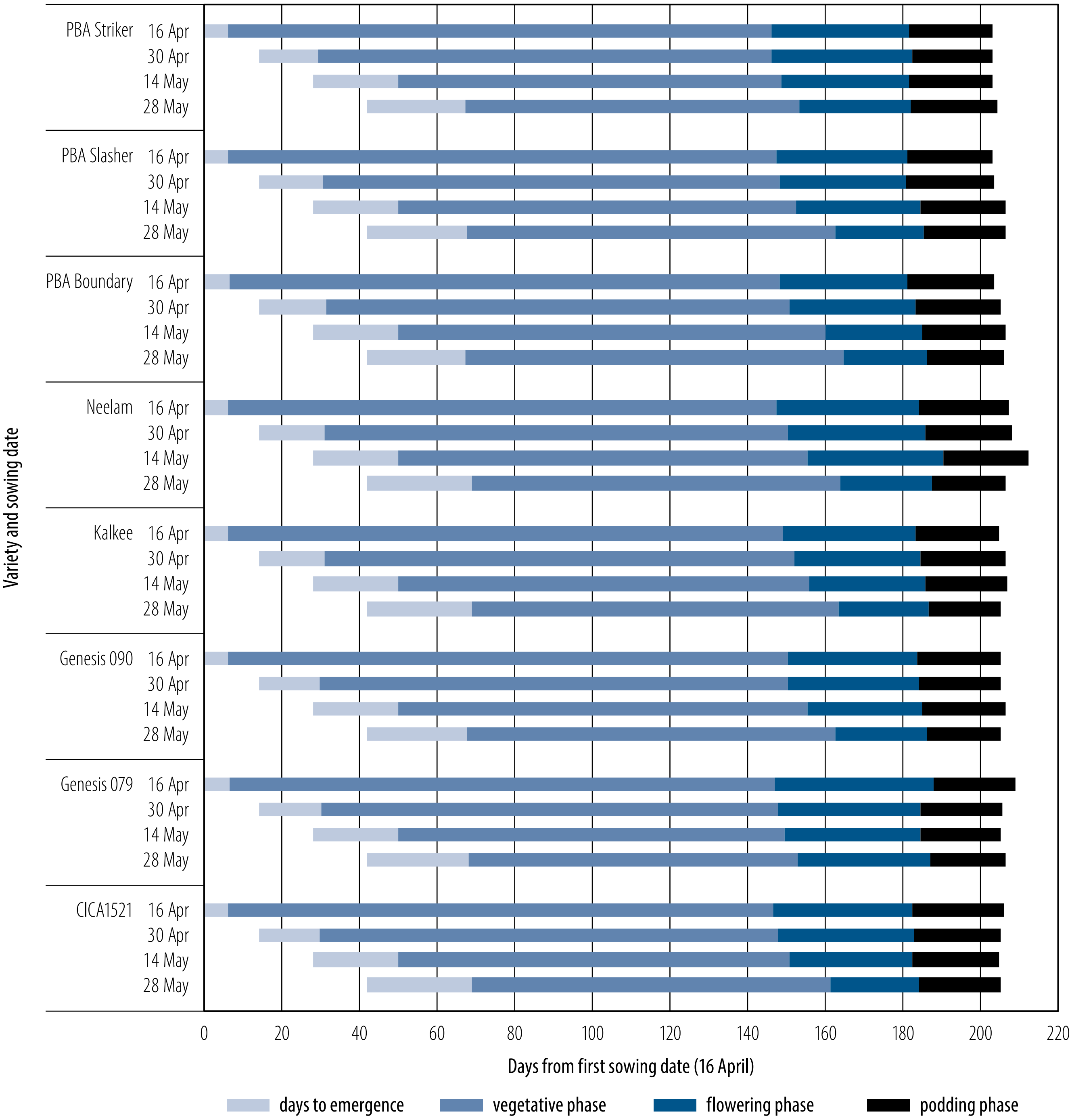

Figure 1. Duration of growth stages of eight chickpea varieties sown on four dates at Wagga Wagga in 2018.

### Grain yield, yield components, harvest index and harvest biomass

Grain yield ranged from 0.97 t/ha for Kalkee (SD4) to 1.57 t/ha for PBA Striker⍉ (SD3) (figures 2 and 3). The highest yield resulted from SD2 and SD3, with a corresponding flowering time of around 120 days after sowing (Figure 2). Varietal response differed with interactions with sowing date and grain yield observed. High grain yield was mainly due to a larger number of seeds and pods per plant, and a larger seed size.

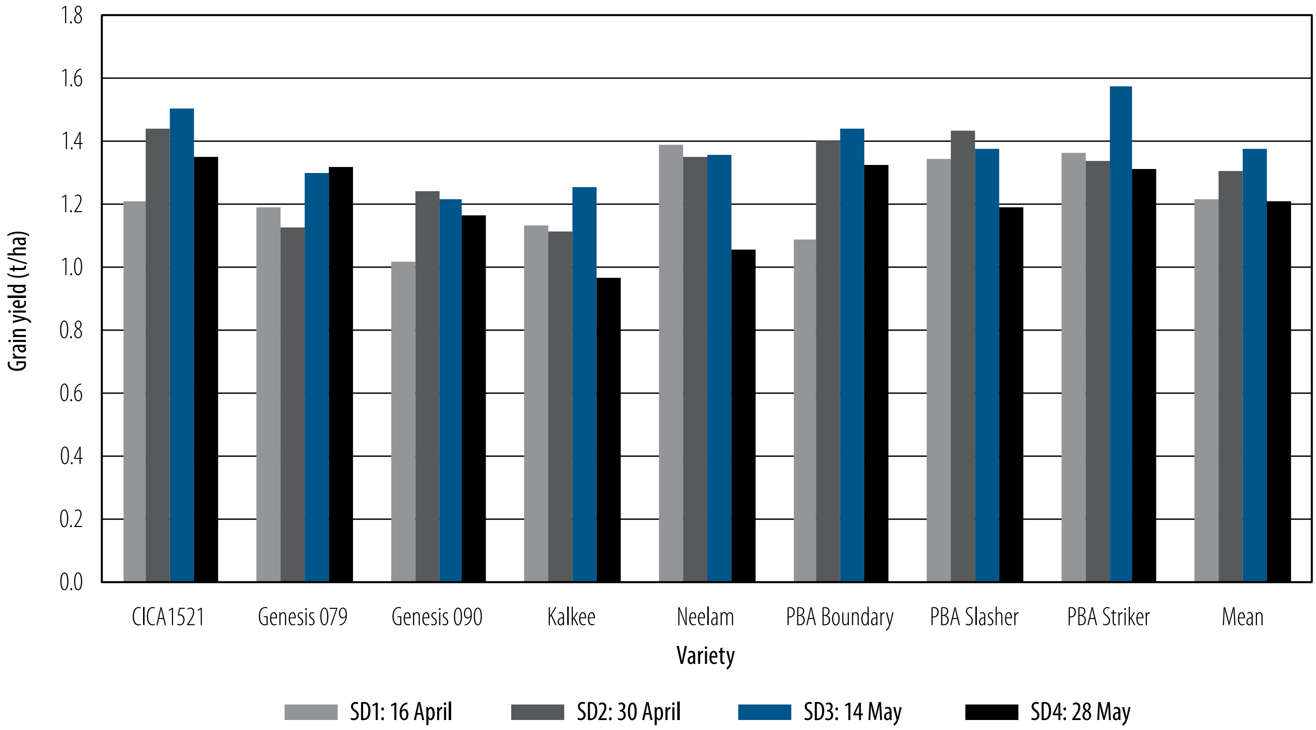

Figure 2. Grain yield of eight chickpea varieties for four sowing dates at Wagga Wagga in 2018; l.s.d. (*P* = <0.017) = 0.22 t/ha.

Harvest index increased with sowing date from 0.29 for PBA Boundary$^{\Phi}$ (SD1) to 0.56 for Genesis™ 079 (SD4). Biomass at harvest decreased as sowing was delayed, with PBA Boundary$^{\Phi}$ and CICA1521 having the highest biomass (3.33 t/ha and 3.32 t/ha respectively) when averaged across sowing dates (Table 1).

Table 1. Harvest index and biomass at harvest of chickpeas sown on four sowing dates at Wagga Wagga in 2018.

| **Variety** | **Harvest index (%)** | | | | | **Harvest biomass (t/ha)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **SD1** | **SD2** | **SD3** | **SD4** | **Mean** | **SD1** | **SD2** | **SD3** | **SD4** | **Mean** |
| CICA1521 | 0.31 | 0.39 | 0.49 | 0.54 | 0.43 | 3.94 | 3.72 | 3.11 | 2.51 | 3.32 |
| Genesis 079 | 0.36 | 0.40 | 0.49 | 0.56 | 0.45 | 3.31 | 2.78 | 2.63 | 2.35 | 2.77 |
| Genesis 090 | 0.32 | 0.38 | 0.45 | 0.49 | 0.41 | 3.21 | 3.27 | 2.73 | 2.38 | 2.90 |
| Kalkee | 0.33 | 0.38 | 0.45 | 0.46 | 0.40 | 3.44 | 2.95 | 2.79 | 2.11 | 2.82 |
| Neelam | 0.42 | 0.46 | 0.49 | 0.52 | 0.47 | 3.31 | 2.91 | 2.79 | 2.02 | 2.75 |
| PBA Boundary | 0.29 | 0.39 | 0.44 | 0.48 | 0.40 | 3.70 | 3.65 | 3.24 | 2.75 | 3.33 |
| PBA Slasher | 0.37 | 0.43 | 0.49 | 0.52 | 0.45 | 3.65 | 3.36 | 2.82 | 2.28 | 3.03 |
| PBA Striker | 0.40 | 0.42 | 0.50 | 0.55 | 0.47 | 3.41 | 3.16 | 3.13 | 2.40 | 3.02 |
| Mean | 0.35 | 0.41 | 0.48 | 0.51 | 0.44 | 3.49 | 3.22 | 2.90 | 2.35 | 2.99 |
| l.s.d (*P*<0.05) | | | | | | | | | | |
| Sowing date | 0.04 | | | | | 0.30 | | | | |
| Variety | 0.02 | | | | | 0.19 | | | | |
| Interaction (sowing date × variety) | 0.05 | | | | | n.s. | | | | |

Note: n.s. indicates not significant

### Effect of temperature on flowering and podding

Low temperatures during flowering and podding affected flower and pod abortion and, ultimately, yield (Figure 3). SD1 had a large number of days with temperatures below 0 °C during flowering and podding. SD2 also had temperatures below 0 °C during flowering and early podding. Chickpea aborts pods at chilling temperatures below 15 °C. Temperatures rose above 15 °C from 2 October causing all cultivars, regardless of sowing date, to start podding. On average, the mean temperatures during podding were higher than 15 °C, but the effect of low temperatures on individual days was also important.

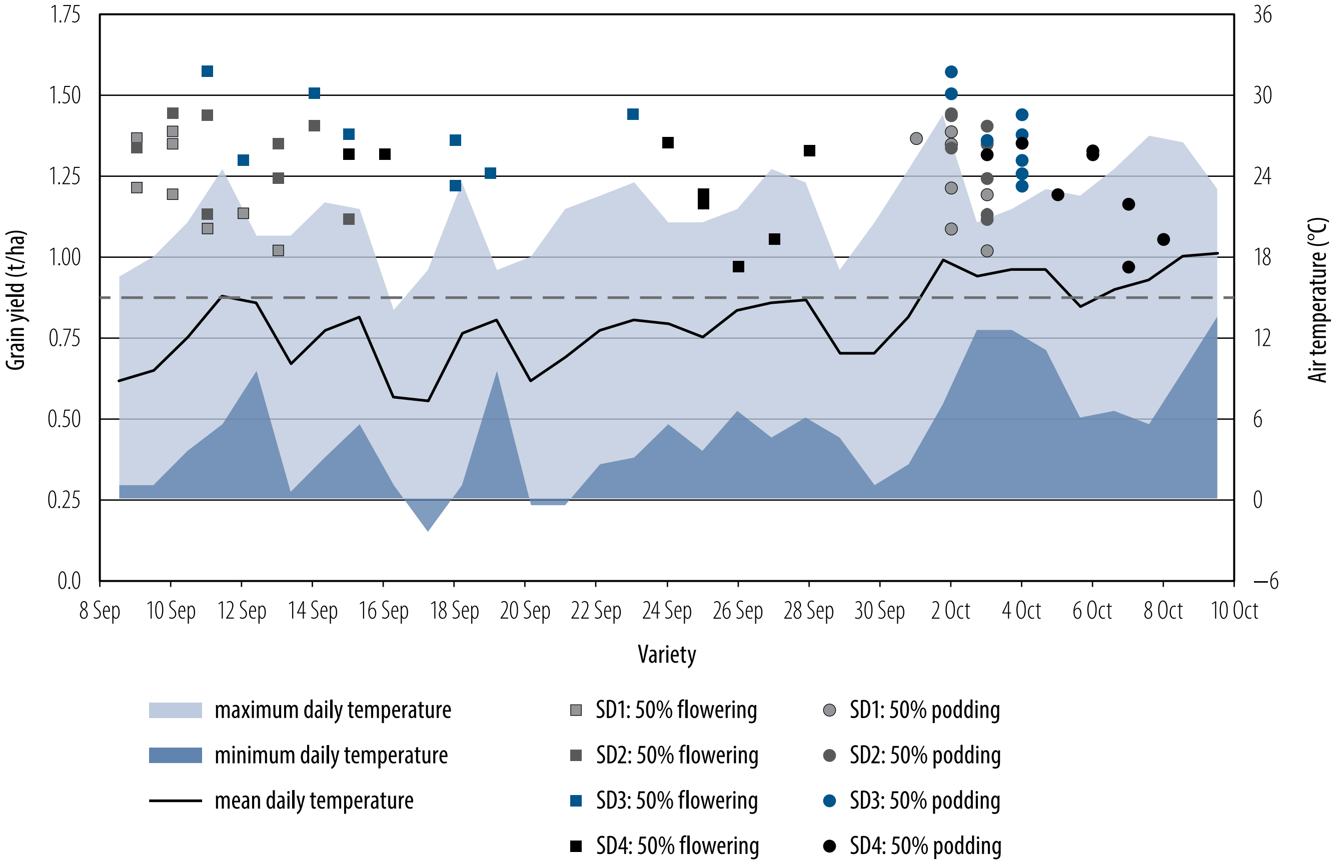

Figure 3. Chickpea grain yield, flowering and podding response to temperature and sowing date at Wagga Wagga in 2018.
*Note: Same colour denotes the same SD, and squares denote flowering phase while circles denote podding phase.*
*Dashed line indicates pod set threshold (15 °C).*

Due to the dry seasonal conditions, disease infection was insignificant in this experiment with severe frosts and moisture stress having a more significant effect on grain yield.

## Conclusion

Despite an unfavourable growing season at Wagga Wagga in 2018, chickpea grain yields ranged from 0.97 t/ha for Kalkee (SD4) to 1.57 t/ha for PBA Striker$^{\Phi}$ (SD3). The highest grain yield averaged across varieties came from the late April (SD2) and mid May (SD3) sowing dates at 1.31 t/ha and 1.38 t/ha respectively. Temperature during flowering and podding were identified as major drivers of phenological response, with lower temperatures resulting in flower and pod abortion at the mid April (SD1) sowing. While lower temperatures produced a significant delay in emergence for SD3 and SD4, they did not affect plant establishment and density. A number of yield components such as the number of pods, filled and unfilled pods, seed number and seed weight per plant were identified as influencing overall yield.

## References

GRDC GrowNotes™ 2017. *Plant growth and physiology*. Grains Research and Development Corporation, https://grdc.com.au/__data/assets/pdf_file/0020/301646/GRDC-GrowNotes-Chickpeas-WESTERN.pdf, viewed on 4 March 2019.

Whish J 2016. *Accessing and using day degrees in field crops as a tool to assist crop management*. GRDC Update Paper, Grains Research and Development Corporation, https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/accessing-and-using-day-degrees-in-field-crops-as-a-tool-to-assist-crop-management, viewed on 4 March 2019.

## 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–June 2020, a joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

Thank you to Nelson West, Ollie Owen, Jim Fairall and Jessica Simpson, for technical assistance and Dr Maheswaran Rohan for biometrical support.

# Lentil phenology and grain yield response to sowing date – Yanco 2018

Tony Napier, Dr Lance Maphosa and Daniel Johnston (NSW DPI, Yanco); Mark Richards (NSW DPI, Wagga Wagga)

## Key findings

- The low mean yield (1.11 t/ha) at this site was largely attributed to low starting soil water and only 87 mm of in-crop rainfall.
- There are differing optimum sowing dates for different varieties, with the mid May sowing date producing higher yields overall.
- While variety and sowing date affected grain yield and harvest index, there was no interaction between these factors at this site.

## Introduction

Identifying the optimum sowing date maximises yield potential by ensuring that critical growth phases such as flowering and podding do not coincide with abiotic stresses such as frost, drought and heat. The aim of this experiment was to determine the optimum sowing date for lentil by identifying the phenological drivers of crop development and grain yield. The experiment was conducted at Yanco, NSW under dryland conditions, but water was applied to ensure crop establishment and later in the season to maintain the experiment in extreme drought conditions.

This experiment was part of a series of ongoing experiments sown in central and southern NSW aiming to:

- identify the phenological drivers of lentil in central and southern NSW
- determine variety response to sowing dates across varying climatic zones
- determine optimal genotype and sowing date combinations.

This paper presents results from the Yanco site in 2018.

## Site details

| | |
|---|---|
| **Location** | Yanco Agricultural Institute |
| **Soil type** | Brown chromosol |
| **Soil $pH_{Ca}$** | 6.0 (0–10 cm) |
| **Previous crop** | Fallow |
| **Target plant density** | 120 plants/$m^2$ |
| **Mineral nitrogen (N)** | 109 kg N/ha (0–60 cm) |
| **Fertiliser** | Energiser Plus at 80 kg/ha (N 13.5: phosphorus [P] 13.5: potassium [K] 0.0: sulfur [S] 9.5) |
| **Pre-sowing watering** | 77 mm applied with overhead sprinkler from 20 March 2018 to 19 April 2018 |
| **In-crop watering** | 10 mm applied with dripper tubes immediately after sowing<br>64 mm applied with overhead sprinkler from 23 August 2018 to 24 September 2018 |

| | |
|---|---|
| **Growing season rainfall** | 87 mm (1 April 2018–31 October 2018) |
| **Pre-emergent herbicides** | 2 L/ha of Rifle® (440 g/L pendimethalin), 1.8 L/ha of Avadex® (500 g/L tri-allate) and 0.6 kg/ha of Terbyne Xtreme® (875 g/kg terbuthylazine) immediately before each sowing date |
| **Post emergent herbicides** | Two applications of Verdict® (520 g/L haloxyfop) at 100 mL/ha (25 May and 3 June)<br>One application of Status® (240 g/L clethodim) at 500 mL/ha (3 June) |
| **Fungicides** | Three applications of Dithane® (750 g/kg mancozeb) at 2.2 kg/ha (7 June, 5 July and 28 August)<br>Two applications of Bravo® (720 g/L chlorothalonil) at 1 L/ha (23 July and 2 August)<br>One application of Cheers® (720 g/L chlorothalonil) at 1.4 L/ha (10 September) |
| **Insecticides** | One application of Decis® (27.5 g/L deltamethrin) at 500 mL/ha (4 October) |

## Treatments

Eight lentil varieties were sown on four sowing dates.

| | |
|---|---|
| **Lentil varieties** | PBA Ace$^{\Phi}$, PBA Blitz$^{\Phi}$, PBA Bolt$^{\Phi}$, PBA Greenfield$^{\Phi}$, PBA Hallmark XT$^{\Phi}$, PBA Hurricane XT$^{\Phi}$, PBA Jumbo2$^{\Phi}$ and Nipper$^{\Phi}$ |
| **Sowing date (SD)** | SD1: 16 April 2018<br>SD2: 30 April 2018<br>SD3: 14 May 2018<br>SD4: 28 May 2018 |

## Results

### Growth phase duration

The total growing time reduced as sowing was delayed. Days to emergence increased from seven days for SD1 to 14 days for SD2 and SD3, and then decreased again to 11 days for SD4 in response to temperature variation (Figure 1). Lentil requires a minimum soil temperature of 5 °C to emerge (GRDC GrowNotes™ 2017). In general the vegetative, flowering and podding phase durations were longest in the early-sown treatment and decreased as sowing was delayed. The longer flowering and podding phases meant that the early-sown treatments had a higher exposure to frosts than those that were sown later. The low yield observed from SD1 can be partly attributed to the high number of unfilled pods per plant due to frost exposure.

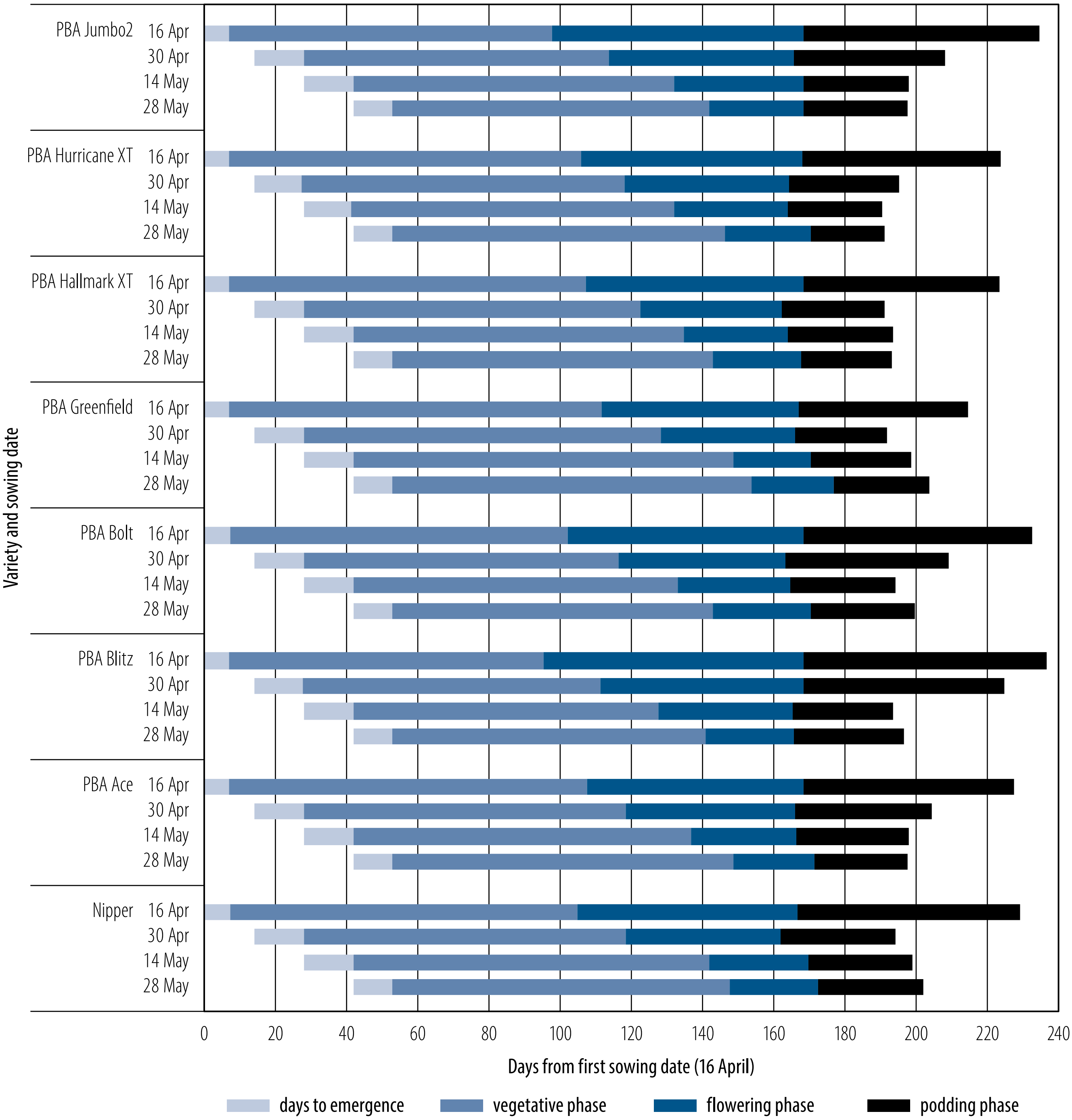

Figure 1. Duration of growth stages of eight lentil varieties sown on four dates at Yanco, 2018.

### Grain yield, yield components and harvest index

Mean grain yield of varieties ranged from 0.76 t/ha from SD1 to 1.40 t/ha from SD3 (Figure 2), while across sowing dates it ranged from 0.76 t/ha for PBA Greenfield$^{\phi}$ to 1.32 t/ha for PBA Bolt$^{\phi}$ (Table 1). The highest yield was obtained from SD3, with a corresponding flowering time of around 105 days after sowing (Figure 3). However, some varieties also had high yields from SD4 (PBA Bolt$^{\phi}$ and PBA Hallmark XT$^{\phi}$) and SD2 (Nipper$^{\phi}$ and PBA Bolt$^{\phi}$) (Figure 3). There were different varietal responses but no interactions between variety and sowing date for yield. Where the grain yield was higher, it was mainly due to a larger number of seeds and pods per plant, and a larger seed size.

Averaged across sowing dates, the mean harvest index increased from 0.26 for PBA Greenfield$^{\phi}$ to 0.36 for PBA Bolt$^{\phi}$, but there was no effect from sowing date or variety on the final harvest biomass mean (Table 1).

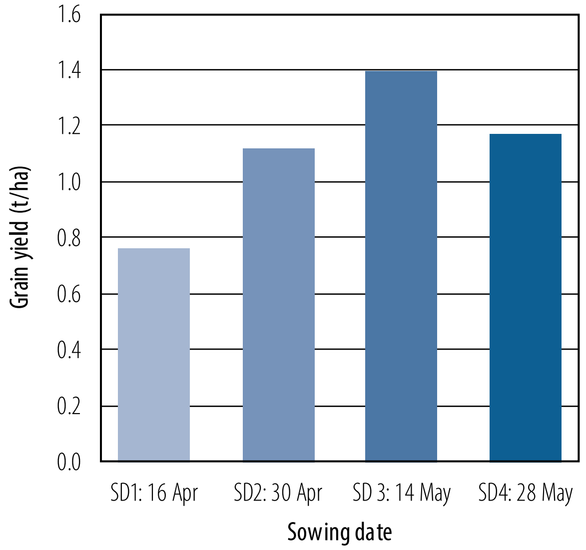

Figure 2. Grain yield of lentils sown on four dates meaned over eight varieties at Yanco, 2018; l.s.d. ($P<0.001$) = 0.23 t/ha.

Table 1. Mean variety grain yield (t/ha) and harvest index across four sowing dates at Yanco in 2018.

| Variety | Grain yield (t/ha) | Harvest index (%) |
|---|---|---|
| PBA Hallmark XT | 1.16 | 0.33 |
| Nipper | 1.26 | 0.33 |
| PBA Ace | 1.09 | 0.29 |
| PBA Blitz | 0.87 | 0.29 |
| PBA Bolt | 1.32 | 0.36 |
| PBA Greenfield | 0.76 | 0.26 |
| PBA Hurricane XT | 1.19 | 0.34 |
| PBA Jumbo2 | 1.25 | 0.34 |
| Mean | 1.11 | 0.32 |
| l.s.d ($P<0.05$) | | |
| Sowing date | 0.23 | 0.03 |
| Variety | 0.27 | 0.04 |
| Interaction (sowing date × variety) | n.s. | n.s. |

Note: n.s. indicates not significant.

### Effect of temperature on flowering and podding

Temperatures during flowering and podding affect flower and pod drop, and ultimately yield. SD1 had more days with temperatures below 0 °C during flowering and podding. This might have led to flower and pod drop (Figure 3). SD2 also had temperatures below 0 °C during flowering and early podding. Some varieties from SD3 started flowering just before or during a severe three-day frost in late August, however this did not appear to affect grain yield. The reduced grain yield from SD4, which flowered after the severe frosts, might not have been due to temperature but more likely due to late season moisture and heat stress (Figure 3). Frost damage was observed on plant tissue in all varieties across all sowing dates during the vegetative phase. However, all varieties appeared to recover vegetatively after the severe frosts making it hard to quantify the effect on grain yield.

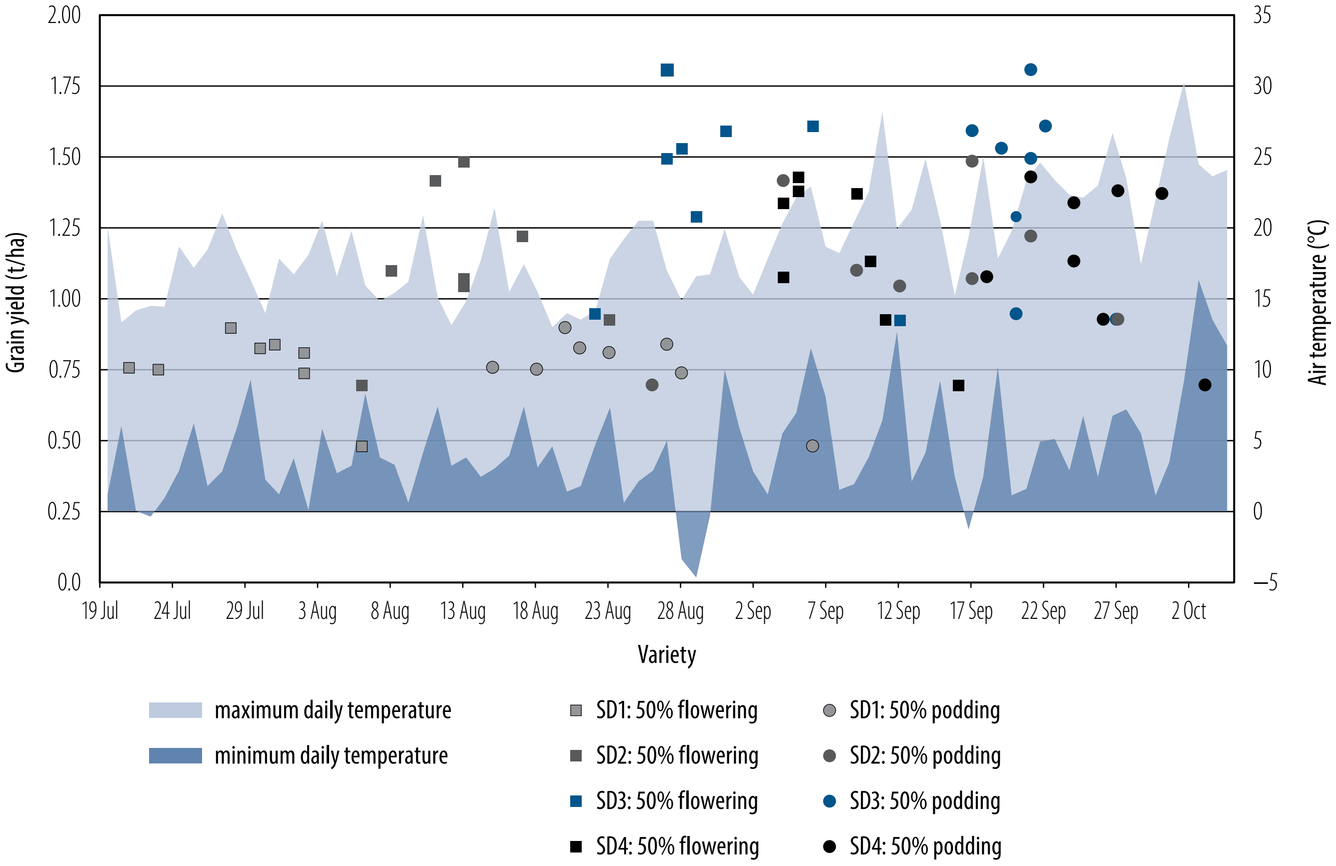

Figure 3. Lentil grain yield, flowering and podding response to temperature and sowing date at Yanco in 2018.
*Note: Same colour denotes the same SD, and squares denote flowering phase while circles denote podding phase.*

## Conclusion

Given a very poor season with only 87 mm of in-crop rainfall supplemented with 74 mm of in-crop watering, lentil still performed well in this dryland environment and produced reasonable yields, with a grain yield of 1.40 t/ha from SD3 averaged across varieties. Limited pre-watering had no effect on establishment and targeted plant density, but did affect overall plant biomass accumulation as the season progressed. In this experiment, SD3 produced the highest grain yield response. This is mainly driven by avoiding very low temperatures during flowering and podding. A number of yield components such as the number of pods, filled and unfilled pods, seed number and seed weight influenced overall yield.

## Reference

GRDC GrowNotes™ 2017. *Plant growth and physiology*. Grains Research and Development Corporation, https://grdc.com.au/__data/assets/pdf_file/0020/243281/GRDC-GrowNotes-Lentil-Southern.pdf, viewed on 4 March 2019.

## 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–June 2020, a joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

Thank you to Michael Hately and Gabby Napier for field assessments and data collection.

# Lentil phenology and grain yield response to sowing date – Leeton 2018

Dr Lance Maphosa, Tony Napier and Daniel Johnston (NSW DPI, Yanco); Mark Richards (NSW DPI, Wagga Wagga)

## Key findings

- The mid May and late May sowing dates produced the highest yields across varieties.
- There was an interaction between sowing date and variety for phenological development, grain yield and harvest index.
- Lentil can be profitably grown on a brown chromosol soil in an irrigated system in the Murrumbidgee Irrigation Area.

## Introduction

Identifying the optimum sowing date maximises yield potential by ensuring that critical growth phases such as flowering and podding do not coincide with abiotic stresses such as frost, drought and heat. This experiment aimed to determine the optimum sowing date for lentil by identifying the phenological drivers of crop development and grain yield. The experiment site, located in Leeton NSW, was flood irrigated before sowing to ensure establishment and to fill the soil profile. Water was applied later in the season to maintain the experiment in extreme drought conditions.

This experiment was part of a series of ongoing experiments sown in central and southern NSW aiming to:

- identify the phenological drivers of lentil in central and southern NSW
- determine variety response to sowing dates across varying climatic zones
- determine the optimal genotype and sowing date combinations.

This paper presents results from the Leeton site in 2018.

## Site details

| | |
|---|---|
| **Location** | Leeton Field Station |
| **Soil type** | Brown chromosol |
| **Soil $pH_{Ca}$** | 6.4 (0–10 cm) |
| **Previous crop** | Barley |
| **Target plant density** | 120 plants/$m^2$ |
| **Mineral nitrogen (N)** | 65 kg N/ha (0–60 cm) |
| **Fertiliser** | No base fertiliser applied |
| **Pre-sowing watering** | 220 mm applied with flood irrigation on 13 March 2018 |
| **In-crop watering** | 10 mm applied with dripper tubes immediately after sowing<br>24 mm applied with overhead sprinkler, 13 September 2018 to 9 October 2018 |
| **Growing season rainfall** | 87 mm (1 April 2018–31 October 2018) |

| | |
|---|---|
| **Weed management** | Pre-emergent: 2 L/ha of Rifle® (440 g/L pendimethalin), 1.8 L/ha of Avadex® (500 g/L tri-allate) and 0.6 kg/ha of Terbyne Xtreme® (875 g/kg terbuthylazine) immediately before each sowing date<br>Post emergent: Two applications of Verdict® (520 g/L haloxyfop) at 100 mL/ha (25 May and 3 June)<br>One application of Status® (240 g/L clethodim) at 500 mL/ha (3 June) |
| **Disease management** | Three applications of Dithane® (750 g/kg mancozeb) at 2.2 kg/ha (7 June, 5 July and 28 August)<br>Two applications of Bravo® (720 g/L chlorothalonil) at 1 L/ha (23 July and 2 August)<br>One application of Cheers® (720 g/L chlorothalonil) at 1.4 L/ha (10 September) |
| **Insect management** | One application of Decis® (27.5 g/L deltamethrin) at 500 mL/ha (4 October) |

## Treatments

Eight lentil varieties were sown on four sowing dates.

| | |
|---|---|
| **Lentil varieties** | PBA Ace$^{\phi}$, PBA Blitz$^{\phi}$, PBA Bolt$^{\phi}$, PBA Greenfield$^{\phi}$, PBA Hallmark XT$^{\phi}$, PBA Hurricane XT$^{\phi}$, PBA Jumbo2$^{\phi}$ and Nipper$^{\phi}$. |
| **Sowing date (SD)** | SD1: 16 April 2018<br>SD2: 30 April 2018<br>SD3: 14 May 2018<br>SD4: 28 May 2018 |

## Results

### Growth phase duration

The total growth duration was shortened as sowing was delayed. Lentil requires a minimum soil temperature of 5 °C to emerge (GRDC GrowNotes™ 2017). Days to emergence increased significantly from SD1 to SD2 and SD3, and then decreased again at SD4 as the daily temperature was starting to decrease (Figure 1).

Vegetative, flowering and podding phase duration were longest in the early-sown treatment (SD1) and decreased as sowing was delayed. The longer flowering and podding phases meant that the early-sown treatment (SD1) had a higher exposure to frosts than those that were sown later (SD2, SD3 and SD4). Averaged across sowing dates, PBA Greenfield$^{\phi}$ was the slowest variety from sowing to flowering at 119 days while PBA Blitz$^{\phi}$ was significantly faster at 107 days (Figure 1).

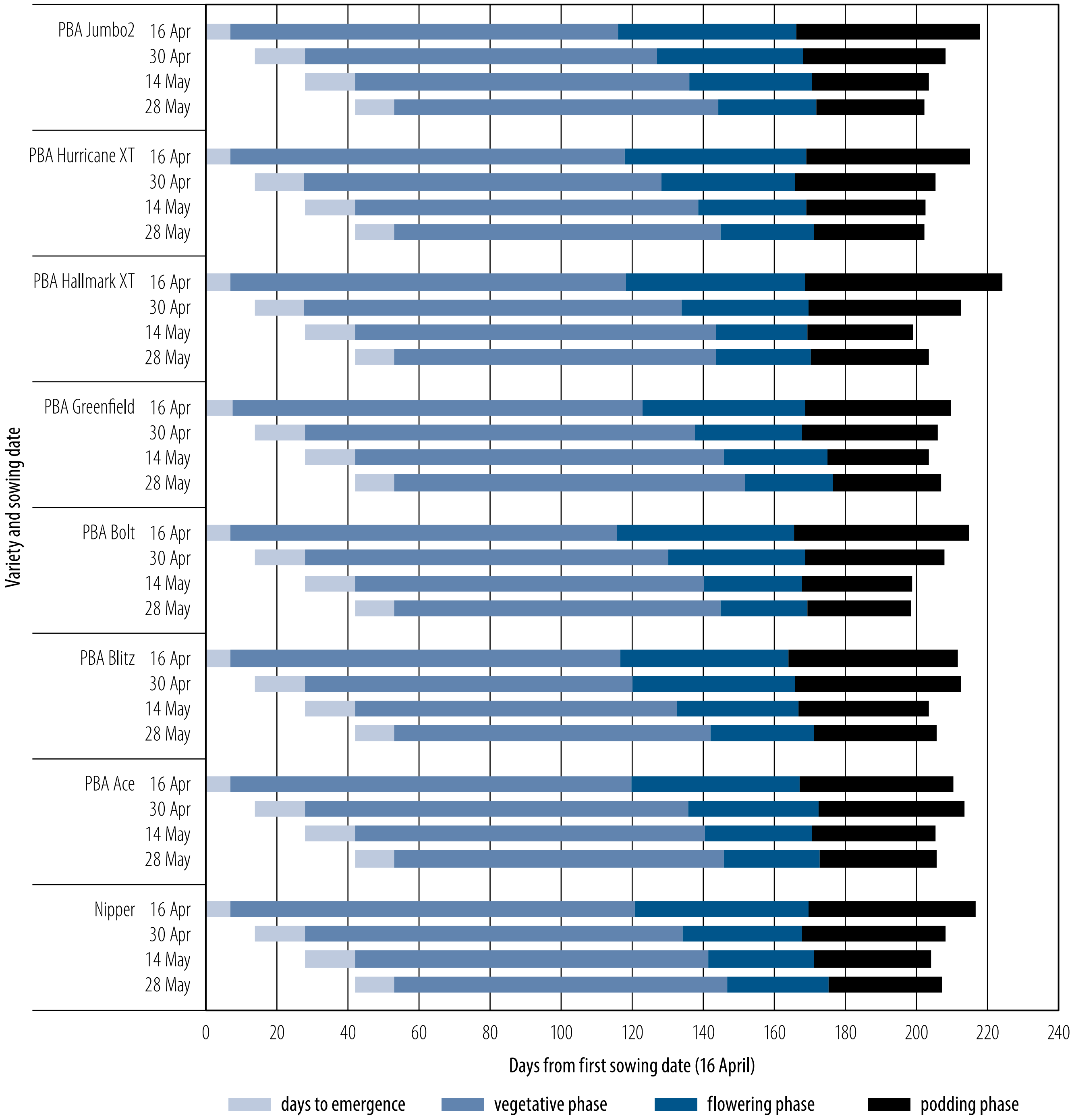

Figure 1. Lentil growth stage duration at Leeton in 2018.

### Grain yield, yield components, harvest index and harvest biomass

- Yields ranged from 0.76 t/ha for PBA Blitz⁽ᶦ⁾ (SD1) to 3.01 t/ha for PBA Bolt⁽ᶦ⁾ (SD2) (Figure 2).
- Except for PBA Bolt⁽ᶦ⁾ at SD2, which was the highest yielding variety at 3.01 t/ha, when averaged across varieties SD3 and SD4 at 2.43 t/ha and 2.36t/ha respectively were significantly higher yielding than either SD1 or SD2. These sowing dates had a corresponding flowering time of around 105–115 days after sowing (Figure 3).
- Some varieties had yields above 2.5 t/ha at SD4 (PBA Bolt⁽ᶦ⁾ and PBA Ace⁽ᶦ⁾) (figures 2 and 3).
- There were different varietal responses and interactions with sowing date for yield.

- The high grain yield was mainly due to a larger number of seeds and pods per plant, and a larger seed size.

Harvest index increased with a later sowing date from 0.12 for PBA Blitz$^{\phi}$ (SD1) to 0.47 for PBA Hallmark XT$^{\phi}$ (SD4); biomass at harvest decreased as sowing was delayed and differed between varieties (Table 1).

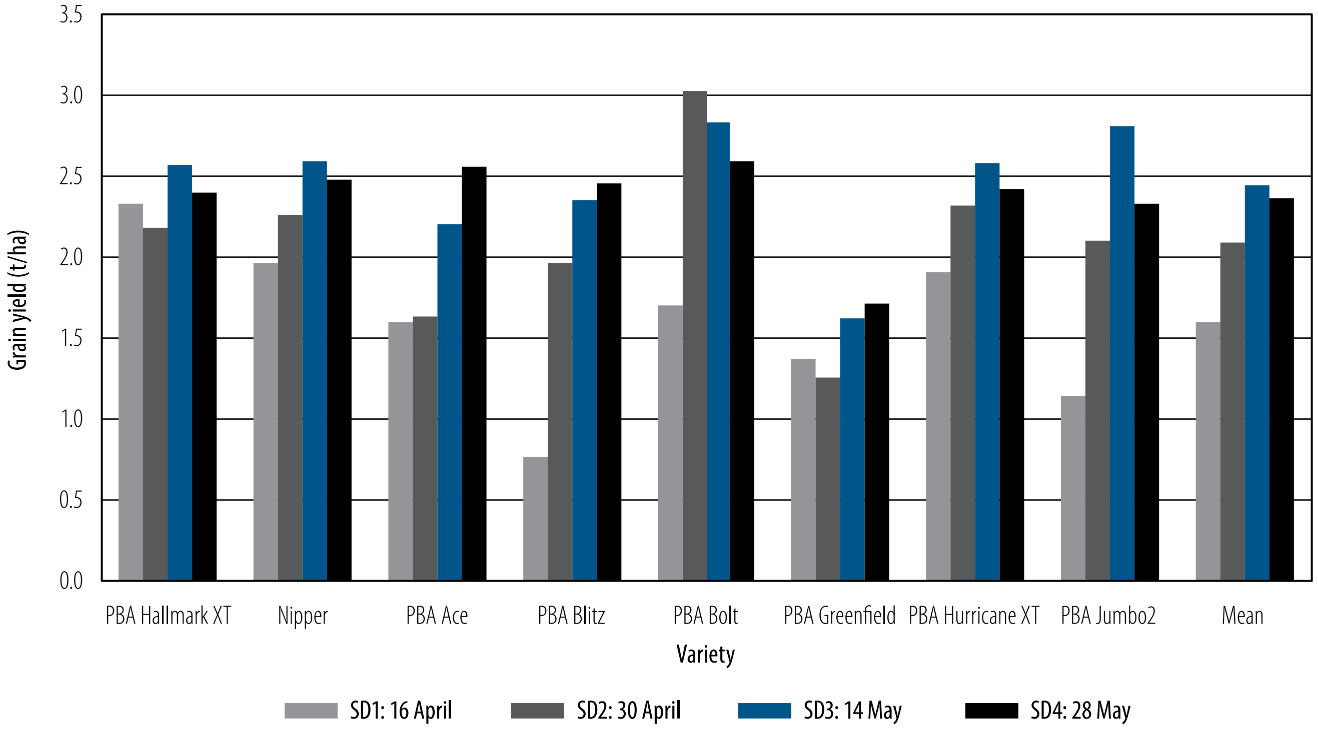

Figure 2. Yield (t/ha) of lentils sown on four sowing dates at Leeton in 2018; l.s.d. ($P = 0.05$) = 0.53 t/ha.

Table 1. Harvest index and biomass at harvest for the four sowing dates at Leeton in 2018.

| **Variety** | **Harvest index (%)** | | | | | **Harvest biomass (t/ha)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **SD1** | **SD2** | **SD3** | **SD4** | **Mean** | **SD1** | **SD2** | **SD3** | **SD4** | **Mean** |
| PBA Hallmark XT | 0.26 | 0.30 | 0.38 | 0.47 | 0.35 | 9.00 | 7.31 | 6.68 | 5.13 | 7.03 |
| Nipper | 0.24 | 0.31 | 0.38 | 0.44 | 0.34 | 8.05 | 7.35 | 6.90 | 5.61 | 6.98 |
| PBA Ace | 0.19 | 0.22 | 0.33 | 0.41 | 0.29 | 8.39 | 7.26 | 6.64 | 6.18 | 7.12 |
| PBA Blitz | 0.12 | 0.33 | 0.40 | 0.45 | 0.33 | 6.54 | 5.88 | 5.85 | 5.41 | 5.92 |
| PBA Bolt | 0.23 | 0.38 | 0.43 | 0.43 | 0.37 | 7.17 | 7.92 | 6.56 | 5.96 | 6.90 |
| PBA Greenfield | 0.20 | 0.22 | 0.32 | 0.40 | 0.29 | 6.58 | 5.53 | 5.09 | 4.25 | 5.36 |
| PBA Hurricane XT | 0.25 | 0.36 | 0.41 | 0.44 | 0.37 | 7.47 | 6.45 | 6.28 | 5.51 | 6.42 |
| PBA Jumbo2 | 0.16 | 0.32 | 0.42 | 0.43 | 0.33 | 7.31 | 6.62 | 6.78 | 5.35 | 6.51 |
| Mean | 0.21 | 0.31 | 0.38 | 0.44 | 0.33 | 7.60 | 6.80 | 6.30 | 5.40 | 6.53 |
| l.s.d ($P<0.05$) | | | | | | | | | | |
| Sowing date | 0.03 | | | | | 0.53 | | | | |
| Variety | 0.03 | | | | | 0.76 | | | | |
| Interaction (sowing date × variety) | 0.06 | | | | | n.s. | | | | |

Note: n.s. indicates not significant.

### Effect of temperature on flowering and podding

Temperatures during flowering and podding affect flower viability, pod abortion and filling and ultimately, lead to unfilled pods and decreased yield. For SD1 and SD2, all varieties flowered before 1 September, a period characterised by low temperatures.

SD1 had a large number of days with temperatures below 0 °C during flowering and podding, which might have led to flower and pod drop. Therefore, the lower yield from SD1 can be partly attributed to the high number of unfilled pods resulting from frost exposure.

There were also temperatures below 0 °C during flowering and early podding at SD2 (Figure 3). However, not just the low mean temperature but individual days with low temperatures could have affected flower and pod viability. Frost damage on vegetative tissues was observed, but the plants recovered thus making it hard to quantify the effect on yield.

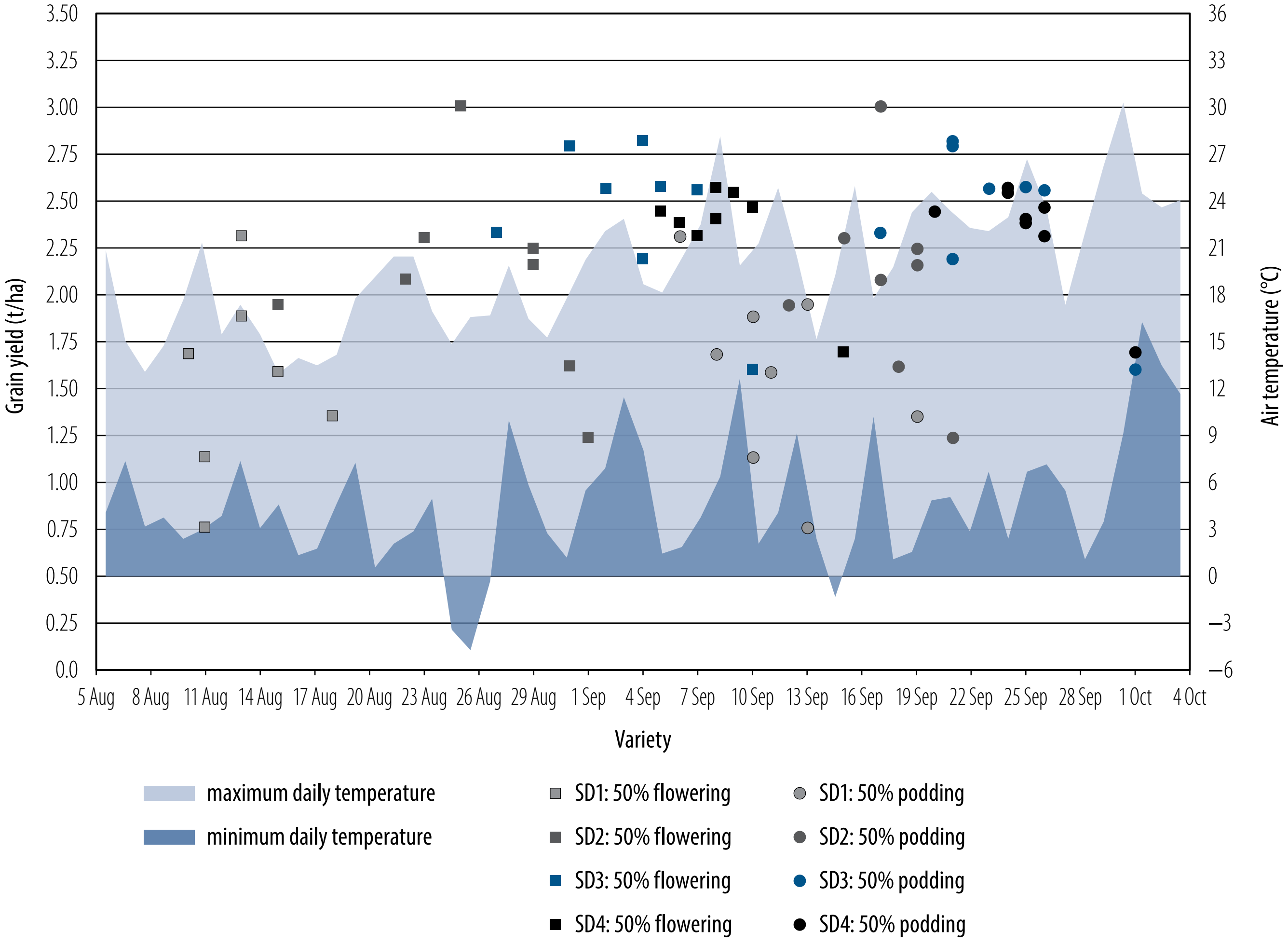

Figure 3: Lentil grain yield, flowering and podding response to temperature and sowing date at Leeton in 2018.
*Note: Same colour denotes the same sowing date, and squares denote flowering phase while circles denote podding phase.*

## Conclusion

While lentil performed well under the tough seasonal conditions it benefited significantly from the pre-sowing watering. This enabled effective establishment and high levels of plant biomass accumulation before the reproductive stage. In this experiment, the mid to late May sowing dates (SD3 and SD4) showed the highest grain yield response. The mid to late April sowing dates (SD1 and SD2) were lower yielding due to the negative interaction between the genotypes and severe cold temperatures during the reproductive phase. Also, the high biomass levels in the early April (SD1) sowing, combined with the dry spring conditions, resulted in exposure to higher levels of moisture stress during pod fill. A number of yield components such as the number of pods, filled and unfilled pods, seed number and seed weight influenced yield.

## Reference

GRDC GrowNotes™ 2017. *Plant growth and physiology*. Grains Research and Development Corporation, https://grdc.com.au/__data/assets/pdf_file/0020/243281/GRDC-GrowNotes-Lentil-Southern.pdf, viewed on 4 March 2019.

## 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–June 2020, a joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

Thank you to Michael Hately and Gabby Napier for field assessments and data collection.

# Lentil phenology and grain yield response to sowing date – Wagga Wagga 2018

Mark Richards (NSW DPI, Wagga Wagga); Dr Lance Maphosa (NSW DPI, Yanco); Karl Moore and Scott Clark (NSW DPI, Wagga Wagga)

## Key findings

- An unfavourable growing season in 2018 has shown there are differing optimum sowing dates for different varieties, with late April and mid May sowing producing the highest and similar grain yield overall.
- Significant interaction was found with sowing date and variety for phenological development, grain yield and harvest index.
- Average yield at this site was 1.45 t/ha.
- Sowing date impacted the number of viable pods per plant. Lentils sown mid April had significantly more unfilled pods than lentils sown at all later dates due to an interaction between flowering time and frost damage.

## Introduction

Identifying the optimum sowing date maximises yield potential by ensuring that critical growth phases such as flowering and podding do not coincide with abiotic stresses such as frost, drought and heat. This experiment aimed to determine the optimum sowing date for lentil by identifying the phenological drivers of crop development and grain yield. The experiment was conducted at Wagga Wagga, NSW under dryland conditions, with water applied for the first three sowing dates to ensure crop establishment.

This experiment was part of a series of ongoing experiments sown in central and southern NSW aiming to:

- identify the phenological drivers of lentil in central and southern NSW
- determine variety response to sowing dates across varying climatic zones
- determine the optimal genotype and sowing date combinations.

This paper presents results from the Wagga Wagga site in 2018.

## Site details

| | |
|---|---|
| **Location** | Wagga Wagga Agricultural Institute |
| **Soil type** | Red chromosol |
| **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) |
| **Previous crop** | Barley |
| **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: 5.1 mm – 18 April; 10.5 mm – 26 April<br>SD2: 10.6 mm – 1 May<br>SD3: 7.9 mm – 24 May |

| | |
|---|---|
| **Growing season rainfall** | 152.6 mm (1 April 2018 –31 October 2018) |
| **Target plant density** | 120 plants/$m^2$ |
| **Weed management** | Pre-emergent: 900 g/ha Terbyne® Xtreme (875 g/kg terbuthylazine),<br>1.6 L/ha Avadex® Xtra (500 g/L tri-allate), 1.7 L/ha TriflurX® (480 g/L trifluralin), incorporated by sowing (IBS)<br>Post emergent: 300 mL/ha Select® Xtra (360 g/L clethodim),<br>500 mL/ha Uptake™ Spraying oil (582 g/L paraffinic oil) |
| **Disease management** | Dithane® (750 g/kg mancozeb) 2.2 kg/ha – 27 June<br>Aviator® Xpro (150 g/L prothioconazole) 600 mL/ha – 14 August |
| **Insect management** | Astound® (100 g/L alpha-cypermethrin) 300 mL/ha – 23 May, 21 September<br>Astral 250EC (250 g/L bifenthrin) 40 mL/ha – 29 September |
| **Harvest date** | Harvest index cuts were taken as varieties reached maturity; crops were machine harvested on 19 November 2018 |

## Treatments

Eight lentil varieties were sown on four sowing dates.

| | |
|---|---|
| **Lentil varieties** | PBA Ace$^{\phi}$, PBA Blitz$^{\phi}$, PBA Bolt$^{\phi}$, PBA Greenfield$^{\phi}$, PBA Hallmark XT$^{\phi}$, PBA Hurricane XT$^{\phi}$, PBA Jumbo2$^{\phi}$ and Nipper$^{\phi}$ |
| **Sowing date (SD)** | SD1: 16 April 2018<br>SD2: 30 April 2018<br>SD3: 14 May 2018<br>SD4: 28 May 2018 |

## Results

### Growth phase duration

The total growth duration shortened as sowing was delayed. Lentil requires a minimum soil temperature of 5 °C to emerge (GRDC GrowNotes™ 2017). Days to emergence increased from four days (SD1) to 19 days (SD4) as daily temperatures started to decrease in late autumn (Figure 1).

Vegetative, flowering and podding phase durations decreased significantly as sowing date was delayed from mid April (SD1) to late May (SD4) (Figure 1). The timing of flowering and podding phases for mid April (SD1) and late April (SD2) sowings increased plant exposure to frost damage more than mid May (SD3) and late May (SD4) sowings. The low grain yield observed in the mid April sowing (SD1) can be partly attributed to the high number of unfilled pods per plant due to frost exposure. The shorter flowering and podding duration in the late May sowing (SD4), combined with moisture stress, likely had a negative effect on grain yield.

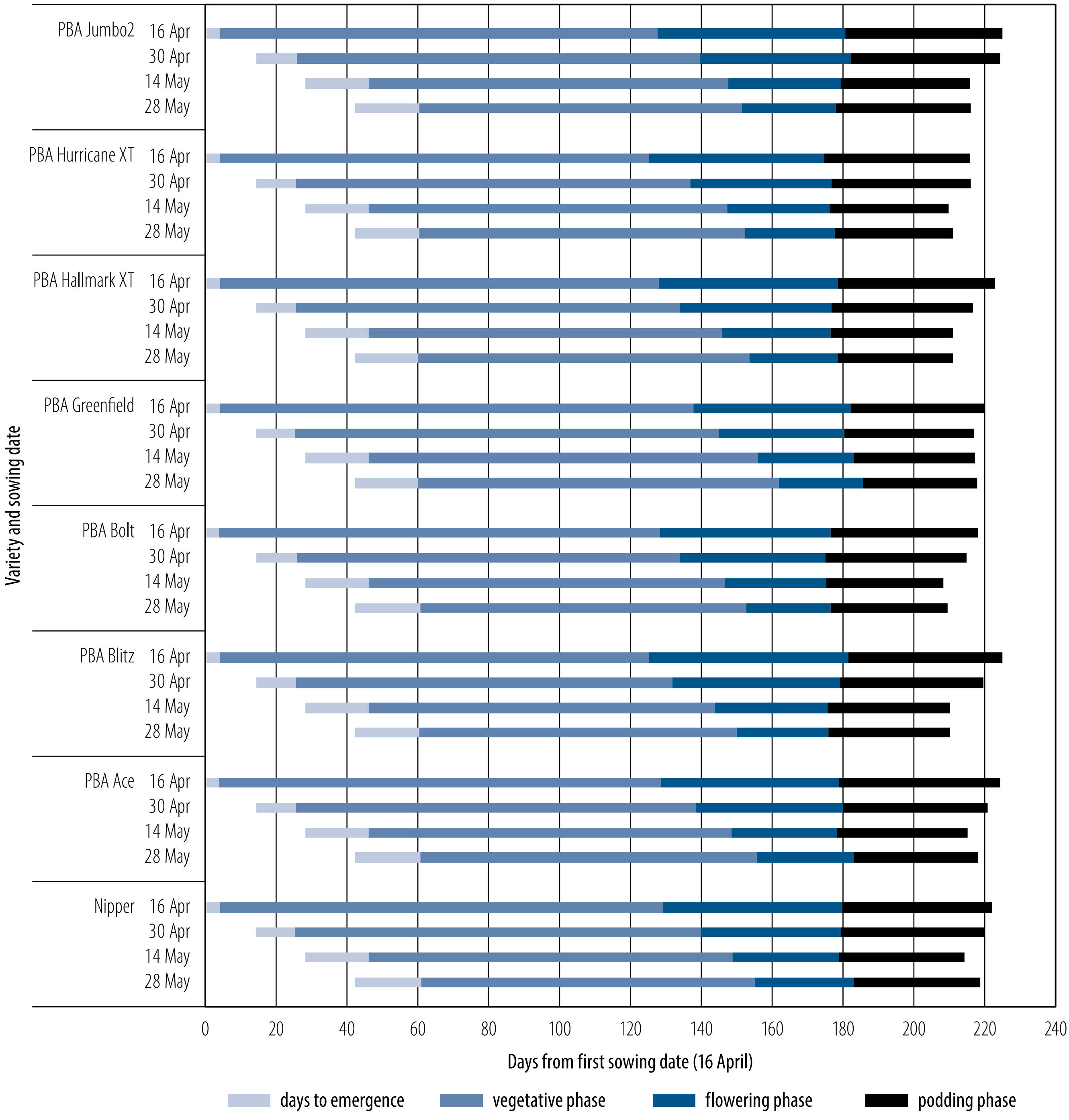

Figure 1. Duration of growth stages of eight lentil varieties sown on four dates at Wagga Wagga in 2018.

### Grain yield, yield components, harvest index and harvest biomass

Significant interactions were observed between variety and sowing date for grain yield, ranging from 1 t/ha for PBA Greenfield$^{\phi}$ (SD4) to 1.68 t/ha for PBA Ace$^{\phi}$ (SD3) (Figure 2). The significantly lower grain yield of PBA Greenfield$^{\phi}$ at SD3 and SD4 can be attributed to its later time to flowering and slower maturity (Figure 3) and thus higher exposure to late season heat and moisture stress in this experiment. The highest grain yields were obtained from the late April (SD2) and mid May (SD3) sowings at 1.51 t/ha and 1.55 t/ha respectively when averaged across varieties, with a corresponding flowering time of around 120–125 days after sowing (Figure 3). Some varieties also had high yields at SD4 (PBA Ace$^{\phi}$ and PBA Hurricane$^{\phi}$ XT) and SD1 (Nipper$^{\phi}$) (Figure 2). The high grain yield was mainly due to a larger number of seeds and pods per plant, and a larger seed size.

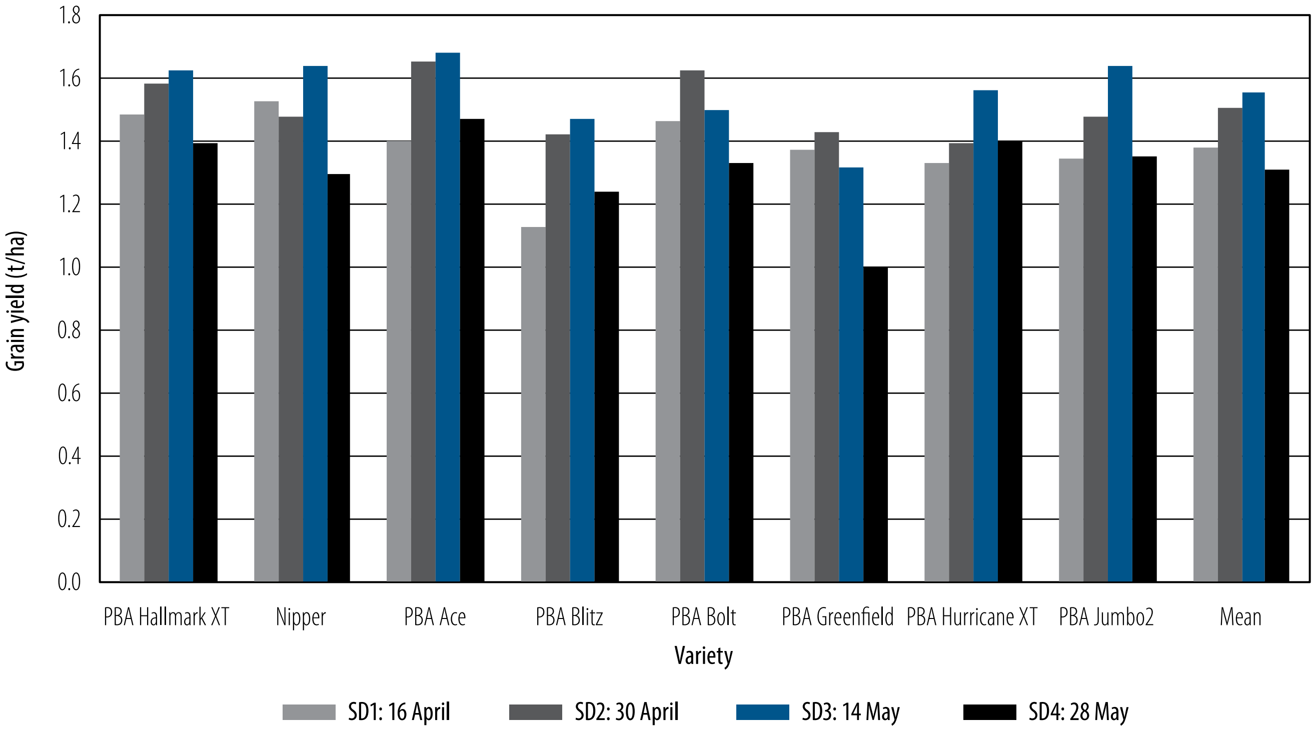

Figure 2. Grain yield of eight lentil varieties sown on four sowing dates at Wagga Wagga, 2018; l.s.d. (*P* = <0.001) = 0.16 t/ha.

There was a significant interaction between variety and sowing date for harvest index. Also, harvest index increased significantly from SD1 to SD4 respectively. Harvest index ranged from 0.31 for PBA Ace$^{\phi}$ (SD1) to 0.54 for PBA Bolt$^{\phi}$ (SD4).

Biomass at maturity decreased significantly with delayed sowing date (Table 1). PBA Ace$^{\phi}$ had the highest biomass at maturity (3.85 t/ha) and PBA Hurricane XT$^{\phi}$ the lowest (3.17 t/ha) averaged across sowing dates.

Table 1. Harvest index and harvest biomass across four sowing dates at Wagga Wagga, 2018.

| **Variety** | **Harvest index (%)** | | | | | **Biomass at maturity (t/ha)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **SD1** | **SD2** | **SD3** | **SD4** | **Mean** | **SD1** | **SD2** | **SD3** | **SD4** | **Mean** |
| PBA Hallmark XT | 0.37 | 0.44 | 0.47 | 0.51 | 0.45 | 3.96 | 3.64 | 3.46 | 2.72 | 3.44 |
| Nipper | 0.40 | 0.43 | 0.46 | 0.52 | 0.45 | 3.84 | 3.42 | 3.58 | 2.51 | 3.34 |
| PBA Ace | 0.31 | 0.41 | 0.44 | 0.49 | 0.41 | 4.49 | 4.08 | 3.83 | 3.00 | 3.85 |
| PBA Blitz | 0.31 | 0.40 | 0.46 | 0.52 | 0.42 | 3.60 | 3.55 | 3.22 | 2.37 | 3.18 |
| PBA Bolt | 0.41 | 0.46 | 0.47 | 0.54 | 0.47 | 3.60 | 3.53 | 3.17 | 2.47 | 3.19 |
| PBA Greenfield | 0.33 | 0.39 | 0.42 | 0.40 | 0.38 | 4.11 | 3.68 | 3.16 | 2.51 | 3.37 |
| PBA Hurricane XT | 0.37 | 0.43 | 0.49 | 0.53 | 0.46 | 3.62 | 3.25 | 3.21 | 2.63 | 3.17 |
| PBA Jumbo2 | 0.33 | 0.40 | 0.45 | 0.51 | 0.42 | 4.03 | 3.73 | 3.68 | 2.64 | 3.52 |
| Mean | 0.36 | 0.42 | 0.46 | 0.50 | 0.43 | 3.90 | 3.61 | 3.41 | 2.61 | 3.38 |
| l.s.d (*P*<0.05) | | | | | | | | | | |
| Sowing date | 0.02 | | | | | 0.23 | | | | |
| Variety | 0.02 | | | | | 0.20 | | | | |
| Interaction (sowing date × variety) | 0.03 | | | | | n.s. | | | | |

Note: n.s. indicates not significant.

Low temperatures during flowering and podding phases affected flower and pod viability and ultimately, grain yield.

SD1 had a large number of days with temperatures below 0 °C during flowering and podding and SD2 also had temperatures below 0 °C (Figure 3).

All varieties sown on SD1, and PBA Blitz⁽ᵖ⁾ sown on SD2 started flowering before a severe three-day frost event between 27 August and 30 August. This event caused flower abortion, but lentil being an indeterminate crop continued to flower. However, the loss of these flowers decreased yield potential and the final yield.

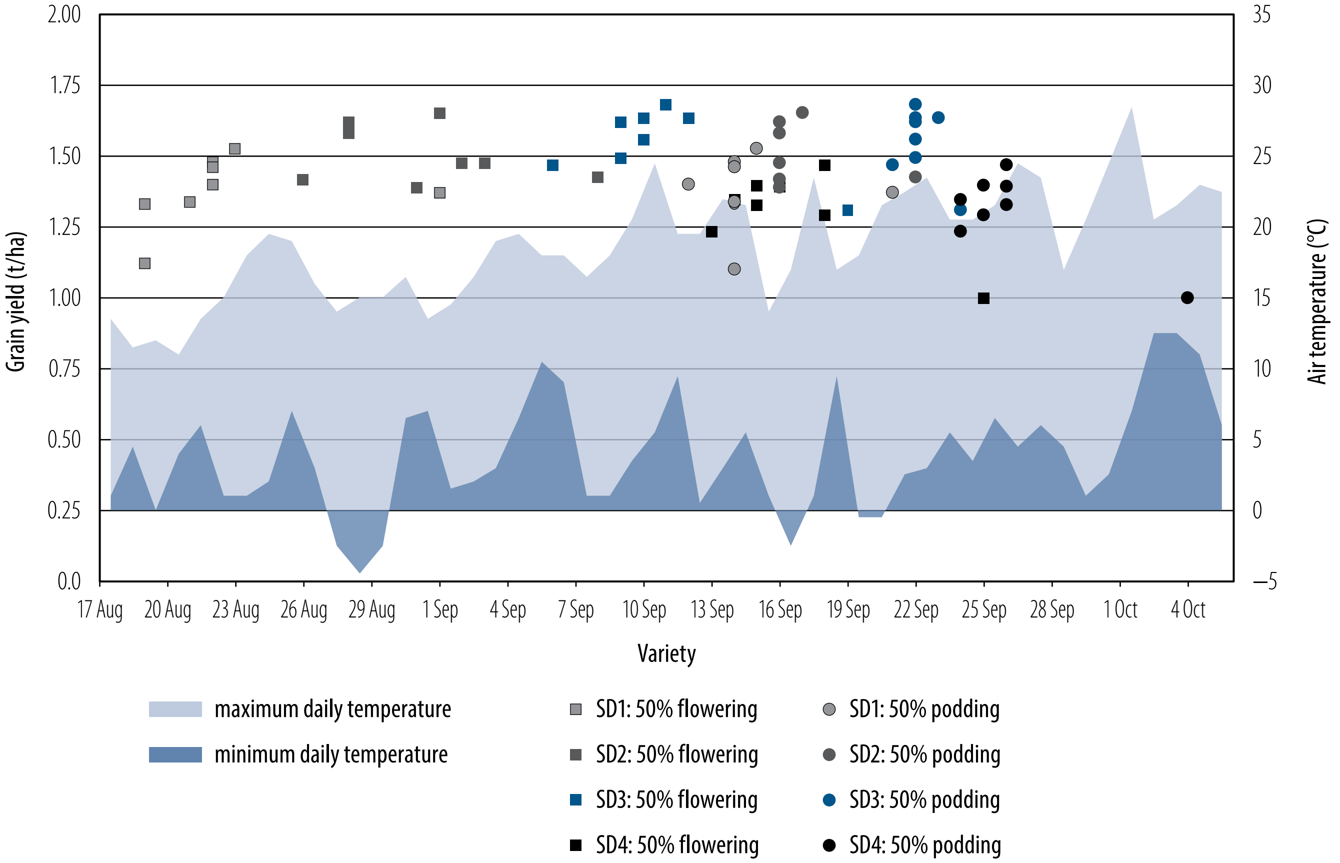

Figure 3. Lentil yield, flowering and podding response to temperature and sowing date at Wagga Wagga in 2018.
*Note: Same colour denotes the same SD, and squares denote flowering phase while circles denote podding phase.*

Due to the dry seasonal conditions, disease infection was not significant in this experiment. Severe frosts and moisture stress interacting with sowing date, variety and phasic development had the most significant effect on grain yield.

## Conclusion

Despite an unfavourable growing season at Wagga Wagga in 2018, lentil grain yields ranged from 1.31 t/ha (SD4) to 1.55 t/ha (SD3) when averaged across varieties. At this site, the 2018 results point to late April and mid May as the best sowing dates. This is largely driven by temperatures and soil moisture levels during flowering and podding which were identified as major drivers of phenological response, with lower temperatures resulting in flower and pod abortion.

## Reference

GRDC GrowNotes™ 2017. *Plant growth and physiology*. Grains Research and Development Corporation, https://grdc.com.au/__data/assets/pdf_file/0020/243281/GRDC-GrowNotes-Lentil-Southern.pdf, viewed on 4 March 2019.

**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–June 2020, a joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

Thank you to Nelson West, Ollie Owen, Jim Fairall and Jessica Simpson, for technical assistance and Dr Maheswaran Rohan for biometrical support.

# Crop protection

## Can parasitoid wasps control aphids in canola?

Dr Jo Holloway, Rachel Wood and Julie Clark (NSW DPI, Wagga Wagga)

### Key findings

- Parasitoid wasps need time for their populations to develop.
- It is important to maintain an environment that supports diverse populations of beneficial invertebrates year-round.
- Aphid mummification is probably higher than can be observed as parasitism is not obvious for up to two weeks.

### Background

Grain crops are host to a number of invertebrate pest species, but each year only a few species will reach high enough densities to cause significant damage and yield loss. Often, the array of beneficial species, such as predators, parasitic wasps and flies also located within or near the crop, are able to suppress the pest population growth, thus preventing the outbreak. However, growers are currently heavily reliant on chemical responses to pest outbreaks. This is partly due to a lack of information regarding how much influence is exerted by beneficials and the proportion required for pest suppression.

The aim of this experiment, therefore, was to determine how effective parasitoid wasps are at controlling aphid populations. Data obtained from this and other experiments will be used to help develop a model that will incorporate parasitoids and other beneficials into economic thresholds for canola aphids.

### Methodology

#### Site

This experiment is part of a national project with co-incidental experiments in South Australia, Victoria and Western Australia.

All NSW experiments and sampling were conducted in a paddock sown to canola (var. ATR Stingray$^{(b)}$) on 8 May 2018 located at the Wagga Wagga Agricultural Research Institute (WWAI). As part of another experiment, this paddock was divided into eight equal sized plots (142 × 105 m): half sown with fungicide-treated seed (Jockey® Stayer®) and the rest sown with insecticide- (Gaucho®) and fungicide-treated seed. In order to standardise the experiment across all state sites, all cages were placed within the insecticide seed-treated plots. No other insecticides were used on the crop. Plants were generally at the 4 to 6-leaf stage when the experiment started in July. Due to the dry conditions, plant emergence was rather sparse throughout the paddock.

#### Cage experiment

To assess how parasitoid wasps (*Aphidius colemani*) affect green peach aphid (*Myzus persicae*), five replicates of six exclusion cages (Figure 1) were set up during early July. Each cage contained three canola plants. Two sets of three sentinel plants, located near the cages, were also marked to serve as the open controls. To avoid any effect to the insecticide-seed treatments, the experiment could not start until at least eight weeks after sowing. Before the experiment started, all plants were checked and any invertebrates located were removed.

While all other parameters remained the same between the state sites, due to insufficient numbers in the SARDI colony, the wasp species used in NSW (*A. colemani*) was different from that used in other states (*Diaretiella rapae*). Wasps were sourced from Biological Services (Loxton, SA) and the green peach aphids were cultured from a colony sourced from WWAI.

Figure 1. Set of exclusion cages in a canola paddock inoculated with aphids and parasitoid wasps.

Treatments involved varying the density of aphids while maintaining the same number of parasitoids. A total of eight treatments were applied:

1. Low population (LP): 20 aphids.
2. Medium population (MP): 100 aphids.
3. High population (HP): 200 aphids.
4. Very high population (VHP): 500 aphids.
5. Medium closed control (MCC): 100 aphids.
6. High closed control (HCC): 200 aphids.
7. Medium open control (MOC): 100 aphids.
8. High open control (HOC): 200 aphids.

Centre plants within all cages, as well as the external sentinel plants, were inoculated with the desired number of aphids on 12 July 2018 and left to establish for two weeks. At this time, the aphids were counted and any excess removed. Three female wasps were then released into all non-control cages (day 0). Counts of aphid and mummy (parasitised aphid) numbers were conducted on days 14, 28 and 42.

Beneficial diversity within the paddock during the experiment was assessed using pitfall and hanging traps (Lindgren funnels and yellow fly traps). A total of 32 pitfalls, eight Lindgren funnels and eight yellow fly traps were used. These were equally distributed among the four insecticide seed-treated plots. Pitfalls were left open for one week every four weeks, while the hanging traps were open continuously, but sample cups changed every four weeks. All traps contained 100% polypropylene glycol. On return to the laboratory, samples were washed before being placed in 100% ethanol for storage before identification.

On day 42, after the field aphid count, each set of plants from each cage/sentinels were bagged and placed within Bugdorm cages in the entomology laboratory. These were left for 14 days to provide an accurate measure of the number of wasps emerging from aphids.

### Data analysis

Data was compared for significant differences using general linear models (GLM), with Tukey comparisons. Differences were considered significant at *P*<0.05. Numbers are presented as mean ± SE.

## Results

The number of aphids in all treatments increased exponentially over the course of the experiment, with the rate of increase generally determined by the initial starting number of aphids (Figure 2). At day 42, mean numbers of aphids ranged from 1194 ± 362 in LP to 7659 ± 1392 in VHP, significantly higher than previous days (*P*<0.001, F = 47.68, DF = 3; *P*<0.05, Tukey). While there was a significant effect from the treatment (*P* = 0.001, F = 3.89, DF = 7), this was only between the extremes (VHP *cf* MOC and LP; HP *cf* LP; *P*<0.05; Tukey). These results indicate that the parasitoid wasps were not able to control aphid population growth in this experiment. However, results from both the Western Australia and South Australia experiments did show some promise, with significant decreases in MP and HP aphid populations compared with their respective caged controls.

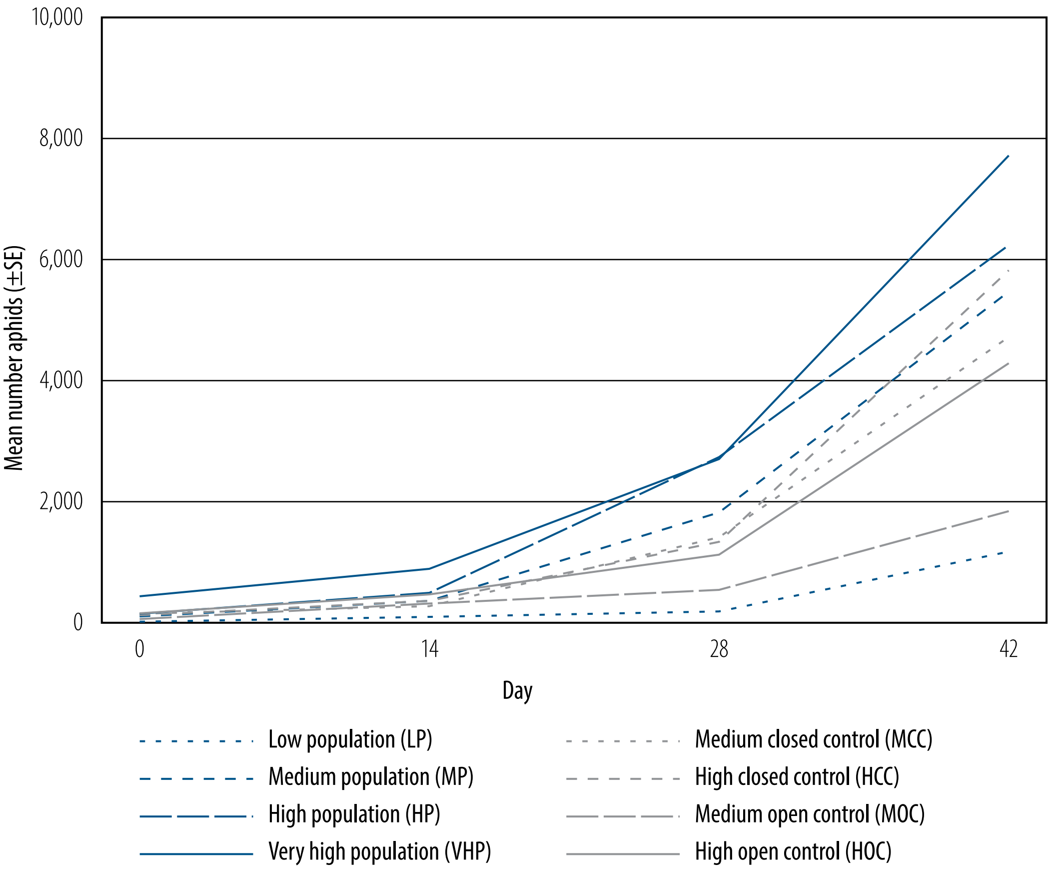

Figure 2. Changes over time in the mean numbers of aphids within each treatment during a cage experiment with canola plants inoculated with three parasitoid wasps.

The number of aphid mummies observed during the experiment also exponentially increased within each treatment. While no mummies were observed on day 14, and only small numbers on day 28, there was a significant increase by day 42 (*P*<0001, F = 26.98, DF = 3; *P*<0.05, Tukey; Figure 3). Despite starting with the same number of parasitoid wasps in each treatment, by day 42 significantly more mummies were found in the VHP treatment (88.8 ± 19.5) compared with the LP treatment (9.6 ± 3.8) and both open controls (*P*<0.001, F = 4.77, DF = 7; *P*<0.05, Tukey). This could indicate that there is a greater potential or stimulus for wasps to inject their eggs when higher numbers of aphids are present. However, by day 42 the percentage of aphids that had been parasitised was only around 1% in all treatments.

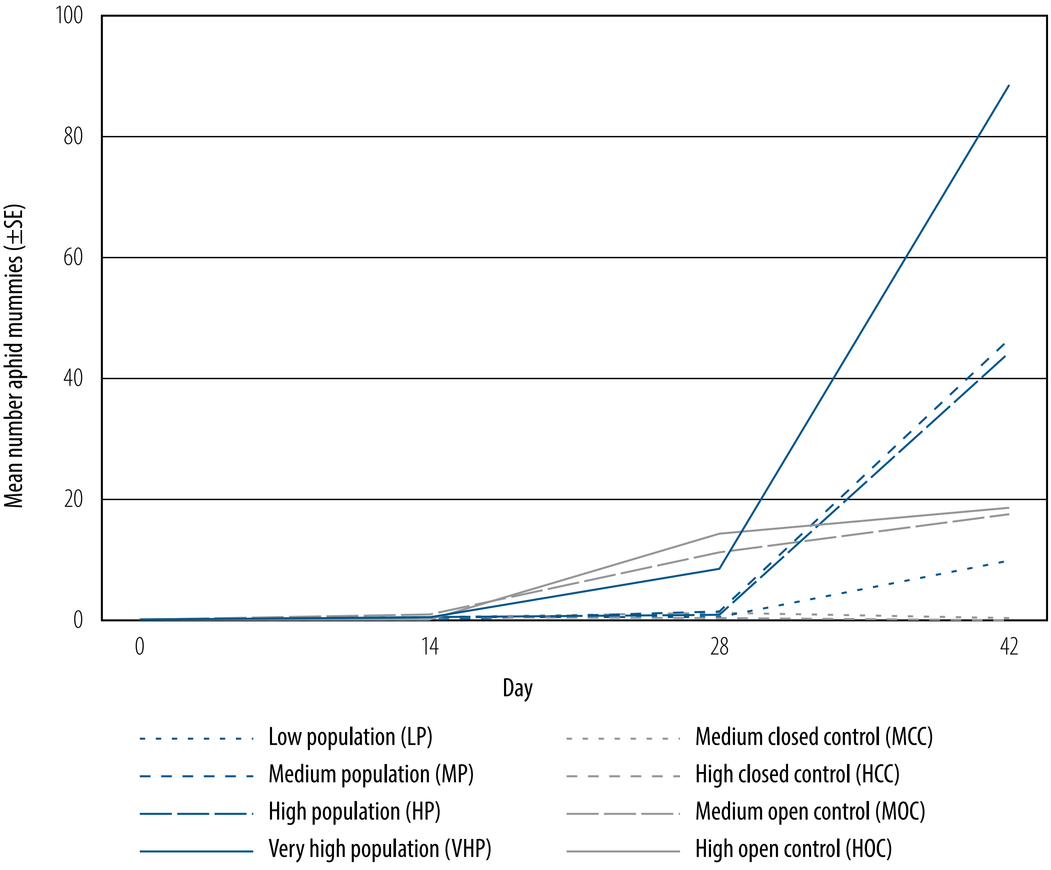

Figure 3. Changes over time in the mean numbers of aphid mummies within each treatment during a cage experiment with canola plants inoculated with three parasitoid wasps.

In the caged treatments, the number of wasps that emerged was only 25–50% of the aphid mummies observed (Figure 4). This was probably due to a combination of wasps already having emerged (i.e. older, empty mummies), and wasps failing to fully develop. However, the reverse was true with the open control plants where up to 20 times more wasps emerged than mummies observed (*P*<0.001, F = 9.61, DF = 7; *P*<0.05, Tukey; Figure 4). It can only be assumed that the aphids on these plants had only recently been parasitised by endemic wasps and so the mummies were indistinguishable from live aphids. It was noticeable during the later stages of the experiment that there was an influx of aphids within the paddock (generally cabbage aphid, *Brevicoryne brassicae*) and this might have resulted in an increased number of parasitoids within the paddock near the experiment's completion. Temperatures had also increased by this stage, which would have resulted in a greater amount of invertebrate activity.

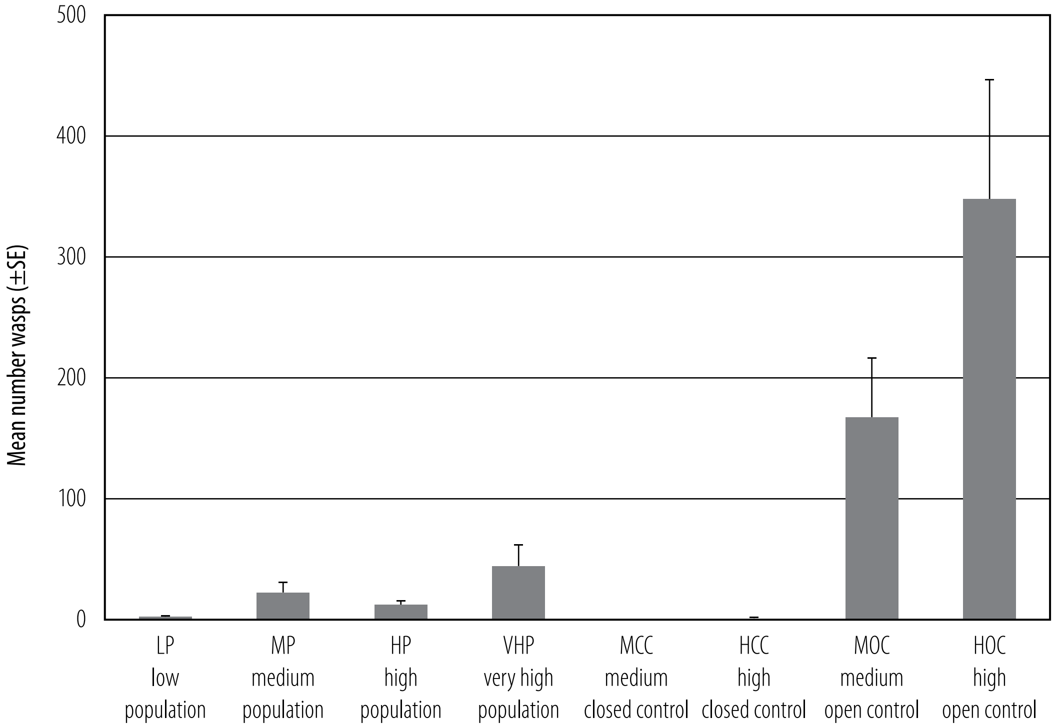

Figure 4. Mean number of wasps to emerge two weeks post-cage experiment.

While parasitoids did not suppress the aphid population during the experiment, mean numbers of aphids in both the open controls were lower than their caged counterparts. Although the high degree of variability between replicates meant these decreases were not significant (MCC vs MOC: $P = 0.078$, F = 4.07, DF = 1; HCC vs HOC: $P = 0.673$, F = 0.19, DF = 1), it does indicate some extra level of control within the paddock. This is probably through a combination of predation and parasitism, though to what level each contributes is unknown. Predators, such as predatory mites, spiders, predatory beetles and centipedes comprised over 80% of the beneficials trapped during the course of the experiment (Figure 5). The absolute numbers of beneficial invertebrates were similar during the two sampling periods at approximately 130 per plot. However, the relative proportion differed, with predatory mites decreasing, while spiders, centipedes and wasps increased. The primary wasp species trapped in the paddock was *D. rapae* (over 90% of the samples), different from the one used in the cage experiment. Although both are aphid-specific parasitoids, it is unknown whether *D. rapae*, well adapted to the local conditions, might have been more effective at controlling the aphid populations. Both South Australia and Western Australia observed some aphid population suppression with *D. rapae*. However, Victoria also used *D. rapae* and, like NSW, was less successful. Consequently, other factors could be involved, such as the environmental conditions.

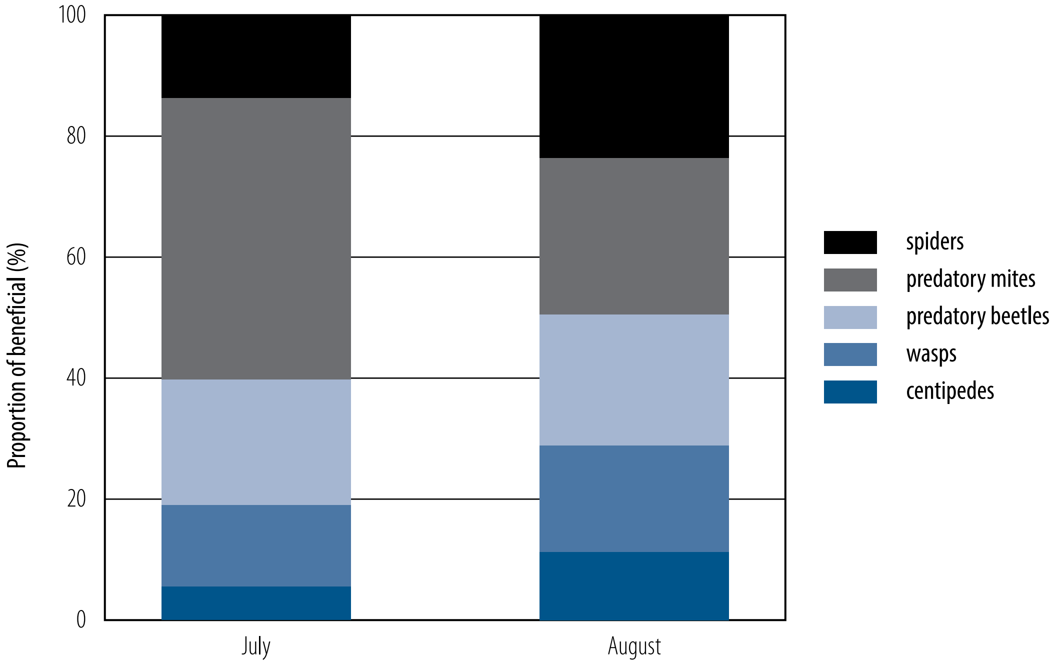

Figure 5. Proportion of beneficials trapped in canola paddock where the cage experiment was held during July and August 2018.

## Summary

Parasitoid wasps are an effective tool for helping to control aphid populations. However, a number of factors will have a bearing on whether they are successful. The number of parasitoids and aphids is crucial. If a sufficient number of parasitoids is present when aphids start to colonise the crop, they could maintain sufficient numbers to overcome the aphids' high reproductive potential. Other factors might include climate and species. Parasitoids also need sufficient time to build up their numbers, so it is important to maintain habitat that supports their presence, plus that of other beneficial species, throughout the year.

## Acknowledgements

This experiment was part of the 'New knowledge to improve the timing of pest management decisions in grain crops' project, CSE00059, 1 March 2015–30 June 2020. This project is a collaboration between CSIRO, cesar, SARDI and WA DPIRD. The project is a joint investment between NSW DPI and GRDC. Thanks to the NSW DPI farm staff for treating the seed and sowing the experiment paddock.

# Early interference between cotton (*Gossypium hirsutum*) and narrow leaf ketmia (*Hibiscus trionum* var. *trionum*)

Dr Md Asaduzzaman and Eric Koetz (NSW DPI, Wagga Wagga)

## Key findings

- Narrow leaf ketmia is a competitive weed during cotton's early growth stage.
- Medium to high infestations of this species can reduce 40% of the root biomass of cotton seedlings.
- Cotton leaf size was reduced by 30% in the 50% cotton:50% narrow leaf ketmia treatment.
- The first square (first fruiting bud) can be delayed two days due to a heavy infestation of narrow leaf ketmia.
- The relative neighbouring effect of narrow leaf ketmia in roots of cotton seedling can be 0.5.

## Introduction

Cotton (*Gossypium hirsutum*) is an economically important crop in Australia, with an export value of almost $3 billion in 2017–18 (Cotton Year Book 2018). There is growing optimism within the Australian cotton industry, in part due to improved varietal choices, and the lure of greater profits from cotton compared with alternative summer crops. However weeds are still detrimental to cotton production and heavy infestations can lead to a significant yield reduction ranging from 10% to 90% (Dogan et al. 2015). Bladder ketmia (*Hibiscus* spp.) is a widespread and troublesome weed found throughout the Australian cotton cropping system. The species is closely related to cotton plants in terms of phenological and physiological traits. There are two different species of bladder ketmia, wide leaf (*Hibiscus trionum* var. *vesicarius*) and narrow leaf (*Hibiscus trionum* var. *trionum*). Understanding the interaction between closely related weed species and cotton in the early crop stage can influence the choice of control options in some situations. This study was undertaken to quantify the early interference between cotton and narrow leaf ketmia.

## Methodology

### Site location and soil type

The experiment was conducted under glasshouse conditions at the Wagga Wagga Agricultural Institute. The soil was collected from the Irrigation Research and Extension Committee (IREC) demonstration site at Whitton, New South Wales. The soil was red and properties are briefly summarised in Table 1.

Table 1. Chemical composition of soil collected from the IREC site.

| pH | Electrical conductivity | Carbon | Nitrogen | Sulfur | Textural class |
|---|---|---|---|---|---|
| 5.9 | 187.29 µs/cm | 1.8% | 0.19% | 0.007% | sandy-loam |

### Previous crop

Cotton (irrigated)

### Weed species

The interference effect of narrow leaf ketmia on cotton seedlings was tested as the species is more persistent after glyphosate applications than broad leaf ketmia, and coexists in cotton farming systems

(Asaduzzaman and Koetz 2018). Like broad leaf ketmia, narrow leaf ketmia has similar physiology and morphology to cotton.

### Treatments of replacements series

A complete replacement series experiment was performed, where cotton and weeds were paired and pots contained either a monoculture or mixtures at 75:25, 50:50, 25:75 (Figure 1). Total plant density (crop + weed) per pot was four.

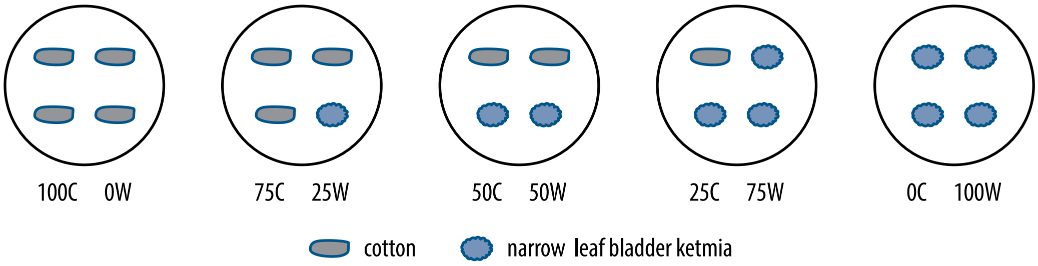

Figure 1. Planting pattern for replacement series early interference experiment of cotton and narrow leaf bladder ketmia. Cotton and weed ratios are presented with C and W respectively.

Cotton seeds were sown directly into soil, but narrow leaf ketmia seeds were initially scarified with sulfuric acid ($H_2SO_4$) for 20 minutes before sowing. Pots were watered as required. Pots were arranged randomly on the shelf of the glasshouse with five replications. Both species were allowed to grow for eight weeks before destructive harvest. Plant height, leaf size, above-ground biomass, root mass, position of the first square (first fruiting bud) of cotton were measured. In addition to that, above-ground weed biomass, absolute competitive intensity (ACI), relative neighbouring effects (RNE), total interaction index (TII), competitive response (CR) and competitive index (CI) of cotton to weed were measured at harvest.

## Results

### Cotton growth and above-ground biomass

Eight weeks after cotton and narrow leaf ketmia emerged, the directly calculated parameter plant height did not vary significantly, but cotton seedling leaf size was significantly affected ($P<0.004$) by narrow leaf ketmia (Figure 2). Leaf size was reduced by 30% in cotton for the 50% cotton and 50% narrow leaf ketmia treatment.

Here we assumed that plant height is not always an accurate indicator of interference. Other traits, however, can be used as an indicator. Plant responses to interference might include either etiolation or a change in habit towards more branches, biomass, a delay in reproductive stage, and reduced below-ground growth.

The correlation and regression analysis demonstrated that cotton biomass was negatively correlated with narrow leaf ketmia ($r = -0.90$; $P<0.005$). The 30% reduction in above-ground cotton seedling biomass occurred with three neighbouring plants of narrow leaf ketmia (Figure 3). The estimated regression model (cotton mass = 4.49 – 0.72 × weed mass) suggests that one unit increase of weed mass can cause a 0.72 g biomass reduction in cotton seedlings.

### First square development

The 25% cotton and 75% narrow leaf ketmia pair can delay first square formation in cotton (Table 2). In particular, a cotton field without a narrow leaf ketmia infestation can produce its first square two days earlier than a cotton field heavily infested with ketmia. Here, a high density of ketmia sufficiently stressed neighbouring cotton seedlings delaying the appearance of first square. This indicates the importance of agronomic management, such as the necessity of keeping weed populations under minimum levels to avoid first square formation delay in cotton plants.

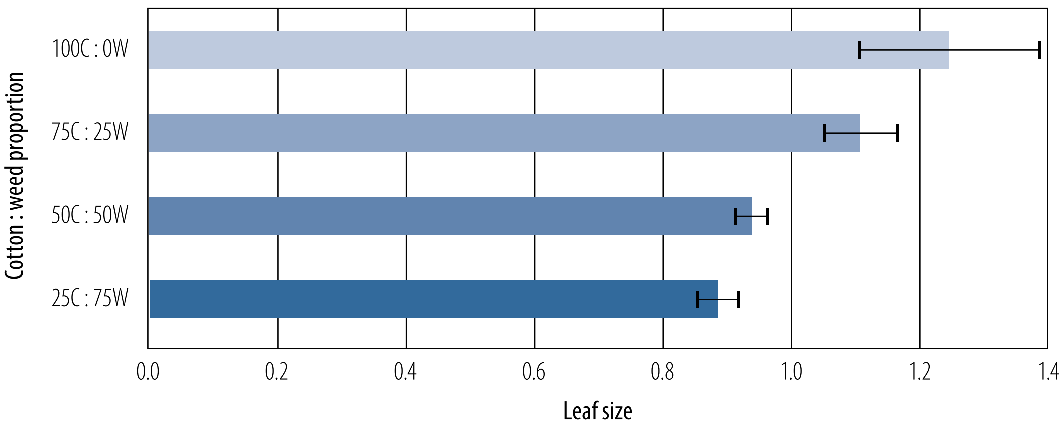

Figure 2. Mean (S.E.M.) leaf size of cotton affected by interference of narrow leaf ketmia. *Post hoc* test indicates a significant difference ($P<0.005$) between treatments.

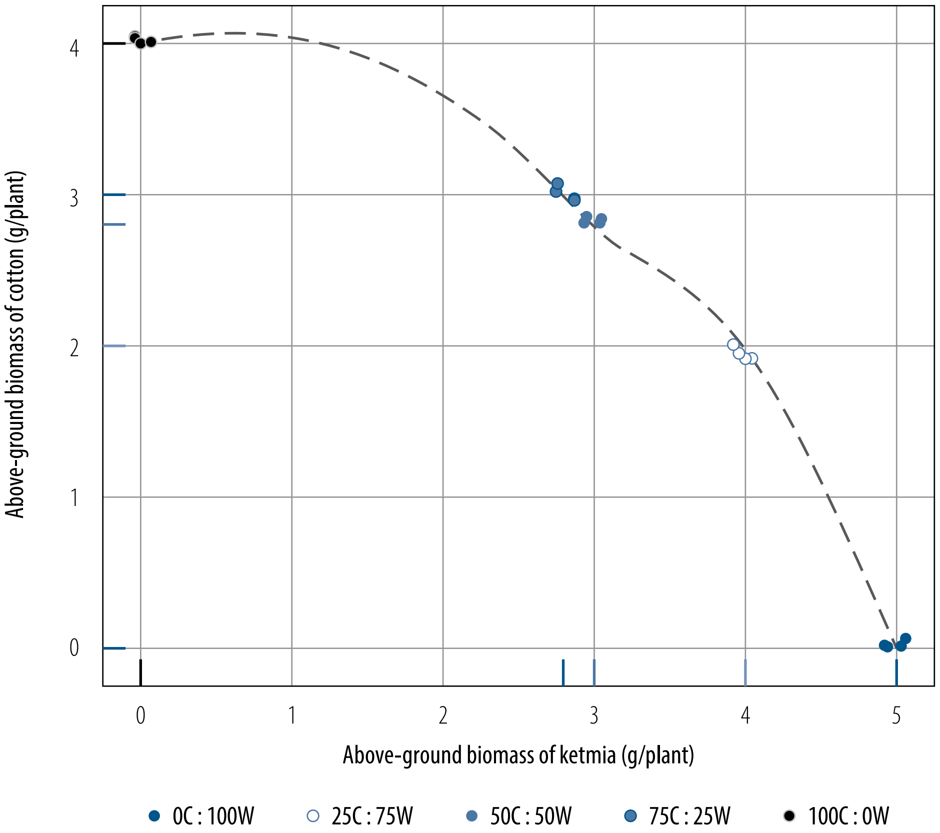

Figure 3. A significant negative relationship is present between above-ground biomass of cotton and narrow leaf ketmia seedlings.

The levels of weeds infestation at the seedling stage of cotton is important especially for closely related weed species such as bladder ketmia. Crop–weed interference mechanisms are regulated by weed density, and high densities induce greater interference, which comprises both competition and allelopathy. Allelopathy is mainly the below-ground non-resources interaction between species.

The interaction between 25% cotton and 75% ketmia significantly affected ($P<0.001$) the cotton seedling root biomass and root growth was reduced by 40% (Figure 4). The other three treatment pairs were not significantly different, suggesting that cotton can tolerate up to 50% density before there is any adverse effect on cotton root growth.

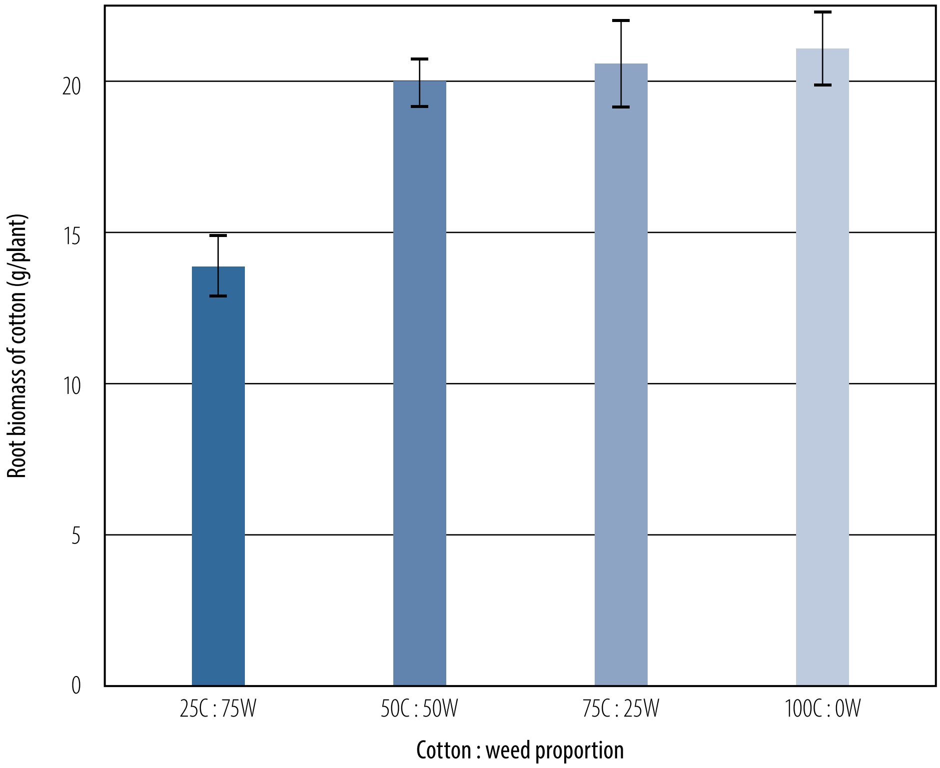

Figure 4. Mean (S.E.M.) root biomass of cotton in combination with narrow leaf ketmia at early growth stage. *Post hoc* test indicates a significant difference (*P*<0.005) between treatments.

### Indices of competition

The mathematical competitive indices were measured by combining several primary measures. The values of cotton seedling absolute competitive intensity (ACI), total interaction index (TII), competitive response (CR) and competitive index (CI) declined with increased narrow leaf ketmia infestation (Table 2). It can be assumed that narrow leaf ketmia is a competitive weed species at cotton's early growth stage.

Table 2. Competitive indices of cotton seedlings measured when grown with narrow leaf ketmia in four different proportions.

| Proportion | Position of first square (mean ± s.e) | ACI | TII | CR | CI |
|---|---|---|---|---|---|
| 100C : 0W | 6.4 ± 0.25 | 4.08 | 1.00 | 1.00 | 1.00 |
| 75C : 25W | 6.6 ± 0.10 | 1.25 | 0.78 | 0.77 | 0.87 |
| 50C : 50W | 6.6 ± 0.11 | 1.08 | 0.74 | 0.73 | 0.80 |
| 25C : 75W | 7.0 ± 0.10 | 0.91 | 0.70 | 0.69 | 0.80 |

The calculated relative neighbour effect (RNE) from narrow leaf ketmia in cotton roots was 0–0.5, which revealed that a below-ground interaction exists between the two (Figure 5). Such interference might require new weed management strategies such as designing self-weeding cultivars comprised of both resource and non-resource competition. It is a fact that below-ground competition is more complex than above-ground and therefore interdisciplinary research is needed to enable thorough understanding of the cotton and weed (inter-species) interference mechanism.

This experiment was performed in a relatively stable and productive climate; where water and nutrient levels were not limiting. The interaction between cotton and ketmia is competitive rather than mutually stimulatory where both belong to the same botanical family. The cost from this interaction between intra-species competition was not interpreted here, however, an overall competitive relationship could be inferred and the data indicates that narrow leaf ketmia was always a superior competitor when grown in a mixture with cotton. Under field conditions, different plant attributes could contribute to the competitive abilities observed here. Further experiments on a large scale relegating specific environment or management effects to plant growth and competitiveness might provide the basis for implementing weed control strategies.

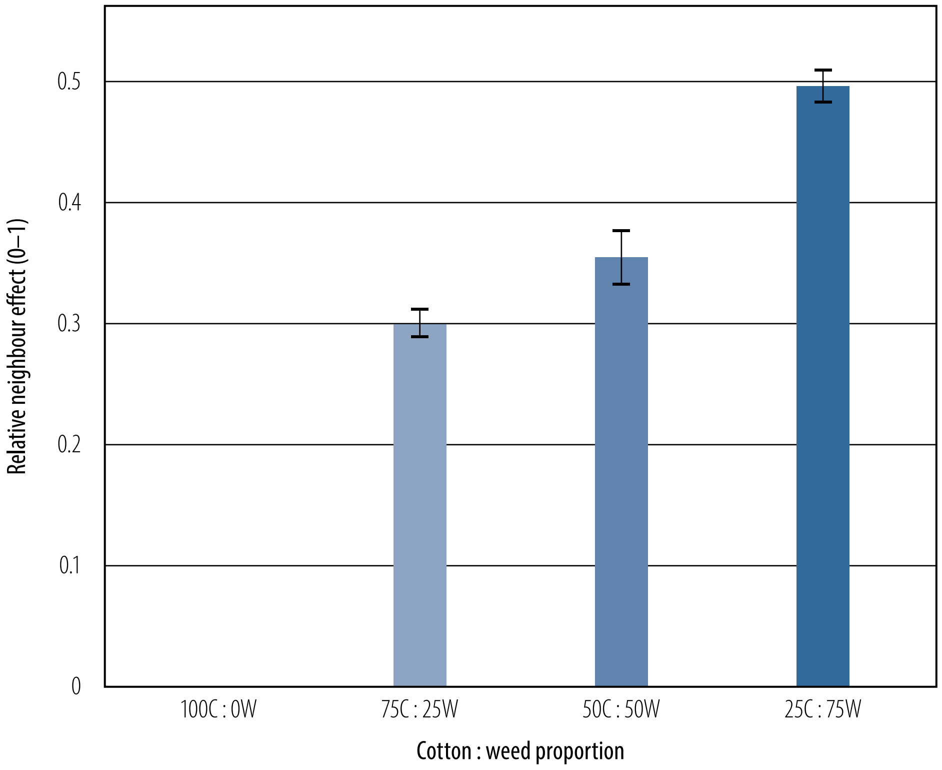

Figure 5. Relative neighbour effect received in cotton seedling roots from narrow leaf ketmia at different proportions. The error bar indicates a significant difference (*P*<0.005) between treatments.

## Conclusion

For this experiment:

1. Cotton seedlings are sensitive to competition with narrow leaf ketmia weed seedlings
2. Narrow leaf ketmia seedlings interfere with cotton seedling roots.

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## Acknowledgements

This experiment was part of the 'Hard to control weeds in the northern cotton farming systems' project, DAN1402, 2013–18, with joint investment by the CRDC and NSW DPI.

Thanks to M A Halim, University of Newcastle for providing the soil analysis report.

# Nutrition & soils

## Research update for the long-term subsoil acidity experiment at Cootamundra, NSW

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### Key findings

- Lime is the most effective amendment to increase pH and reduce exchangeable aluminium (Al).
- Deep placement of organic amendments (e.g. lucerne hay pellets) had limited effect on soil pH, but reduced exchangeable Al% significantly.
- The nutrients in lucerne hay pellets, particularly nitrogen (N), increased soil mineral N significantly, but its effectiveness depends on available soil water. In dry years, there was no yield improvement, despite more soil mineral N being available at sowing.
- In dry years, crops developed more roots at 0–10 cm, presumably to capture valuable rainfall, rather than producing deeper roots to seek non-existent soil moisture. However, in a wet year (i.e. 2016), root systems were distributed more evenly in the soil profile.
- There was no crop response in grain yield in 2017 and 2018 due to lack of soil moisture. The available soil water was in deficit for much of the soil profile during most of the growing season in 2017 and 2018 for canola and cereal crops.
- Grain protein was higher under the deep lucerne hay pellet treatments, with and without lime addition, compared with other treatments, in both wet and dry years.

### Introduction

A long-term field experiment was established in 2016 to manage soil acidity at depths of 10–30 cm. The objectives were to:

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

### Site details

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

| | | |
|---|---|---|
| **Previous crop** | Oats | |
| **Crop rotation** | Phase 1 | EGA Gregory$^{\Phi}$ wheat |
| | Phase 2 | Hyola® 559TT canola |
| | Phase 3 | La Trobe$^{\Phi}$ barley |
| | Phase 4 | Morgan$^{\Phi}$ field pea (2016)<br>PBA Samira$^{\Phi}$ faba bean (2017)<br>Morgan$^{\Phi}$ field pea (2018) |
| **Liming history** | No lime applied in the previous 10 years | |
| **Fallow rainfall (November–March)** | 2016 (265 mm); 2017 (302 mm); 2018 (244 mm); long-term average (257 mm) | |
| **In-crop rainfall (April–October)** | 2016 (682 mm); 2017 (269 mm); 2018 (173 mm); long-term average (332 mm) | |
| **Starter fertiliser** | 14 kg 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** | Canola and barley: 86 kg N/ha as urea, total N fertiliser input 100 kg N/ha<br>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.<br>Grain legumes: no additional N fertiliser input apart from 14 kg N/ha as DAP at sowing. | |
| **Ripping machine** | 3-D Ripper (5 tynes), designed and fabricated by NSW DPI (Li and Burns 2016) | |
| **Ripping width and depth** | 50 cm between rip lines; to 30 cm deep | |

## Crop rotation and treatments

There were four crops in rotation arranged in a fully-phased design. The crop sequence was wheat (*Triticum aestivum*), canola (*Brassica napus*), barley (*Hordeum vulgare*), pulse – either faba bean (*Vicia faba*) or field pea (*Pisum sativum*) depending on the season (field pea was sown in year one and year three, and faba bean was sown in year two). Each crop appeared once in any given year so that:

- responses of different crops to different soil amendments can be assessed
- underlying treatment effects, taking account of seasonal variation, can be compared.

Table 1. Soil amendment and treatment description at Ferndale, 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 0–10 cm deep to achieve an average $pH_{Ca}$ of 5.5 over eight years. |
| 3 | Deep ripping only | Soil was ripped down to 30 cm to quantify the physical effect of ripping. No amendment was applied below 10 cm, but lime was applied at 2.5 t/ha at the surface, incorporated to 0–10 cm deep after plots were ripped, to achieve an average $pH_{Ca}$ of 5.0 over eight years. |
| 4 | Deep liming | Lime was placed at three depths: (surface, 10–20 cm and 20–30 cm). Approximately 5.5 t/ha of lime was applied in total to achieve a target pH >5.0 throughout the whole soil profile, which should eliminate pH restrictions to plant growth for most crops. |
| 5 | Deep organic amendment (OA) | Organic amendment (in the form of lucerne hay pellets) at 15 t/ha was placed at two depths (10–20 cm and 20–30 cm). The surface soil was limed to pH 5.0. |
| 6 | Deep liming plus OA | Treatments 4 and 5 were combined to maximise the benefits of lime and organic amendment. |

## Measurements

Soil samples were taken in autumn at 10 cm increments from 0–40 cm, and 20 cm increments from 60–100 cm at phase 1, but only to 60 cm at remaining phases. Soil samples were analysed for pH, exchangeable cations, soil mineral N and Colwell P.

Rooting depth and root density were measured at crop anthesis in each year using breaking corer methods (Smit et al. 2000). Two soil cores were taken between crop rows on the ripping line and between ripping lines on each plot. Data was averaged across two cores on each plot as no significant difference between the two cores was found for any year.

Neutron probe access tubes were inserted in autumn each year for approximately 12 months immediately after crops were sown and removed within a week before new crops were sown in autumn in the following year. One access tube was inserted to a depth of 150 cm between two ripping lines on each plot. Measurements were taken at six depths every 25 cm from 15 cm below soil surface down to 140 cm at 4–6 week intervals.

The site received 576 mm of rain from June to September in 2016; by 26 September the soil profile was nearing field capacity. Therefore, the soil moisture measured on 26 September 2016 was deemed as the crop drainage upper limit (DUL). Over three years, the lowest neutron moisture meter (NMM) count readings were recorded on 19 November 2018 for all depths except for the first depth at 15 cm where the lowest NMM count was on 9 October 2018. However, the soil moisture measured at 15 cm on 19 November 2018 was similar to the plant permanent wilting point at 1.5 kPa tension measured in the laboratory (0.08 g/cm$^3$). Therefore, the soil moisture measured on 19 November 2018 was deemed as the crop lower limit (CLL) for the calculation. The available soil water (ASW) was soil water stored at a given time less the CLL for given soil depths.

Seedling numbers at establishment, crop dry matter (DM) at anthesis and harvest, grain yield and quality were also measured.

## Results and discussion

### Rainfall pattern

At the Cootamundra site, the long-term annual rainfall is 589 mm. It was an extremely wet year in 2016 with 947 mm of rain when the experiment was set up. However, the following two years, 2017 and 2018, were extremely dry, particularly during the growing season. In 2017, the site only received 3.2 mm of rain in June and in September. In 2018, over four months from July to October, the site only received 16.5, 26.5, 25.9 and 21.2 mm of rain, respectively (Figure 1).

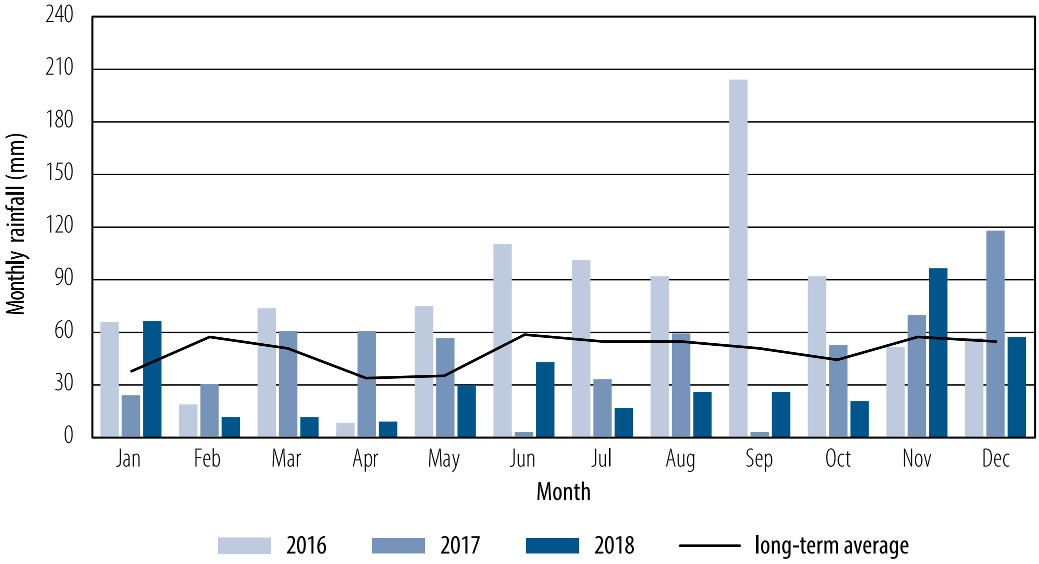

Figure 1. Monthly rainfall and long-term average rainfall at Cootamundra, NSW.

### Soil chemical properties

#### *Soil pH*

The baseline samples showed that soil pH was 4.52 at 0–10 cm deep, 4.31 at 10–20 cm and 4.70 at 20–30 cm. There was no difference in soil pH between treatments at any depth in year one before treatments were imposed. In autumn 2017, 12 months after treatments were imposed, surface liming increased pH to 5.9 at 0–10 cm as designed. The deep-lime treatment with and without organic amendment (OA) significantly increased soil pH at 10–20 cm and 20–30 cm as expected. Similar trends were found in 2018 (Figure 2).

The deep OA treatment did not increase pH to the level that pilot laboratory/glasshouse experiments suggested (unpublished data). There are several explanations for this unexpected result. Firstly, in the incubation or soil column experiments, the organic amendment was fully mixed with soil in contrast to the field experiment where it was banded at two depths after one pass with the 3D ripper. Secondly, there was adequate water supply in the controlled environment, maintained at 80% of field capacity, whereas in the field soil moisture was variable. In addition, nearly all controlled environment experiments were conducted over a comparatively short duration, up to three months.

It is reported that decomposed organic materials initially increased soil pH (Butterly et al. 2010b), however, the nitrification process decreased soil pH (Butterly et al. 2010a). The net effect would keep soil pH unchanged assuming that the magnitude of change cancel each other. A number of soil column experiments demonstrated that the soluble component from organic materials moves down the soil profile with the alkali if combined with lime (Butterly and Tang 2018; Nguyen et al. 2018). However, there is no evidence to show that the alkalinity moved vertically under lime plus organic amendment in the first three years of the current field experiment.

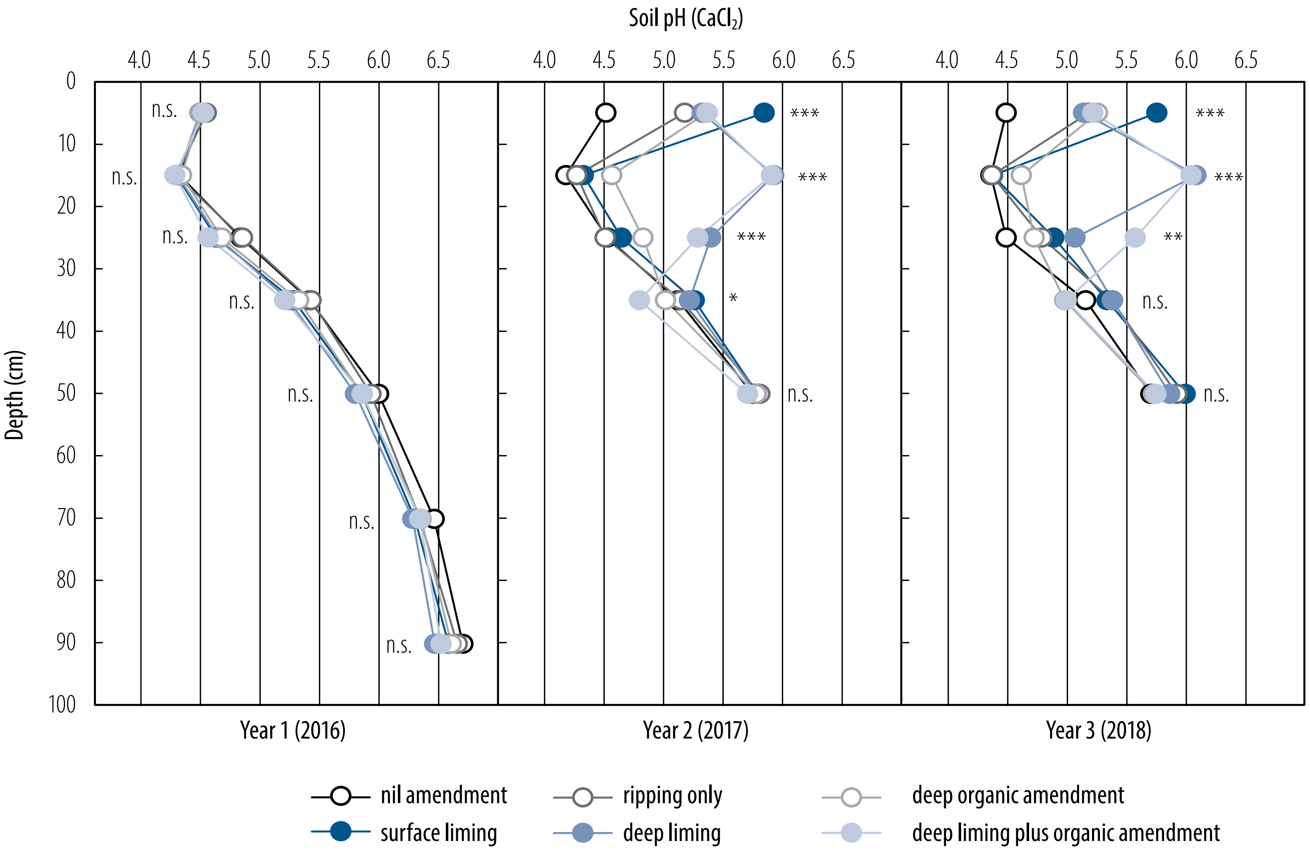

Figure 2. Soil pH in CaCl$_2$ under different soil amendment treatments in autumn in years 1–3.
**, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$; n.s., not significant.*

### *Exchangeable aluminium (Al)*

Before imposing treatments in 2016, the baseline exchangeable Al was 19.6% and 6.2% at 10–20 cm and 20–30 cm, respectively. The deep-liming treatments, either with or without organic amendment, reduced exchangeable Al to less than 2% in 2017 and 3% in 2018 at 10–30 cm (Figure 3). Although the organic amendment did not increase soil pH, it did reduce exchangeable Al significantly at 10–30 cm compared with those treatments without deep soil amendment placement. Haynes and Mokolobate (2001) suggested that the soluble organic molecules from organic amendment could combine active $Al^{3+}$ to form insoluble hydroxy-Al compounds. The exchangeable Al remained high in the 10–30 cm depths for ripping only and surface liming treatments. The nil amendment treatment had the highest exchangeable Al at all three depths at 0–30 cm (Figure 3).

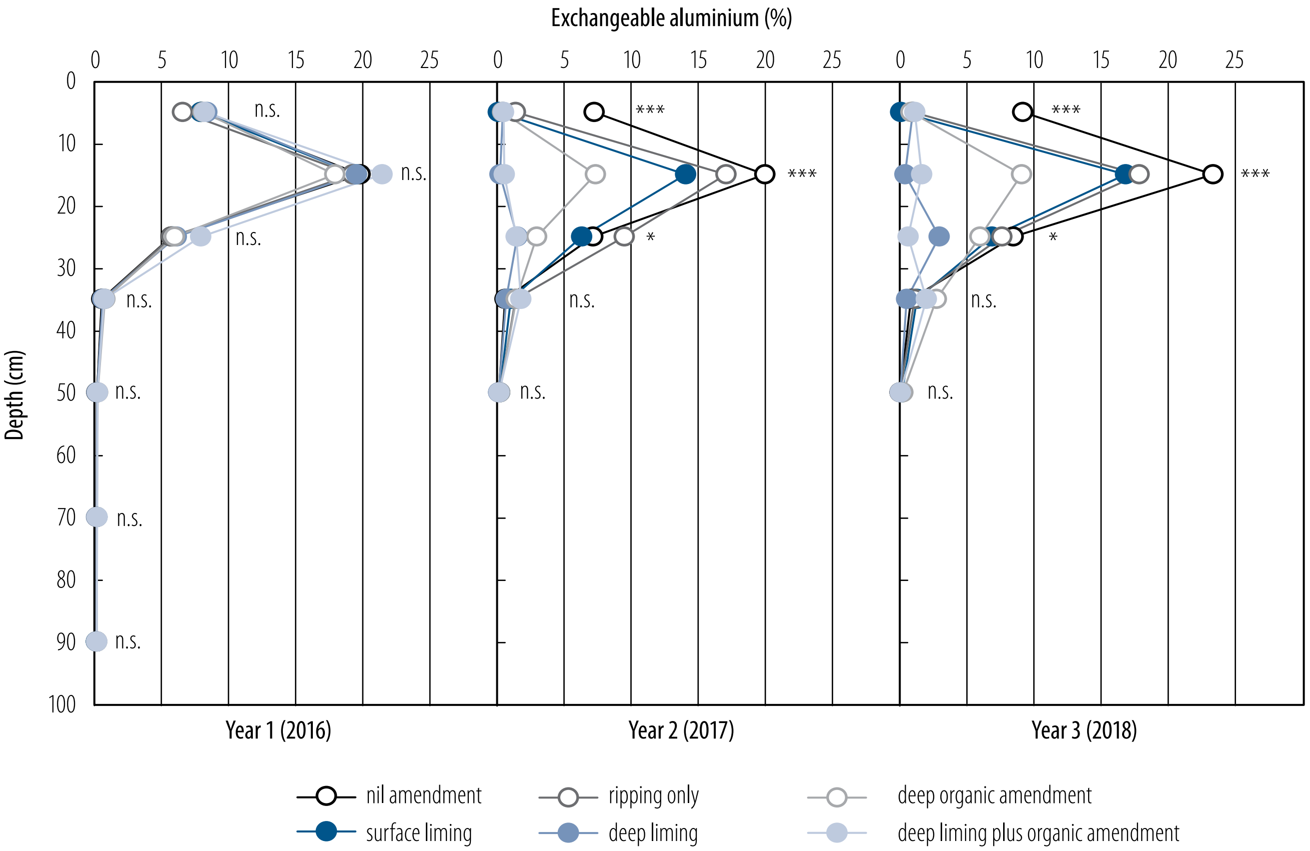

Figure 3. Soil exchangeable Al (%) under different soil amendment treatments in autumn in years 1–3.
**, P<0.05; **, P<0.01; ***, P<0.001; n.s., not significant.*

### *Soil mineral nitrogen (N)*

There was significantly more soil mineral N at 0–60 cm under deep OA treatments with and without lime in both 2017 and 2018 ($P<0.001$) compared with other treatments without organic amendments (Figure 4). On average, there was more than 100 kg of additional mineral N/ha available in the deep OA and deep liming plus OA treatments compared with all other treatments in autumn 2017 and 2018 (Figure 4). The soil mineral N was up to 278 kg N/ha in the deep OA treatment in autumn 2018.

There was no difference in soil mineral N between treatments in any depths in 2016. In autumn 2017, two treatments with OA had significantly higher soil mineral N at all depths compared with other treatments due to extra organic N from OA (Figure 5). In autumn 2018, the difference in soil mineral N between treatments with and without OA became smaller, but was still significant at all depths, particularly at 40–60 cm. This provides some evidence of movement of soil mineral N down the soil profile, i.e. nitrate leaching in those treatments with deep OA.

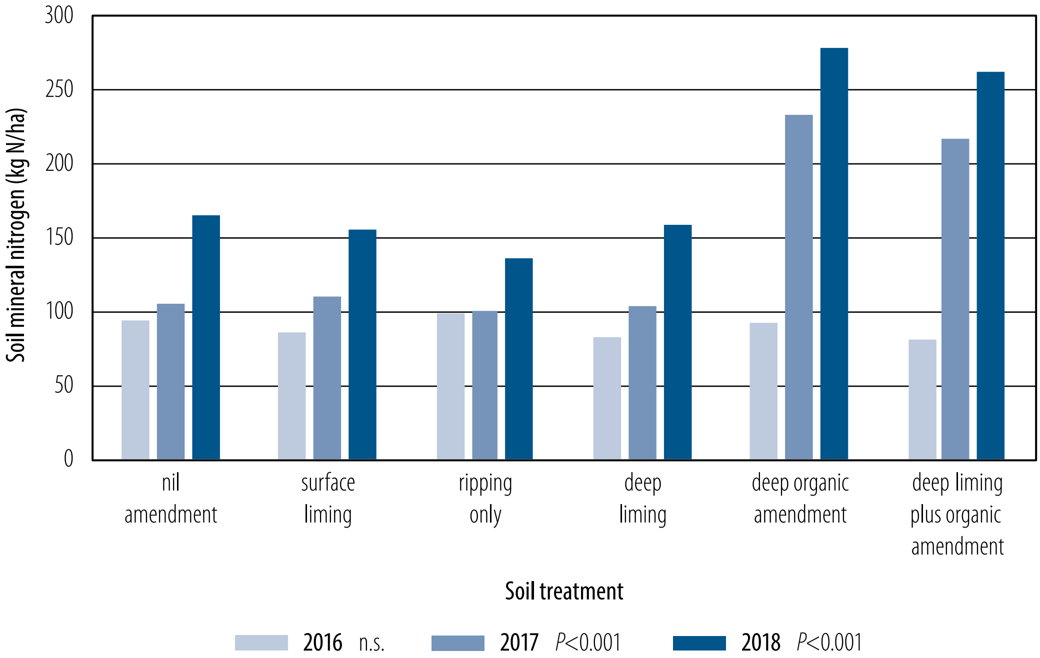

Figure 4. Soil mineral N (kg/ha) in 0–60 cm soil profile under different soil amendment treatments in autumn in years 1–3.

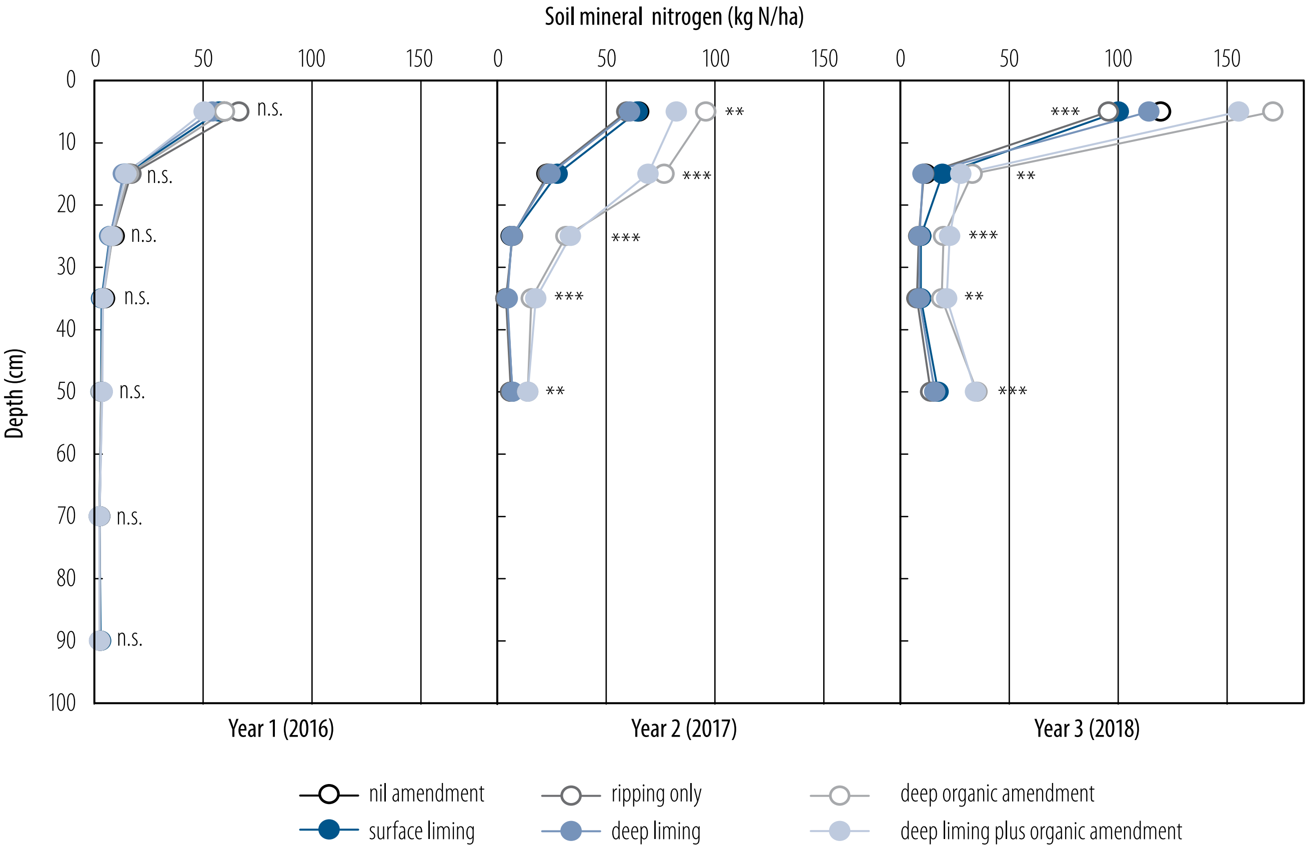

Figure 5. Soil mineral N (kg/ha) in soil profile under different soil amendment treatments in autumn in years 1–3.
**, P<0.05; **, P<0.01; ***, P<0.001; n.s., not significant.*

### *Colwell phosphorus (P)*

There were no differences in Colwell P at any depth in any year except at 10–20 cm in year three. At the site, 15 kg/ha of fertiliser P as DAP was applied at sowing each year. Phosphorus remained at a similar level across three years (Figure 6).

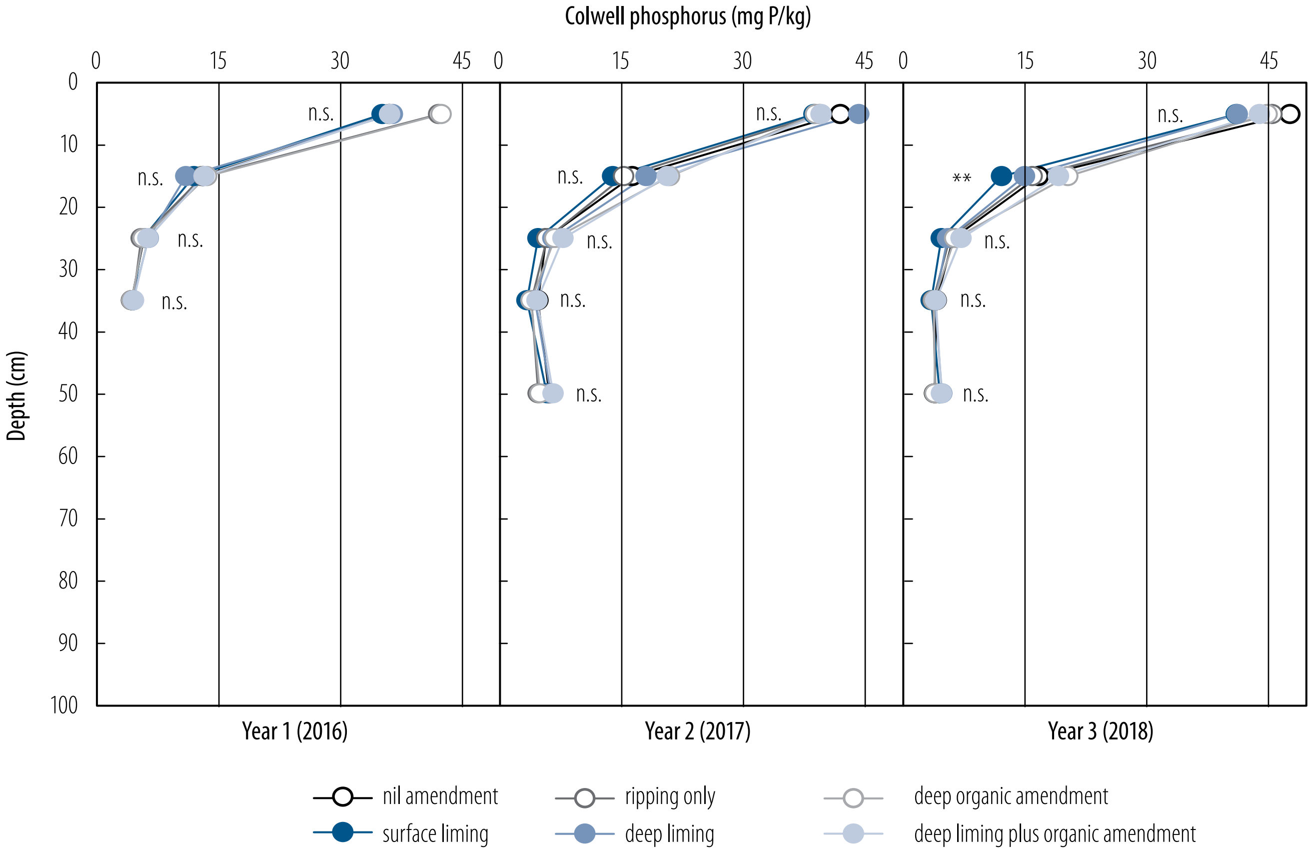

Figure 6. Soil Colwell P (mg/kg) in soil profile under different soil amendment treatments in autumn in years 1–3.
**, P<0.05; **, P<0.01; ***, P<0.001; n.s., not significant.*

### Rooting depth and root density

There was no significant difference in average maximum rooting depth between treatments. Canola was the deepest rooting, reaching 145 cm deep. Pulses (field pea or faba bean) had the shallowest rooting depth (<100 cm deep in general), whereas wheat and barley rooting depths were intermediate (Figure 7). Figure 7 shows that in general, in a wet year (2016), rooting depth was shallower than in a dry year (2018).

There was large variation in root density between treatments at various depths for all four crops (Figure 8). Root density decreased with increased soil depth in general, with the majority of roots located at 0–10 cm for all crops, particularly in dry years. There were considerably fewer roots below 80 cm for pulse crops, compared with the relatively high root density at 80–100 cm for canola and barley crops (Figure 8).

One of the surprising findings from the root density measurements was that all crops developed a dense root system in the top 10 cm (Figure 8) rather than allocating more resources to developing a deep root system as perennial plants do in dry years. In both 2017 and 2018, the soil profile was so dry that plants relied on growing season rainfall. This could be one of the plants' survival strategies, i.e. to use limited water at the soil surface more efficiently rather than allocating valuable resources to search for deep moisture in deep soil.

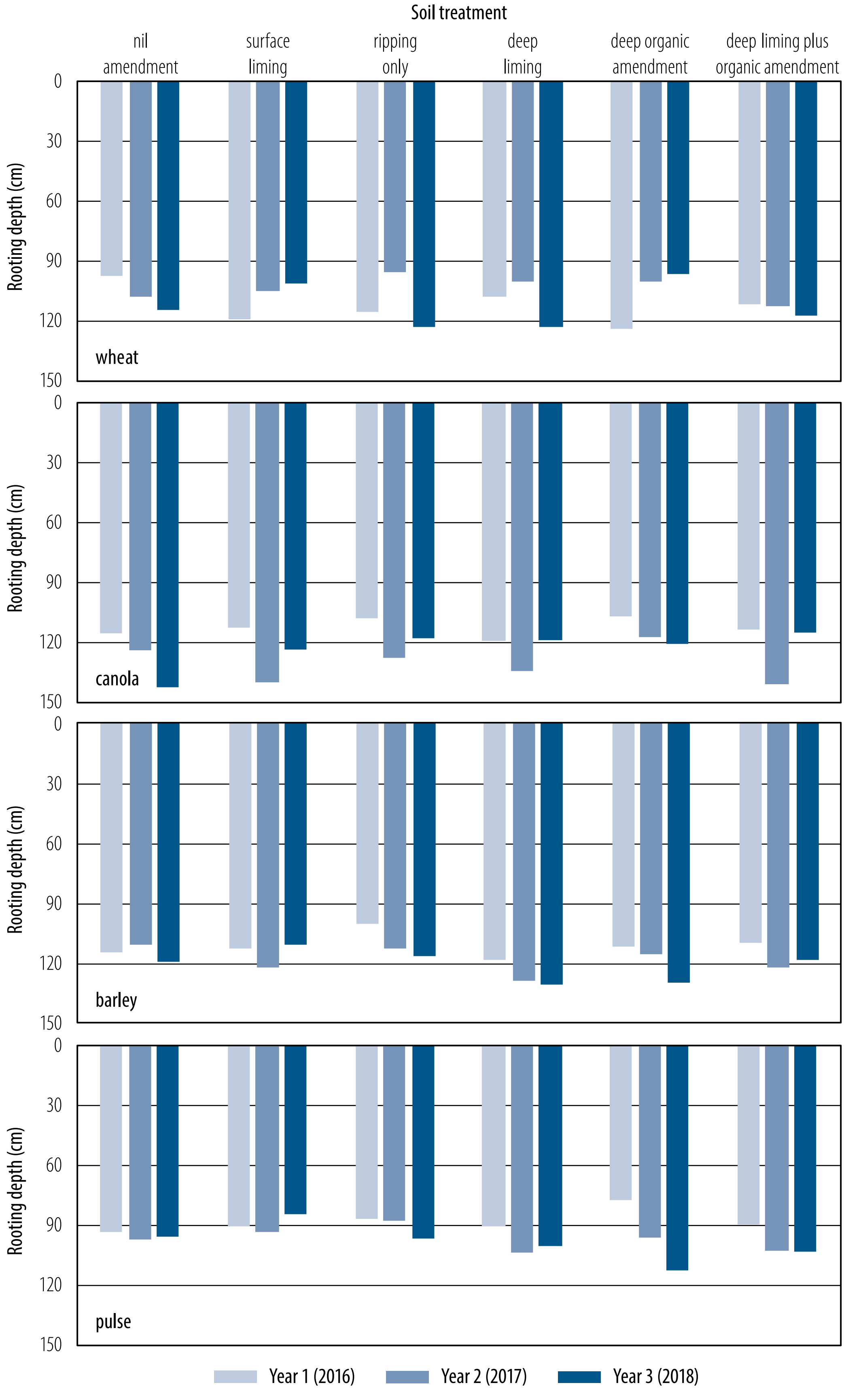

Figure 7. Maximum rooting depth (cm) for each crop in the rotation under different soil amendment treatments at crop anthesis in years 1–3.

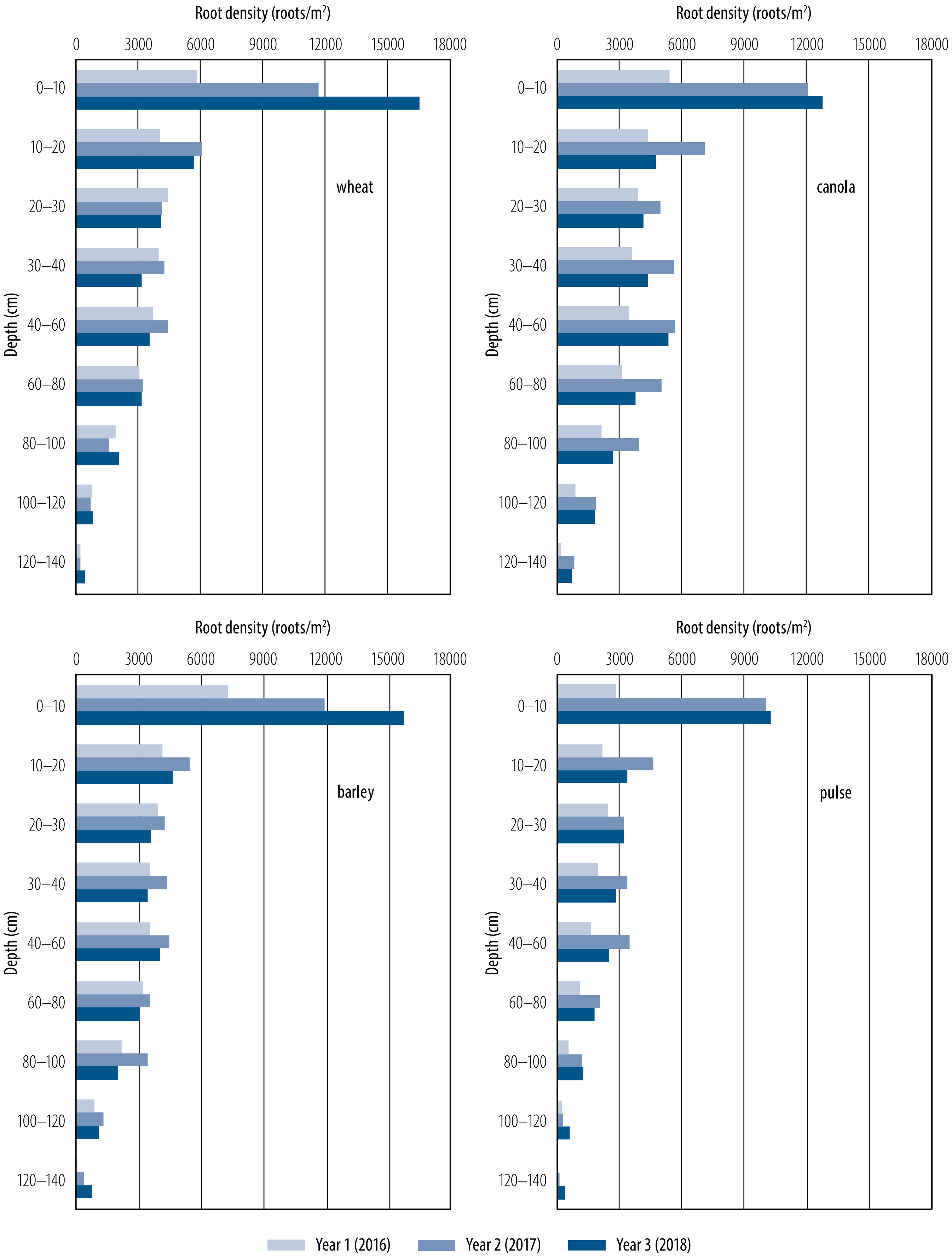

Figure 8. Root density (roots/m²) for each crop in the rotation under different soil amendment treatments at crop anthesis in years 1–3.

### Soil volumetric water content and available soil water

*Soil volumetric water content*

The soil volumetric water content had a strong seasonal pattern – generally following the rainfall pattern but dependent on crop growth (Figure 9). Most changes in the soil water occurred above 40 cm, where most of the plant roots were concentrated (Figure 8). Below 65 cm, the soil moisture remained relatively constant after the soil profile was replenished in 2016. Averaged across all crops, there were no significant differences in soil volumetric water content between treatments at any depths.

*Available soil water*

There was strong seasonal variation in ASW in the 15–40 cm depth (Figure 10) and 65–140 cm depth (Figure 11), reflecting the rainfall pattern and crop growth stages.

In year one, ASW peaked at the end of September, then decreased sharply for all crops in the 0–40 cm depth due to high evapotranspiration in the grain filling period, but decreased less dramatically below 65 cm in the soil profile.

- There was more ASW under the field pea crop at the end of November as that crop matured, and also because of the shallower root system compared with other crops (Figure 7). There was not much difference in ASW between treatments for the field pea crop (Figure 10).
- It appeared that ASW was less under the deep liming plus OA treatment for wheat and canola crops than that under deep OA for barley crops in the 15–40 cm depth at crop maturity. ASW was lower under the deep liming treatment with wheat crop, than under deep liming plus OA treatment with the canola crop.
- The rip only treatment under the barley crop had the least ASW compared with other treatments (Figure 11). In the 65–140 cm depth, there were large differences between treatments for all crops, particularly after crops were harvested.

In year two, ASW in the 15–40 cm depth stayed at a similar level until the end of August when the crop growth rate increased rapidly (Figure 10). During spring, ASW was at a deficit due to vigorous crop growth and limited rain. The early summer rain re-filled the soil profile to levels that varied across crops and treatments. Below 65 cm, ASW remained relatively constant for all crops apart from spring, when ASW reduced slightly, indicating that the crops extracted soil water from deep in the soil profile (Figure 11).

- Under the canola crop, the deep liming treatment had the lowest ASW in the 15–40 cm depth during the growing season, but significant rain late in the growing season in October and November reduced the treatment difference in ASW.
- For the wheat crop, surface liming and deep liming plus OA had less soil moisture deficit in spring than the other treatments (Figure 10).
- There was less variation in ASW for the barley and faba bean crops between treatments apart from large seasonal variation than for the canola and wheat crops (Figure 10). Deep in the soil profile below 65 cm, the treatment difference in ASW was more obvious than in the shallow soil profile for all crops.
- Under the canola crop, deep liming had the lowest ASW, whereas deep liming plus OA had the highest ASW throughout the season. In contrast, under the barley and faba bean crops, the deep liming plus OA treatment had the lowest ASW, but under the wheat crop, the deep OA had the lowest ASW throughout the season (Figure 11).

In year three, ASW in the 15–40 cm depth depended very much on previous crops and the growth stages of the current crops (Figure 10). ASW was generally lower under the barley and wheat crops, but higher under the pulse (field pea) and canola crops among crops (Figure 10). In general, there was not much difference in ASW in the 15–40 cm depth between treatments in any crop until harvested. There was a water deficit under the wheat and canola crops in spring. In the 65–140 cm depth, the wheat and canola crops drew more soil water from deep in the soil than barley or field pea (Figure 11).

- The barley crop, following wheat and canola, had the lowest ASW compared with other crop sequences, with a water deficit for most of the growing season and summer period.
- In contrast, field pea, with a shallow root system, had the highest ASW among crops despite the previous crops being canola and barley.
- There was not much difference in ASW between treatments for the barley crop. However, the surface liming and ripping only treatments had higher ASW throughout season under field pea compared with the other treatments.
- Under wheat, deep liming had the highest ASW compared with the other treatments.
- With the canola crop, the deep OA treatment had the lowest ASW among other treatments, but the ripping only treatment had the highest ASW between treatments (Figure 11).

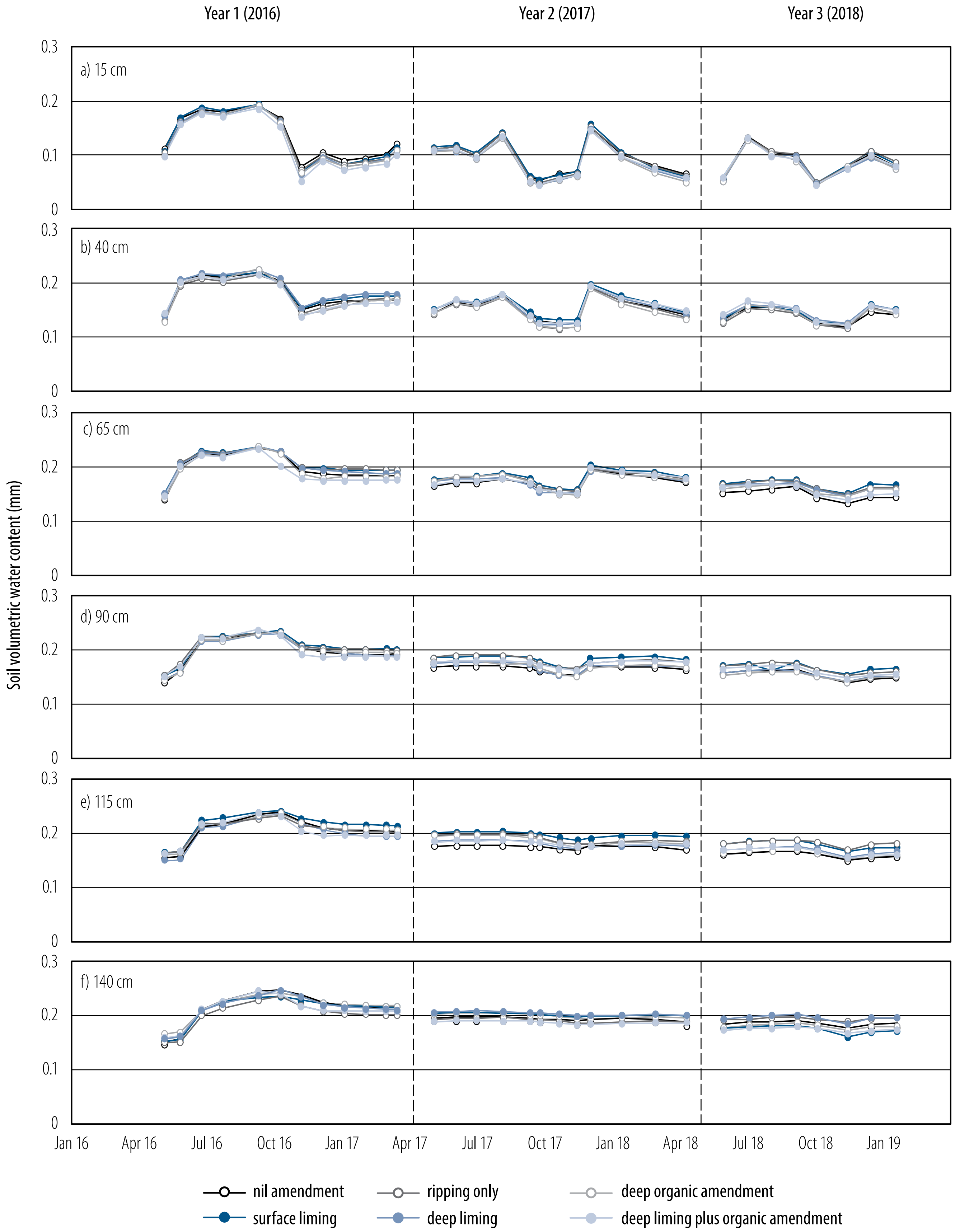

Figure 9. Soil volumetric water content (mm) for each crop in the rotation under different soil amendment treatments over three growing seasons.

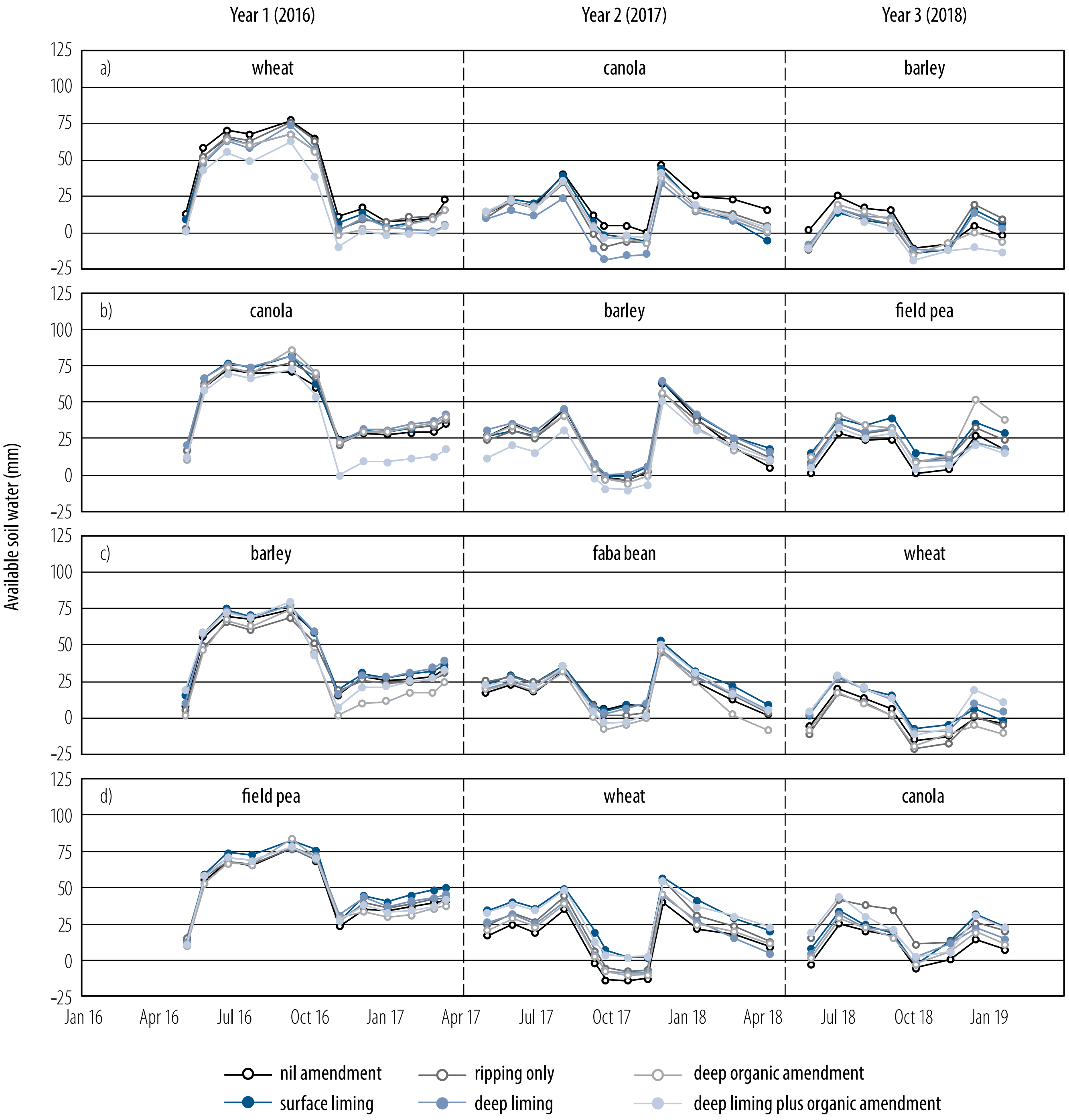

Figure 10. Available soil water (mm) at 15–40 cm for each crop in the rotation under different soil amendment treatments over three growing seasons.

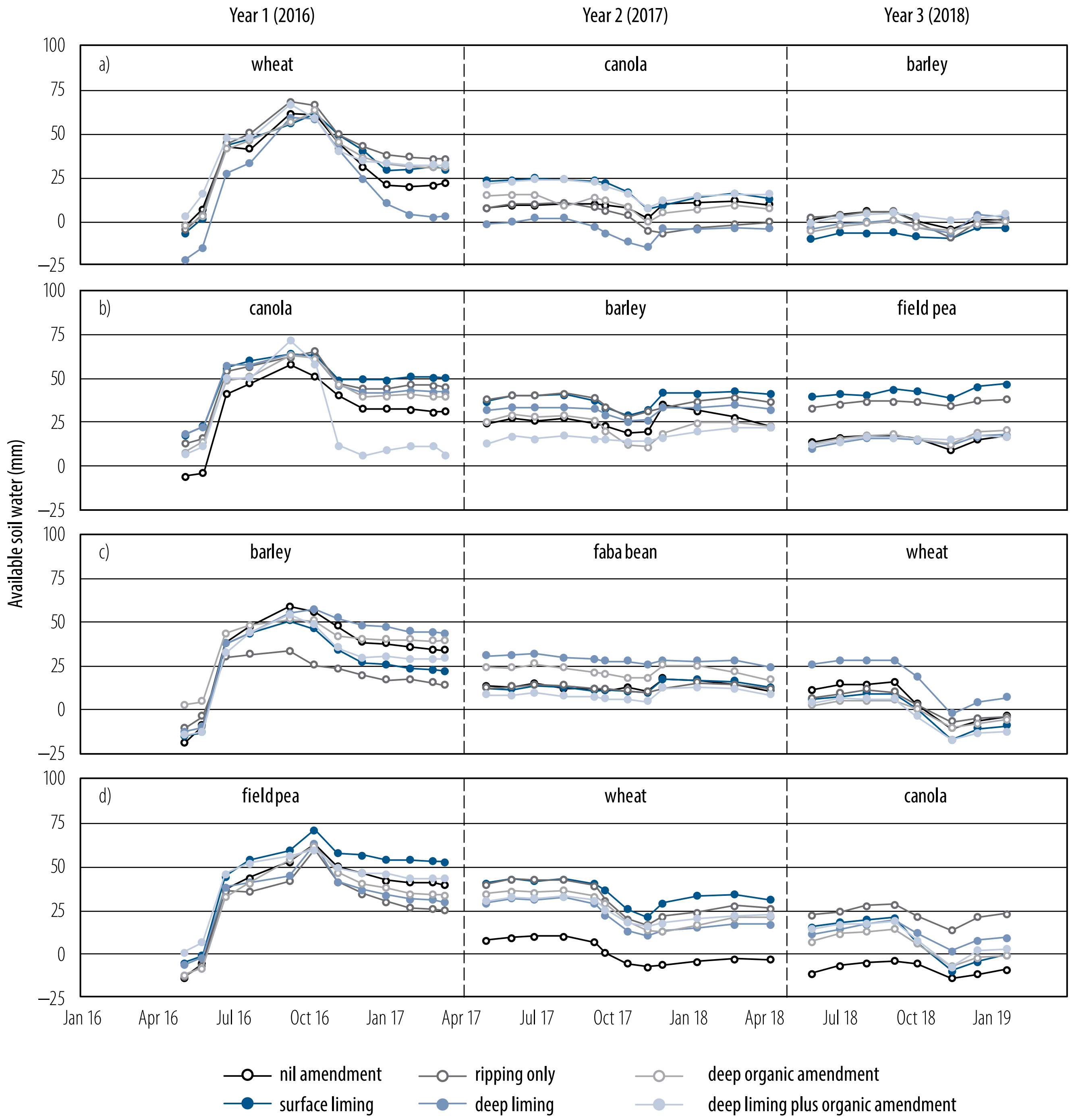

Figure 11. Available soil water (mm) at 65–140 cm for each crop in the rotation under different soil amendment treatments over three growing seasons.

## Agronomic performance

### *Seedling count*

At the seedling stage, there was no significant difference in seedling density for any crops, except for barley, where the two treatments with deep OA had higher seedling density (Figure 12). No treatment difference in seedling density for any crop was likely due to the extremely dry conditions during crop establishment in year two and throughout year three. The site only received 269 mm and 173 mm of rain during the growing season (April–October) in years two and three, respectively (Figure 1).

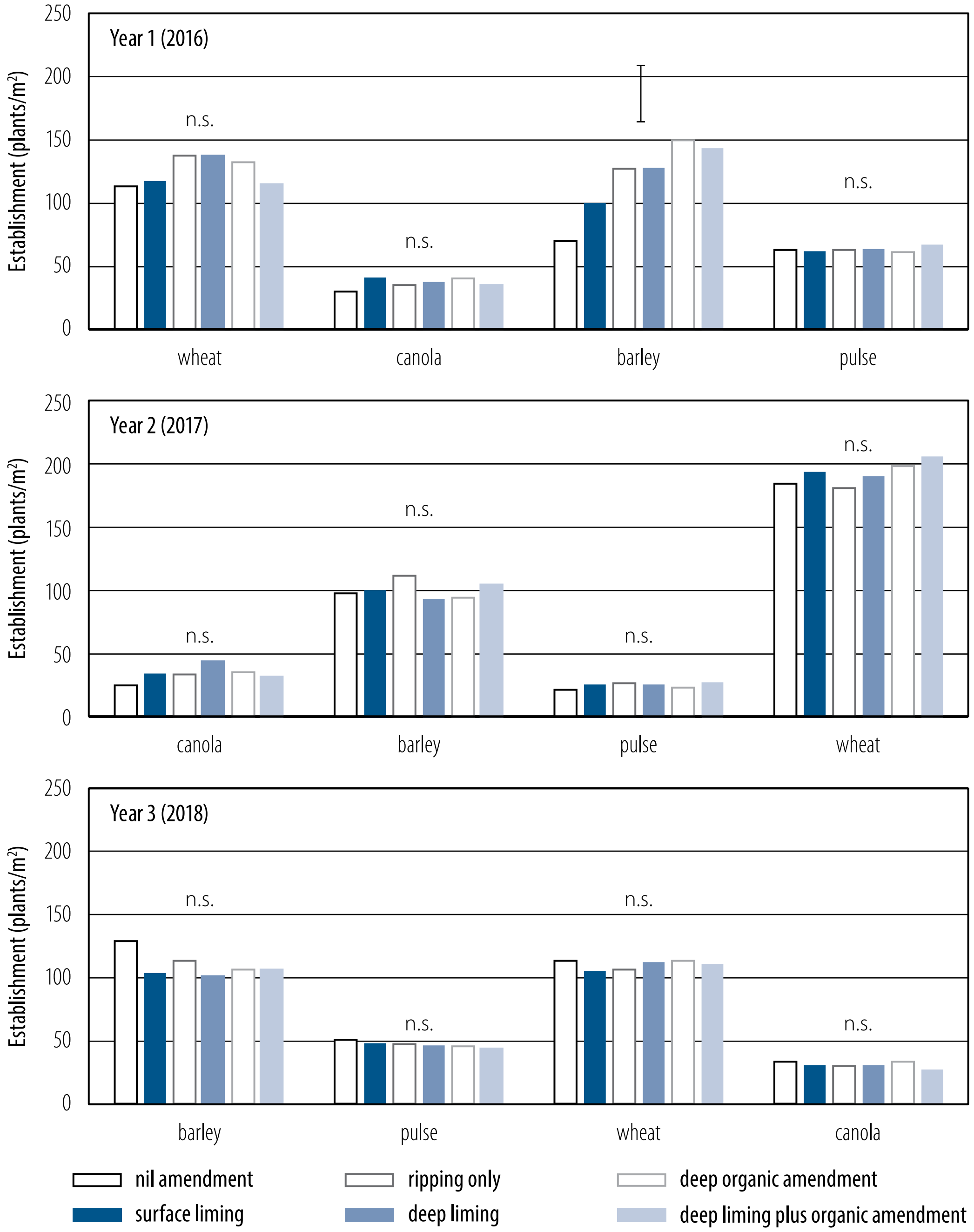

Figure 12. Seedling density (plants/$m^2$) at crop establishment in response to different soil amendments in years 1–3. *Vertical bar represents least significant difference at P = 0.05, n.s., not significant.*

### *Anthesis dry matter*

At anthesis, there were significant differences in DM for all crops in year one (2016), but no differences were found in years two or three (Figure 13). Soil water was not limiting in year one and treatment differences were most likely attributable to increased nutrient supply from those treatments with OA. In years two and three, the most limiting factor was soil water. There was no effect of soil treatment on anthesis DM, although there was significantly more soil mineral N at 0–60 cm at sowing in autumn under deep OA treatments with and without lime compared with other treatments (Figure 4).

### *Harvest dry matter and grain yield*

In year one, the dramatic crop biomass responses observed under treatments with OA at anthesis for the canola and barley crops did not translate into grain yield at harvest, due to severe lodging (Figure 13). In 2017 and 2018, there were no significant differences in grain yield for any crop (Figure 13), which is most likely due to severe moisture stress in both years (Figure 10). The site only received 269 mm and 173 mm of rain during the growing seasons (April–October), respectively, compared with a long-term average growing season rainfall of 332 mm (Figure 1). Canola yielded less than 1 t/ha of grain in both years, whereas faba bean yielded about 1 t/ha grain in year two and field pea had less than 0.8 t/ha in year three (Figure 14). Cereal crops had higher protein under deep OA treatments ($P<0.05$) in both wet and dry years simply due to high available soil mineral N (Figure 4).

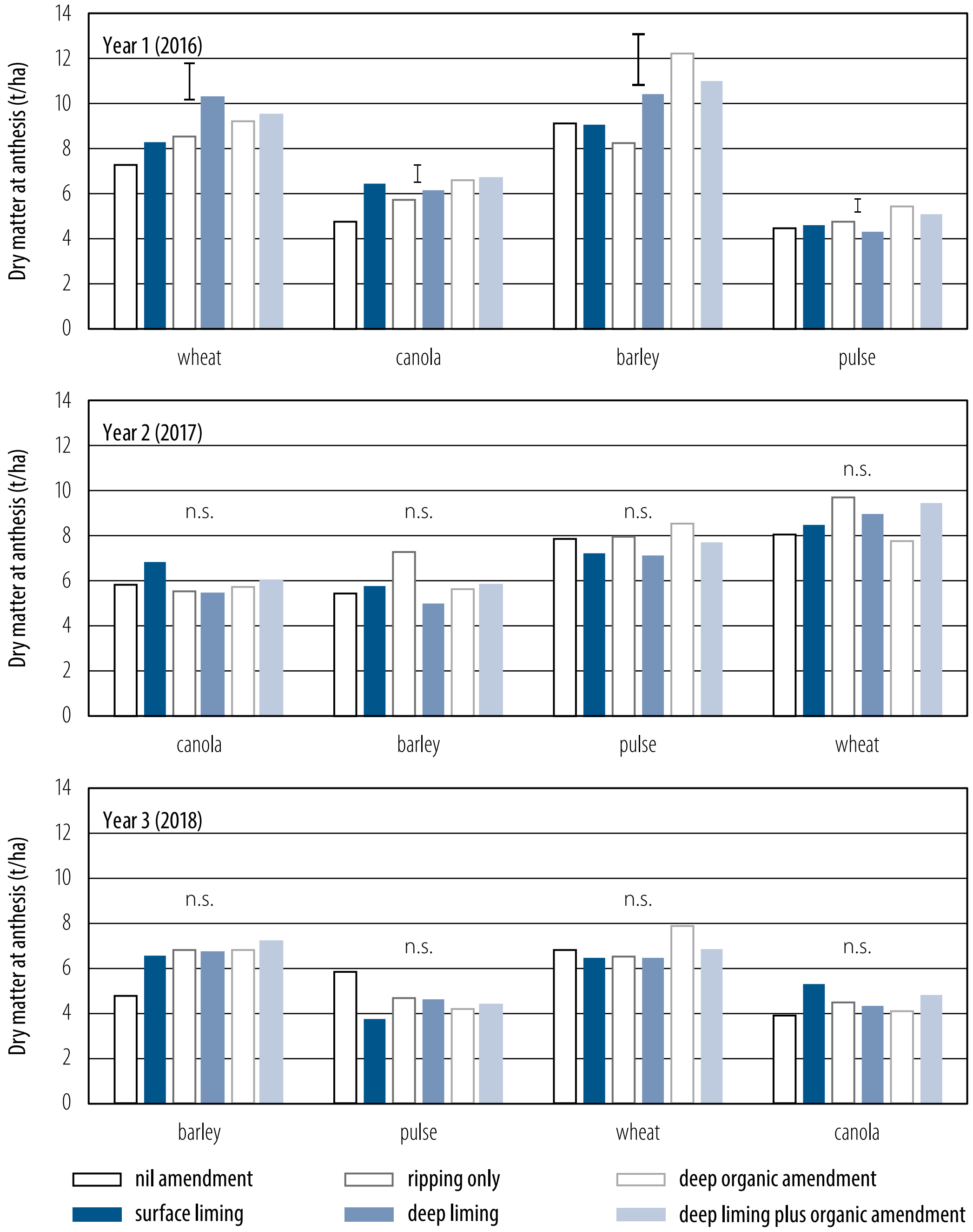

Figure 13. Crop dry matter at anthesis (t/ha) in response to different soil amendments in years 1–3. *Vertical bars represent least significant difference at P = 0.05. n.s., not significant.*

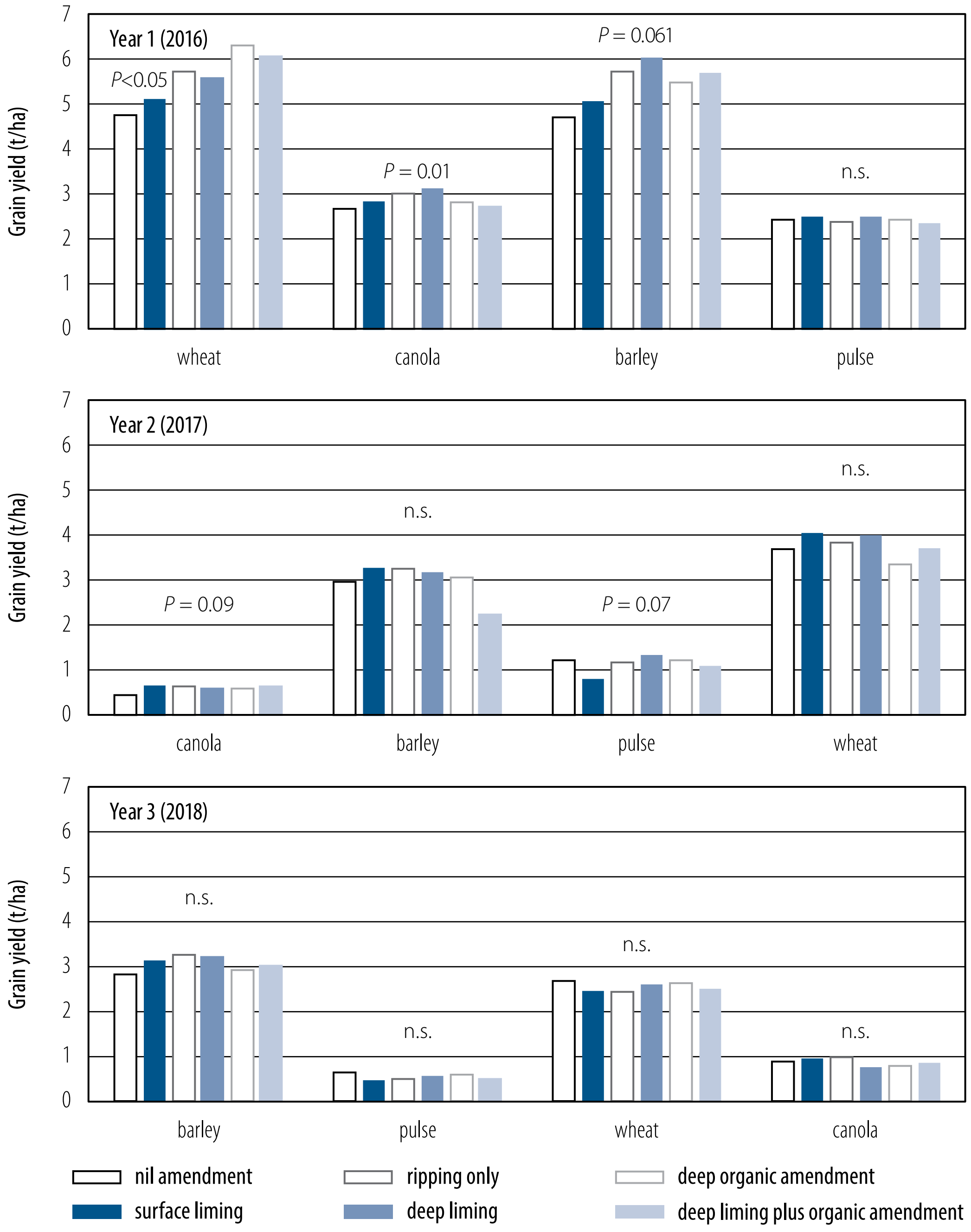

Figure 14. Grain yield (t/ha) in response to different soil amendments in years 1–3.
*Vertical bars represent least significant difference at $P = 0.05$. n.s., not significant.*

## Conclusions

Lime is the most effective amendment to increase pH and reduce exchangeable Al%. Deep placement of organic amendments had a limited effect on soil pH, but significantly reduced the exchangeable Al percentage. The nutrients in lucerne hay pellets, particularly N, increased soil mineral N significantly, but its effectiveness depended on available soil moisture. In dry years, no yield improvement was found despite more soil mineral N being available at sowing.

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## Acknowledgements

This experiment was part of the 'Innovative approaches to managing subsoil acidity in the southern region' project, DAN00206, 2015–20, with joint investment by NSW DPI and GRDC. Our thanks extend to the property manager, Tony Flanery, and land owner, Ian Friend, of Ferndale, Dirnaseer, NSW for their ongoing cooperation since 2016.

# Amelioration of subsoil acidity using organic amendments

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## Key findings

- The crop responded to nutrients rather than improvements in soil acidity in the establishment year.
- Grain yield was higher under the lucerne hay pellets and poultry litter treatments compared with other treatments. There was no yield improvement with the lime treatment compared with the nil treatment in the first year.
- Nitrogen content in plant tissues was higher, compared with other organic amendments, at seedling stage and at anthesis under the lucerne hay pellets and poultry litter treatments due to their high nutrient contents.

## Introduction

A field experiment focusing on organic amendments was established on a highly acidic soil in 2018 and will be monitored over next three years.

## Site details

| | |
|---|---|
| **Location** | Billa, Holbrook NSW |
| **Soil type** | Yellow chromosol (Isbell 1996) |
| **Previous crops** | 2015 Hyola® 970CL canola<br>2016 EGA Wedgetail⍉ wheat<br>2017 EGA Wedgetail⍉ wheat |
| **Crop in 2018** | Grazing canola (SF Edimax CL) |
| **Fallow rainfall (November–March)** | 2018 (292 mm), long-term average (409 mm) |
| **In-crop rainfall (April–October)** | 2018 (214 mm), long-term average (388 mm) |
| **Fertiliser at sowing** | 60 kg/ha mono-ammonium phosphate (MAP) with 11% nitrogen (N), 22.7% phosphorus (P), 2% sulfur (S) |
| **Top-dressing fertiliser (urea)** | 50 kg N/ha as urea |
| **Ripping machine** | 3-D Ripper (5 tynes), designed and fabricated by NSW DPI (Li and Burns 2016) |
| **Ripping width and depth** | 50 cm between rip lines; to 30 cm deep |

| | |
|---|---|
| **Treatments** | There are nine treatment contrasts, with and without lime, focusing on organic amendments (Table 1). Two additional treatments are a nil amendment treatment as a control and a rip-only treatment to assess ripping effects. All treatments were surface limed to pH 5.0 at 0–10 cm except for Treatment 1with no lime and Treatment 3 with a high lime rate (limed to pH 5.5). All surface lime was applied after deep ripping with amendments, then incorporated into 0–10 cm. Plot size: 5 × 20 m = 100 m$^2$. Buffer between plots: 2.5 m, buffer between blocks: 20 m. |

Table 1. Treatment description and amendments.

| ID | Treatment[A] | Description | Organic amendment rate | Other additives | Lime rate (t/ha) | | Target pH | Note[A] |
|---|---|---|---|---|---|---|---|---|
| | | | | | 0–10 cm | 10–30 cm | | |
| 1 | Nil amendment | No amendment | | | – | – | No lime at surface | Control treatment |
| 2 | Deep rip only | Ripped to 30 cm | | | 1.5 | – | Surface pH 5.0 | To assess ripping effect |
| 3 | Surface lime | Surface liming | | | 2.8 | – | Surface pH 5.5 | Treatment contrast 1<br>Surface vs deep lime |
| 4 | Deep lime | Applied at 10–30 cm | | | 1.5 | 2.6 | pH 5.0 at 0–30 cm | |
| 5 | Deep lucerne hay | Applied at 10–30 cm | 15 t/ha | | 1.5 | – | pH 5.0 at 0–10 cm | Treatment contrast 2<br>Lucerne hay with and without lime |
| 6 | Deep lucerne hay with lime | Applied at 10–30 cm | 15 t/ha | | 1.5 | 2.6 | pH 5.0 at 0–30 cm | |
| 7 | Deep pea hay | Applied at 10–30 cm | 15 t/ha | | 1.5 | – | pH 5.0 at 0–10 cm | Treatment contrast 3<br>Pea hay with and without lime |
| 8 | Deep pea hay with lime | Applied at 10–30 cm | 15 t/ha | | 1.5 | 2.6 | pH 5.0 at 0–30 cm | |
| 9 | Deep wheat straw | Applied at 10–30 cm | 15 t/ha | | 1.5 | – | pH 5.0 at 0–10 cm | Treatment contrast 4<br>Wheat straw with and without lime |
| 10 | Deep wheat straw with lime | Applied at 10–30 cm | 15 t/ha | | 1.5 | 2.6 | pH 5.0 at 0–30 cm | |
| 11 | Deep wheat straw plus NPS[B] | Applied at 10–30 cm | 15 t/ha | NPS | 1.5 | – | pH 5.0 at 0–10 cm | Treatment contrast 5<br>Wheat straw plus NPS with and without lime |
| 12 | Deep wheat straw plus NPS[B] with lime | Applied at 10–30 cm | 15 t/ha | NPS | 1.5 | 2.6 | pH 5.0 at 0–30 cm | |
| 13 | Deep NPS[B] | Applied at 10–30 cm | | NPS | 1.5 | – | pH 5.0 at 0–10 cm | Treatment contrast 6<br>Nutrients with and without lime |
| 14 | Deep NPS[B] with lime | Applied at 10–30 cm | | NPS | 1.5 | 2.6 | pH 5.0 at 0–30 cm | |
| 15 | Deep poultry litter | Applied at 10–30 cm | 15 t/ha | | 1.5 | 2.6 | pH 5.0 at 0–10 cm | Treatment contrast 7<br>Poultry litter with and without lime |
| 16 | Deep poultry litter with lime | Applied at 10–30 cm | 15 t/ha | | 1.5 | 2.6 | pH 5.0 at 0–30 cm | |
| 17 | Deep biochar[C] | Applied at 10–30 cm | 10 t/ha | Biochar | 1.5 | 2.6 | pH 5.0 at 0–10 cm | Treatment contrast 8<br>Biochar with and without lime |
| 18 | Deep biochar[C] with lime | Applied at 10–30 cm | 10 t/ha | Biochar | 1.5 | 2.6 | pH 5.0 at 0–30 cm | |
| 19 | Deep RPR[D] 2 | Applied at 10–30 cm | 2 t/ha | RPR | 1.5 | – | pH 5.0 at 0–10 cm | Treatment contrast 9<br>High RPR vs. low RPR |
| 20 | Deep RPR[D] 4 | Applied at 10–30 cm | 4 t/ha | RPR | 1.5 | – | pH 5.0 at 0–10 cm | |

[A] All organic amendments (lucerne hay, pea hay, wheat straw, poultry litter and biochar) were pelletised prior to implementation.

[B] NPS (nitrogen [N], phosphorus [P], sulfur [S]), 5 kg N/t, 2 kg P/t and 1.3 kg S/t as per Kirkby et al. (2013).

[C] Biochar was pelletised with pea hay (50:50).

[D] RPR, Reactive phosphate rock.

## Results and discussion

### Rainfall pattern

It was extremely dry in 2018, particularly in spring with only 22.5 mm and 27.0 mm of rainfall in September and October. The growing season rainfall was only 214 mm from April to October whereas the long-term average is 388 mm (Figure 1).

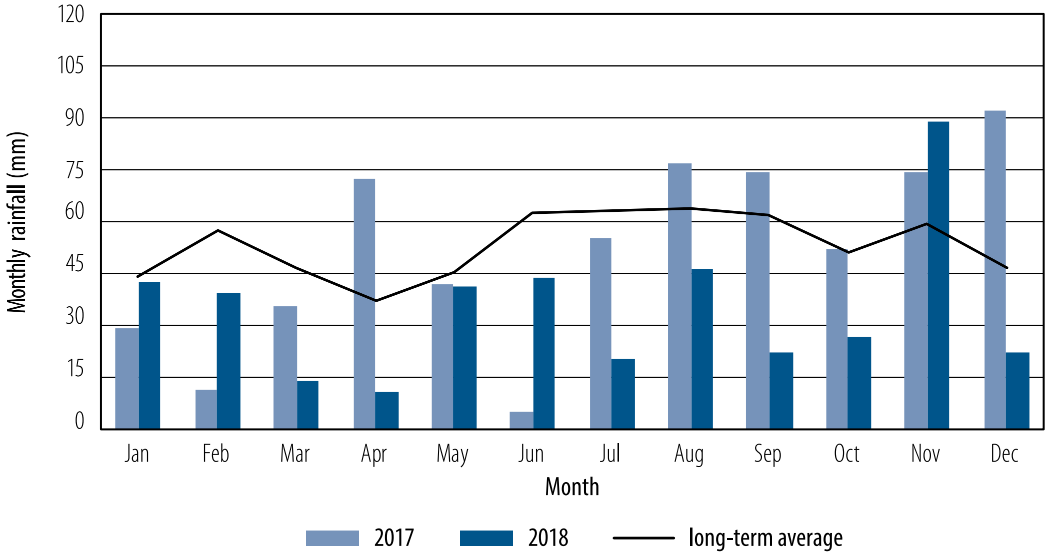

Figure 1. Monthly rainfall and long-term average rainfall at Holbrook, NSW.

### Soil chemical properties

There were no differences in soil pH and exchangeable aluminium (Al%) before treatment was implemented. Averaged across the site, the soil pH was 5.09, 4.09 and 4.24 at 0–10 cm, 10–20 cm and 20–30 cm with exchangeable Al% of 2.6%, 30. 9% and 18.9% at the corresponding depths (Figure 2). The Colwell P was 66.8, 22.3 and 7.1 mg/kg, while soil mineral N was 570, 14.8 and 11.7 kg/ha at 0–10 cm, 10–20 cm and 20–30 cm (Figure 2).

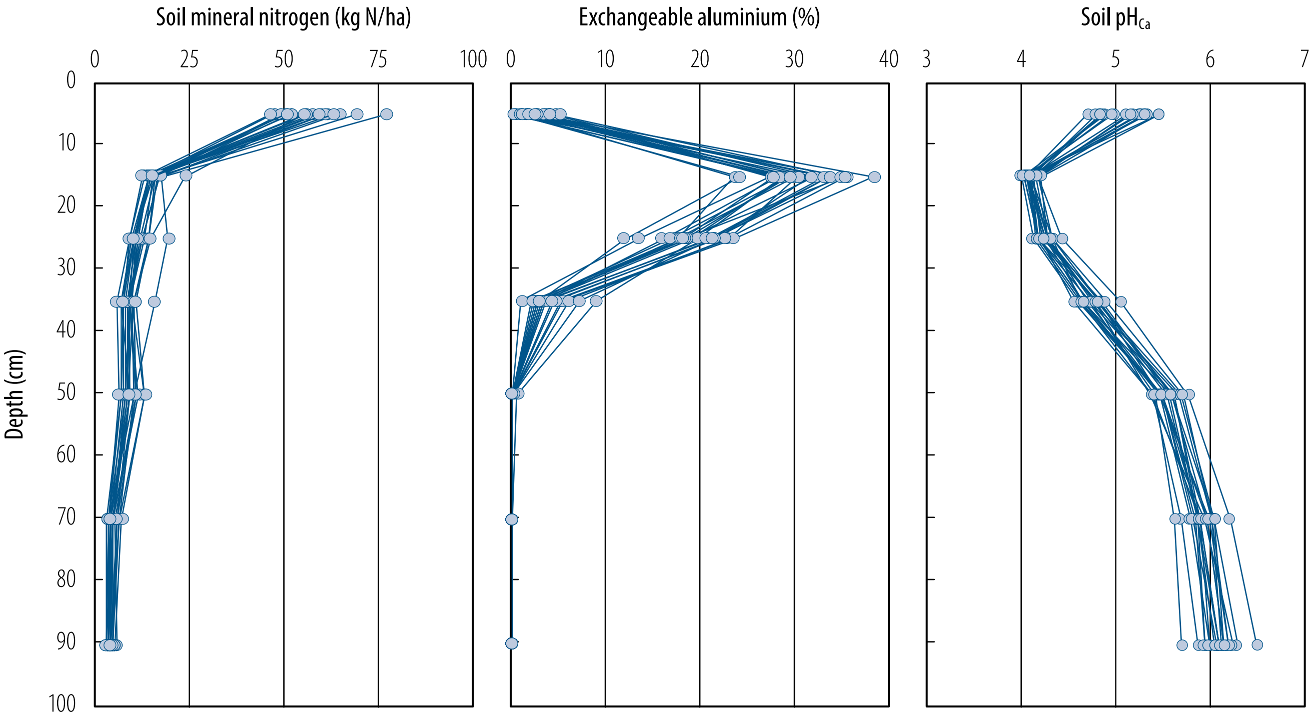

Figure 2. Baseline soil chemical analysis (soil mineral N, exchangeable Al% and pH$_{Ca}$) under designated treatments before treatment was imposed. No significant differences in any parameters at any depths.

### Agronomic performance

The seedling number at establishment varied from eight to sixteen plants/m$^2$ across treatments (Figure 3), but there was no significant difference between treatments due to the large variation across the site.

There were significant differences in crop N content between treatments at seedling stage and at anthesis (Figure 4). Lucerne hay pellet treatments and poultry litter treatments had the highest crop N contents. Wheat straw without nutrients and biochar with pea hay had relatively low crop N contents, which was similar to the non-organic amendment treatments, such as the liming treatment and reactive phosphate rock (RPR) treatments.

At anthesis, the lucerne hay pellet treatment produced 9.6 t/ha of dry matter (DM), whereas the biochar with lime and the wheat straw treatment had only 5.2 t/ha of DM. Both poultry litter treatments had more than 8 t/ha of DM. The non-organic amendment treatments had similar DM at anthesis (Figure 5).

At harvest, grain yield followed a similar trend to anthesis DM. Lucerne hay pellet treatments with and without lime had the highest grain yield, close to 2 t/ha, followed by the poultry litter with lime treatment, whereas the deep lime treatment had similar grain yield to the control (nil amendment) treatment (Figure 5).

In general, the crop responded to nutrients, particularly N, rather than soil acidity amelioration in the first year after treatments were implemented. The higher N contents in plant tissues at seedling stage and at anthesis under lucerne hay pellets and poultry litter treatments were due to their high N contents. Grain yield was higher under lucerne hay pellets and poultry litter treatments compared with other treatments. In this first year, no yield improvement was found with lime compared with its pair treatment with any organic amendment.

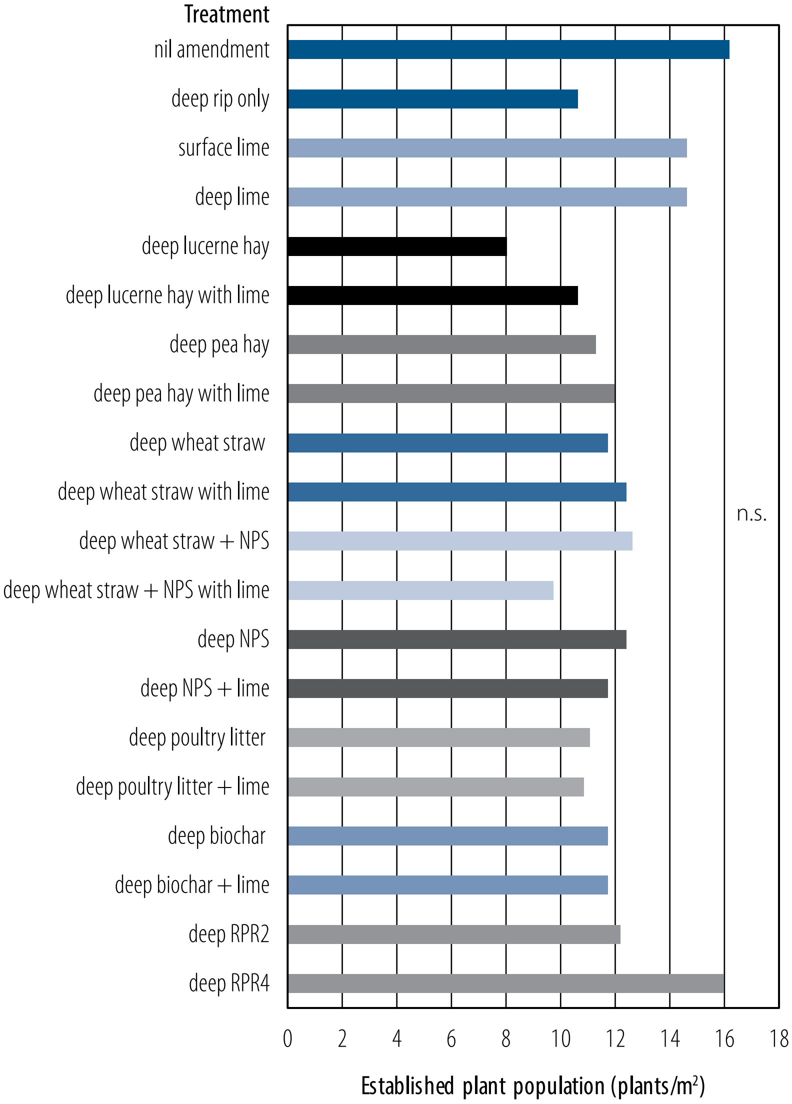

Figure 3. Seedling count (plants/$m^2$) at establishment under different treatments.

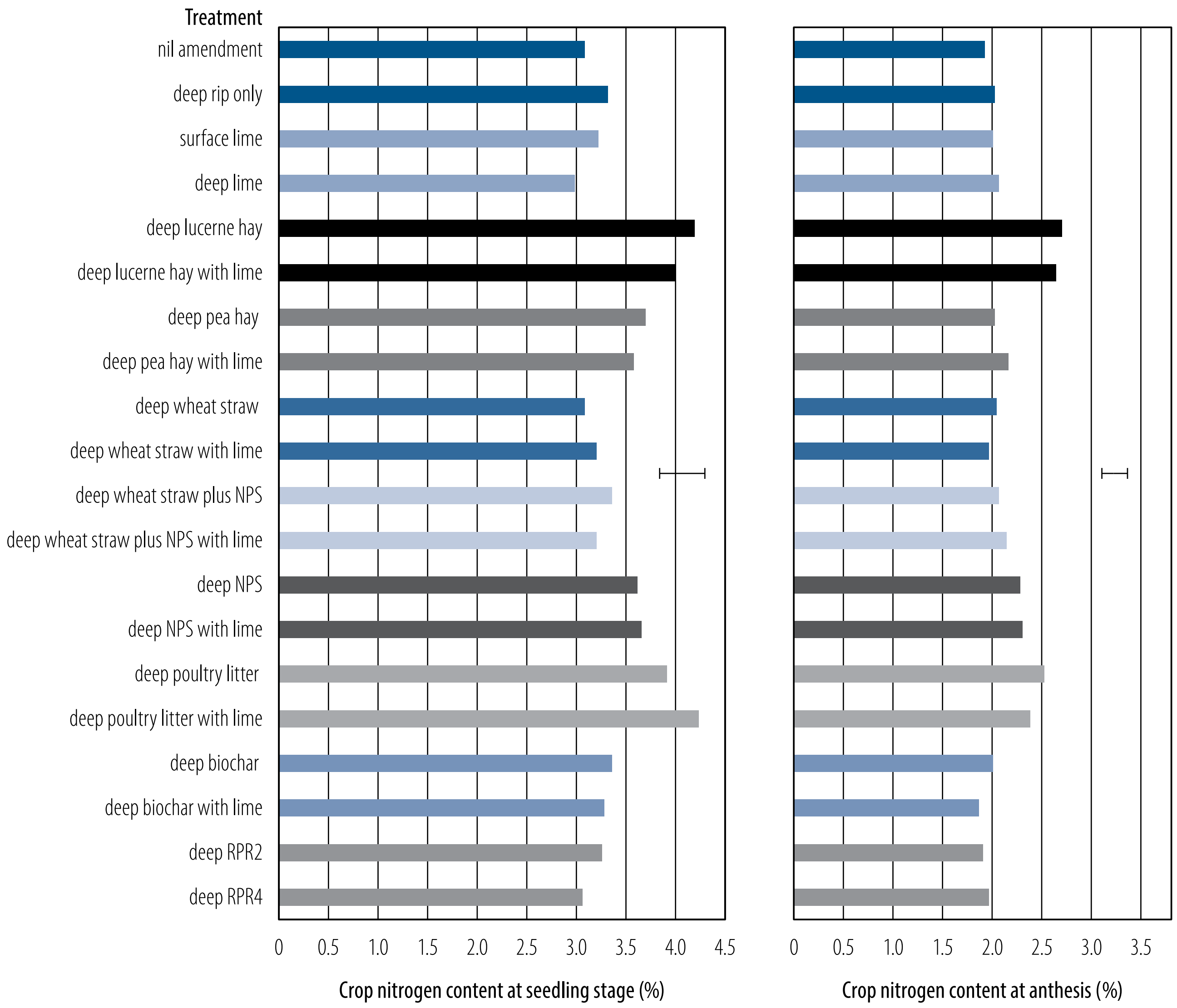

Figure 4. Nitrogen content (%) in plant tissue at seedling stage and at anthesis under different treatments.

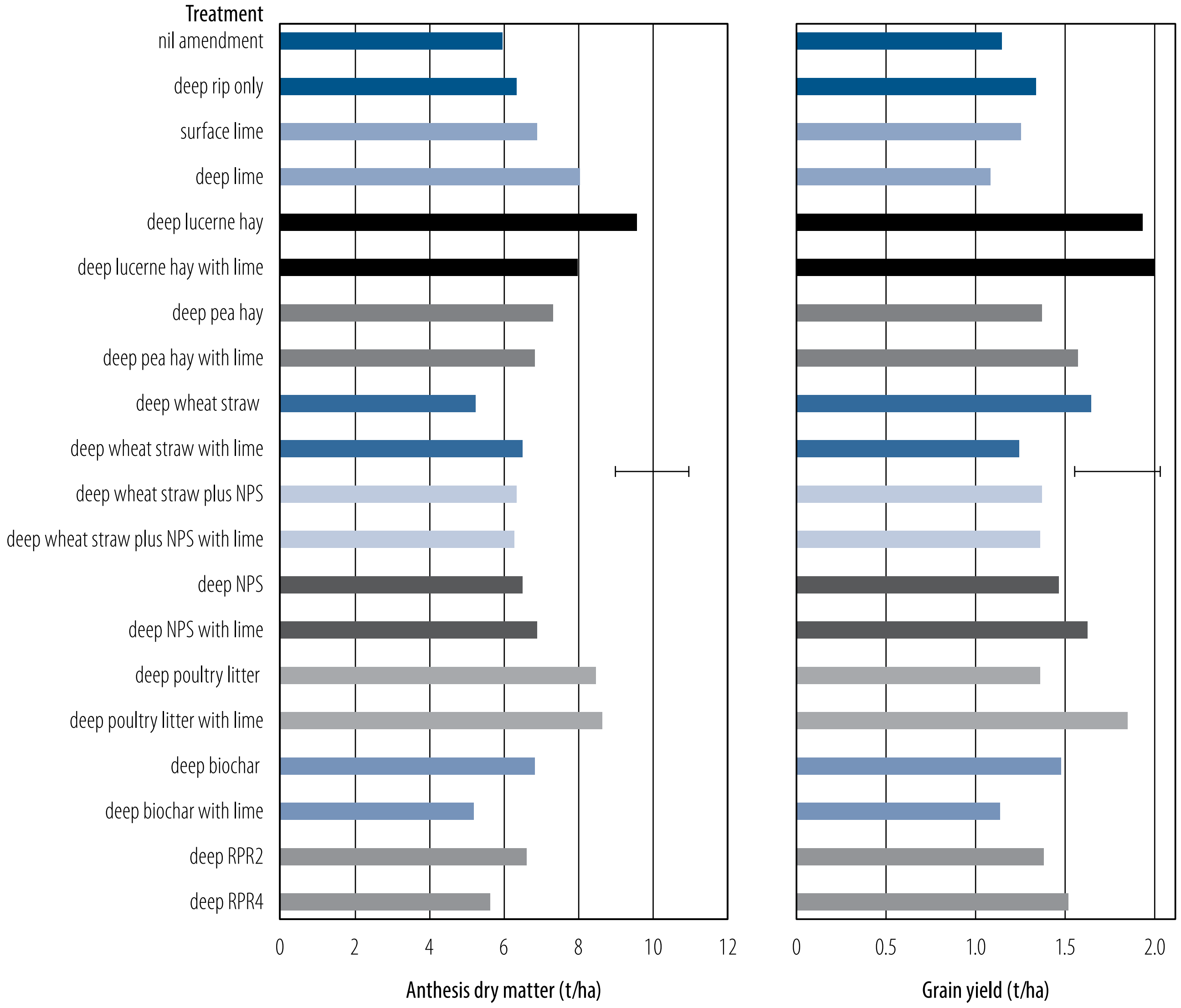

Figure 5. Crop dry matter at anthesis and grain yield at harvest under different treatments.

## Conclusions

The crop responded to nutrients rather than improvements in soil acidity in the establishment year. Grain yield was higher under the lucerne hay pellets and poultry litter treatments compared with other organic amendments. There was no yield improvement with the lime treatment compared with the nil treatment in the first year.

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## Acknowledgements

This experiment was part of the 'Innovative approaches to managing subsoil acidity in the southern region' project, DAN00206, 2015–20, with joint investment by NSW DPI and GRDC. Our thanks extend to land owner Tony Geddes for his ongoing cooperation during the experiment.

# Soil constraints in Australian agriculture: Research priorities and approaches

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## Key findings

- Mapping specific constraints at less than the paddock scale will better define soil constraint extent and spatial distribution. This is particularly important for areas where there are multiple interacting constraints and soil-type specific responses to amelioration.
- The potential to increase production and profitability will guide research investments into soil constraints. Advisors and producers need to ground truth any soil amelioration strategy to maximise farm readiness and adoption.
- Multiple soil constraints should always be evaluated in combination with each other, and not in isolation.
- Amelioration strategies that are practical, feasible, accessible, system-integrated, and target the major constraints are more likely to be adopted than expensive niche products.
- Machinery for applying ameliorants should be flexible to manage various soil amendment product choices. Alternatively, products should be designed to be used with existing farm machinery, so that growers can switch to different materials depending on issue, season, availability and cost.

## Introduction

In Australia, approximately 75% of agricultural soils have constraints that limit productivity (Orton et al. 2018). Soil constraints can be any physical, chemical or biological characteristic that limits root access to moisture and nutrients or reduces plant function. Some examples of soil constraints include:

- low water and nutrient holding capacity
- low nutrient status
- acidity
- alkalinity
- dispersiveness
- salinity

- compaction
- hard-setting soils
- non-wetting properties.

Identifying, understanding and managing these constraints are major challenges to increasing agricultural productivity, especially when multiple constraints occur in the same soil. Soil constraints can occur in the surface, subsurface or subsoil, or throughout the profile. Although a number of amelioration strategies are available to manage some of these constraints, there are fewer technologies developed for ameliorating subsoil constraints compared with surface constraints.

Emerging technologies such as subsoil manuring and injection, and adding clay and organic matter (OM) into bleached horizons of lighter texture soils are currently being examined to manage subsoil constraints. This paper presents an overview of the cost and benefits from various methods of soil constraint amelioration and identifies the future research and development (R&D) priorities to increase production on these soils.

## Methods

This analysis used expertise from key practitioners, managers, technical experts, advisers and innovators. Interrelated activities were conducted, including:

- a combination of reviews and mapping activities (to define the location, scale and magnitude of soil constraints)
- technical working groups (to review literature and findings on soil constraint mapping and amelioration products)
- adviser and industry surveys (to collect baseline information on current amelioration strategies and limitations to adoption).

## Results and discussion

The scoping study examined constraints including dispersive clays, alkalinity, acidity, salinity, compaction, poor nutrient holding capacity and supply. Tables 1 and 2 summarise the key findings.

Table 1. Overview of the likely effect from investment in soil constraints for agriculture.

| Issue, area (ha), location, industry | Main production benefits from overcoming constraint |
|---|---|
| Dispersive and alkaline soils:<br>Over 13.4M ha in NSW, Vic, Tas, SA and WA. Wide range of crops, grazing and irrigated horticulture. | 13.2M t/yr if the whole area is treated based on an increase in wheat yield with 60–80% water use efficiency. Amelioration can lead to increased and more reliable production with the potential for higher value crops. |
| Soil acidity:<br>35M ha of highly acidic ($pH_{Ca}$ <4.8); 55 M ha moderately–slightly acidic ($pH_{Ca}$ 4.9–6.0); ~50% agricultural land $pH_{Ca}$<5.5. Issue in western, southern, and eastern Australia; cropping, grazing and horticulture. | Estimated cost of acidity to the agricultural sector is $1.58B/yr. Current research indicates yield increases of 10–18% for crops, and GRDC research reported a net benefit of $85/ha due to pH correction in WA. Amelioration can lead to increased and more reliable production with the potential for higher value crops and legumes. |
| Salinity:<br>Over 5.5M ha, with ~2M ha agricultural and 140,000 ha irrigated. Majority of salinity is in WA (1.2M ha) where severity is greater. | Benefits are primarily off-site, whereas costs are likely to be incurred on-site. Cost to agriculture is ~$130M in lost production potential, with a further $100M/yr flow-on effect on infrastructure. The total cost of salinity is $1.1B, of which $130M is agricultural. |
| Nutrient constraints:<br>Most agricultural soils; insufficient information to define subsoil deficiencies; cropping, grazing and horticulture. | Fertiliser comprises ~30% of crop production costs. Widespread negative potassium (K) and magnesium (Mg) balances, and positive balances for phosphorus (P) on farms. Magnitude of subsoil nutrient deficiencies not known. |
| Sandy soils:<br>>7M ha in WA and >3.5M ha in southern Australia. Grain cropping (most species, except lentil and chickpea), mixed farming and grazing. | The area that could benefit from clay addition is >7.5M ha (4.5M ha in WA; 2M ha in SA; 0.5M ha in Vic and NSW) and OM inclusion is 10M ha. Yield increases ~50% from added clay (Esperance, over 15 years) and 1.3 t/ha/yr (in SA). Co-benefits: increased available P, K, sulfur (S), pH buffering capacity; decreased risk of erosion, frost damage and waterlogging. |

Table 2. Research type required (applied or basic) and likely adoption.

| Constraint | Research type required (applied or basic) and likely adoption |
|---|---|
| Dispersive and alkaline soils | **Applied** – soil type to determine how much, what form and how often to apply amendments.<br>**Basic** – understand how amendments affect the soil function, structure and nutrient availability; opportunities for novel products, e.g. organic amendments and nanofertilisers. Adoption timeframe 5–20 years. |
| Soil acidity | **Applied** – update acidification risks and modify recommendations for modern farming systems. Develop and test new amendment types and application technologies for subsurface and subsoil acidity. Adoption timeframe 5 years. |
| Salinity | **Applied** – landscape hydrology: complex modelling and development at a small scale (catchment and farm) is required. Adoption timeframe 5–10 years, with effects likely to be sooner for irrigated soils impacted by salinity. |
| Compaction | **Applied** – quantify the cost impost on production from compaction and hard-setting soils; framework for determining the compaction benchmark on a soil-specific basis; determine enduring solutions for hardpans; further evidence on controlled traffic farming (CTF) conversion options. |
| Nutrient constraints | **Applied** – site-specific nutrient management.<br>**Basic** – novel fertiliser product development and understand the role of subsoil nutrient supply. Adoption timeframe 5–20 years. |
| Sandy soils | **Applied** – use types of sand by rainfall zones to determine a package of clay and OM amelioration practices.<br>**Basic** – the role of subsoil OM and clay on subsoil root function, water and nutrient availability, and soil functions. Adoption timeframe 5–10 years. |

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## Acknowledgements

The work has been supported by the Cooperative Research Centre for High Performance Soils whose activities are funded by the Australian Government's Cooperative Research Centre Program (Soil CRC Scoping Study 3.3.01).

# Potential of commercial rhizobial strains for new and existing perennial pasture legume cultivars on the NSW Tablelands

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## Key findings

- Sites with a history of inoculation might have competitive populations of rhizobia with variable effectiveness for a given host.
- Some commercial inoculants for perennial legumes suited to the NSW tablelands can form root nodules with more than one legume species, and in some cases this can compromise nitrogen fixing.
- Within legume species, some cultivars formed effective root nodules with certain rhizobial strains, while others did not.
- Most of the rhizobial strains in nodules correlated with the commercial inoculant used before sowing. However, the persistence of some these rhizobial species is likely to be influenced by acidic soils and high exchangeable aluminium at some sites.
- Our results suggest:
  - Where a history of annual subclover (and commercial inoculant WSM1325) is common, perennial legume cultivars with a capacity to form an effective symbiosis with the rhizobial strain WSM1325 might be desirable.
  - Select pasture mixes with similar rhizobial strain requirements and inoculate accordingly.
  - Where multiple hosts are sown together, ensure legume seeds are inoculated with the most effective rhizobia strain separately, before sowing.

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## Introduction

Perennial legumes are thought to have the potential to increase pasture productivity due to their ability to use summer rainfall and fix nitrogen. However, relatively few viable varieties exist for the NSW Tablelands and pasture mixtures are likely to include subterranean clover. It is therefore critical to understand the compatibility/competitiveness attributes of host–plant rhizobia associations. Typically, rhizobial species have a host range and only form an effective symbiosis (a functional nodule) with certain legume species. We studied the effectiveness of commercial rhizobial strains for perennial legumes.

## Experiment 1 – Legume–rhizobia compatibility study

Thirteen legume cultivars – white clover (six cultivars), talish clover (1), red clover (1), strawberry clover (1), Caucasian clover (1), birdsfoot trefoil (1) and lucerne (2) – were assessed for nodulation and biomass growth against five commercial rhizobial strains (CC283b, RRI128, SU343, TA1 and WSM1325). Inoculant effectiveness was measured by comparing the inoculated plant's shoot dry matter with the controls. The number and colour of nodules per plant was also recorded.

### Results – Experiment 1

There were highly significant differences between rhizobial strains in the nodule number (Figure 1) and shoot biomass production (Figure 2). There were also significant interactions with the lucerne cultivar, red clover (shoot biomass only) and white clover. While some rhizobial strains formed root nodules on multiple species and/or legumes cultivars, certain strains were more effective at increasing the amount of shoot biomass produced relative to the control.

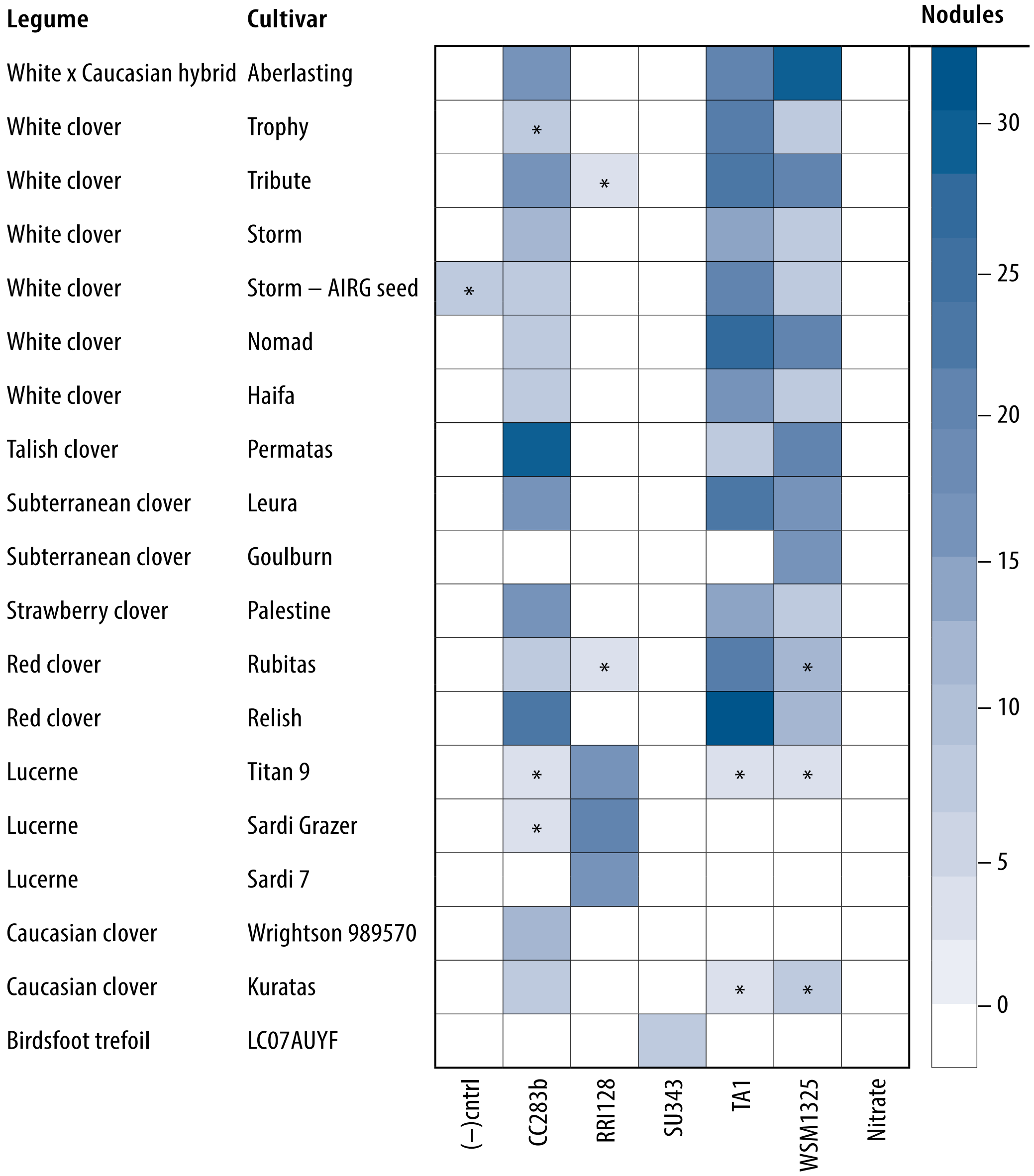

Figure 1. Heat map of mean number of nodules for legume × rhizobia strain. Legume × rhizobia strains with high variability (defined as CV>100%) are indicated by asterisk (*).

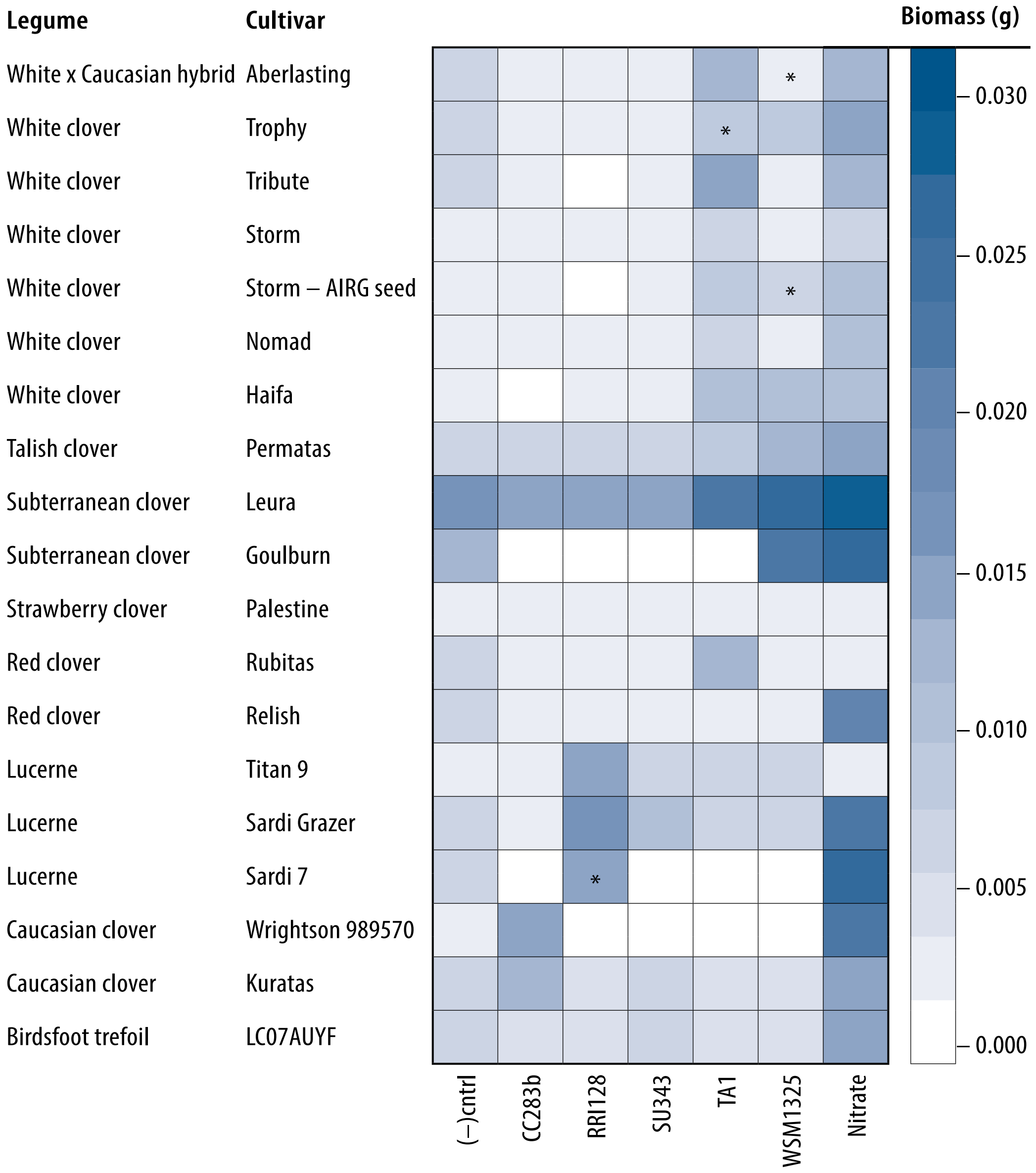

Figure 2. Heat map of mean shoot biomass weight (g) for legume × rhizobia strain. Legume × rhizobia strains with high variability (defined as CV>50%) are indicated by asterisk (*).

## Experiment 2 – Nodule occupancy field study

This experiment collected samples from five field trials (Gunning, Paling Yards, Mandurama, Wandsworth and Orange) sown in autumn 2018 to evaluate the adaption and persistence of the same (as above) selected perennial legumes on the tablelands of NSW. These legumes were inoculated with the commercially recommended rhizobia using recommended practice. Nodules were collected in October 2018 (5–7 months post-sowing) and the rhizobial strains present identified.

### Results – Experiment 2

Overall, most of the rhizobial strains found in the nodules correlated with the inoculants used for each legume host. However, at some sites there were slight genetic variations from commercial inoculants. This could be due to occupancy by naturalised rhizobial strains in the soil, including from previous rhizobial inoculant applications from which surviving organisms have mutated. However, based on Experiment 1, these nodules are unlikely to be effective.

## Discussion

For perennial legumes to increase pasture productivity in the tablelands of NSW they need to form effective root nodules with commercially available rhizobial strains applied when pastures are sown. Our results show that this might be complicated when pastures are sown as a mixed sward containing more than one legume species, with different rhizobial strain requirements. In addition, sites that have a history of inoculation could have competitive populations of rhizobia with variable effectiveness for a given host. More research is needed on the role and manipulation of selection for effective nodulation in the field, so that introduced inoculant strains are favoured in pasture systems that have a history of inoculated annual clovers typical of the tablelands of NSW.

## Acknowledgements

Funded with joint investment by NSW DPI and MLA Donor Company and through the Livestock Productivity Partnership (Project P.PSH.1030).

Rhizobial mother cultures were supplied by the Australian Inoculant Research Group, NSW DPI.

We acknowledge Susan Langfield and Cameron Murray (Pastures Unit, NSW DPI) for assistance in field collection of legume roots. Thanks to Rowan Smith and Beth Penrose (UTAS) for Talish Clover seed.

# Monitoring long-term soil condition in the Murray irrigation districts

Sam North, Alex Schultz and Don Griffin (NSW DPI, Deniliquin)

## Key findings

- Sites in one of the Murray Irrigation Districts where CSIRO sampled soil in the 1940s have been found and geolocated. If this can be done for all districts, then it will be possible to establish a baseline condition for agricultural soils in the central Murray Valley at a time that pre-dates the advent of modern, intensive agriculture.
- This has the potential to provide valuable information on long-term changes in soil salinity, acidity and soil carbon. For instance, resampling at 12 sites in the Deniboota Irrigation District in 2017 showed that salts present in all profiles in the 1940s have been leached from both dryland and irrigated sites over the past 70 years.

## Introduction

Monitoring has a key role in managing natural resources and improving our understanding of biophysical processes. It also informs decisions and provides feedback on how those decisions affect the resources being managed. One such resource is soil, upon which terrestrial ecosystems and agriculture depend. A considerable amount of soil data was collected by CSIRO in the 1940s to assess land suitability and capability for irrigation. This pilot project aimed to locate and resample a small number of these sites to assess the potential usefulness of an expanded resampling program. This might allow changes in soil condition that have occurred over the past 70 years to be identified and provide valuable data to inform future investment in management and research, development and extension (RD&E) plans.

## Methodology

### Site selection

The Deniboota District soil survey report (Johnston 1953) was the only Murray Valley survey report that contained both full chemical analyses and location details. The location details allowed a latitude and longitude to be found for each site in Google Earth™. Twelve sites were selected for resampling in 2017 to provide four soil replicates in each of three major soil types: chromosols, sodosols, and sodic vertosols (Isbell and NCST 2016). Duplicates for each of these selected soils were found nearby to provide either a dryland or an irrigated soil pair, depending on the land-use history of the selected 1940s site. Thus, four replicate soils were sampled in 2017 in each of three soil types by two land-use categories; a total of 24 sample locations at 12 sites.

### Sampling procedure and analytical methods

Soil was sampled from pit walls in 1946–48, while the 2017 soil samples were obtained by coring. Five intact cores (50 mm diameter by 1.2 m long) were taken approximately 0.5 m apart at each sample location. Each core was wrapped in plastic (Clingfilm™), placed in a PVC tube to maintain its integrity, labelled, and boxed for transport back to the laboratory.

The five cores were photographed in the laboratory and profile characteristics were noted (horizon depths, colour, consistence, carbonate, presence/absence of roots). Samples were taken from four cores at depths corresponding to those originally sampled. These samples were bulked and sent to the NSW DPI laboratory at Wollongbar for analysis. Where possible, modern analytical methods were chosen that corresponded with the analytical methods described by Piper (1942) and the modifications reported by Johnston (1953). These were methods 4A1, 4A2, 3A1, 19A1, 5A2b, 6A1, 7A2, 9A3a, 15A1 and 15G1 of Rayment and Lyons (2011).

## Results

### Soluble salts

The greatest change between 1947 and 2017 was the leaching of chloride from both dryland and irrigated profiles (Figure 1a). In contrast, exchangeable sodium changes were minimal (Figure 1b).

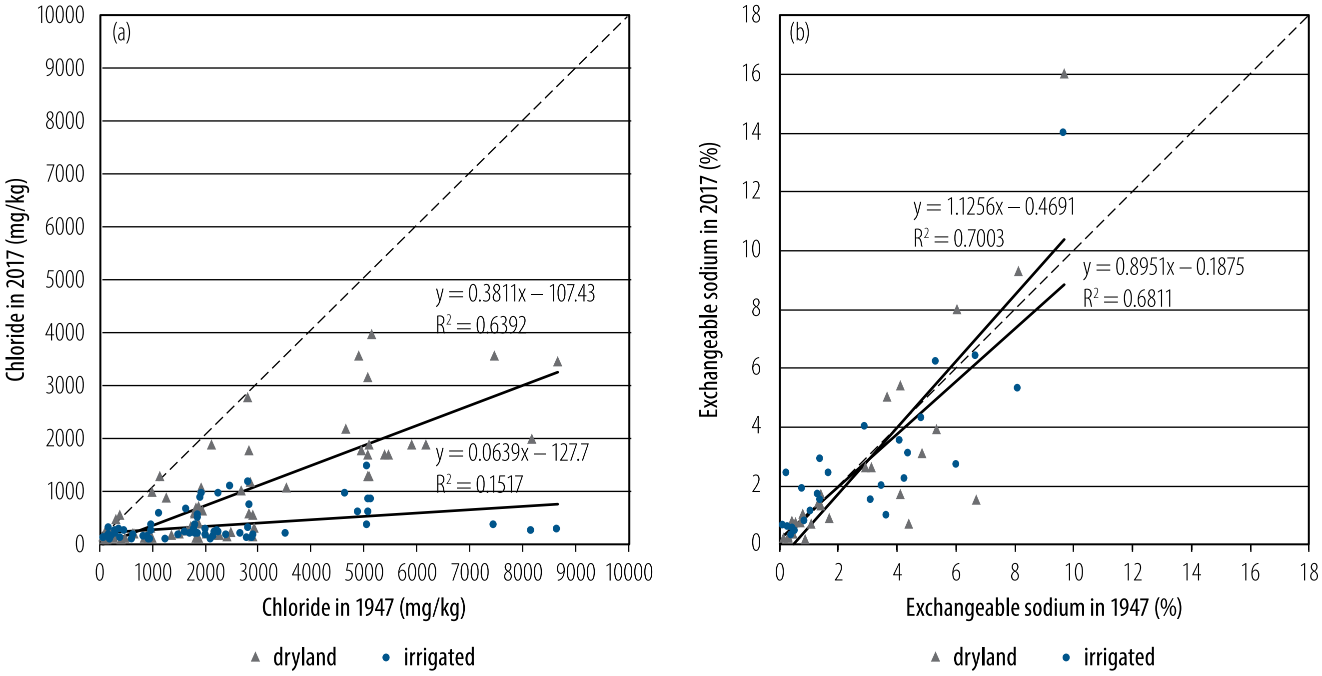

Figure 1. The relationship between 1946–48 and 2017 concentrations of (a) soluble chloride and (b) exchangeable sodium in soil samples taken from the Deniboota Irrigation District.

### Acidity

There has been no appreciable change in the acidity (pH) of soil profiles at these sites over the past 70 years (Figure 2), except for a possible slight decrease in the pH of lighter textured top soils at irrigated sites.

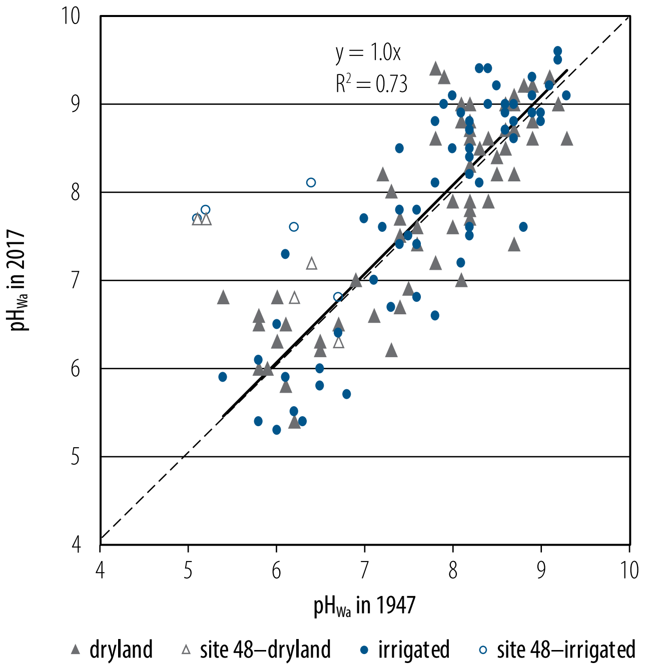

Figure 2. $pH_{Wa}$ of Deniboota soils sampled in 1946–48 and in 2017. The solid black line shows the least squares regression for all sites except sites DBA048 and DBA048a.

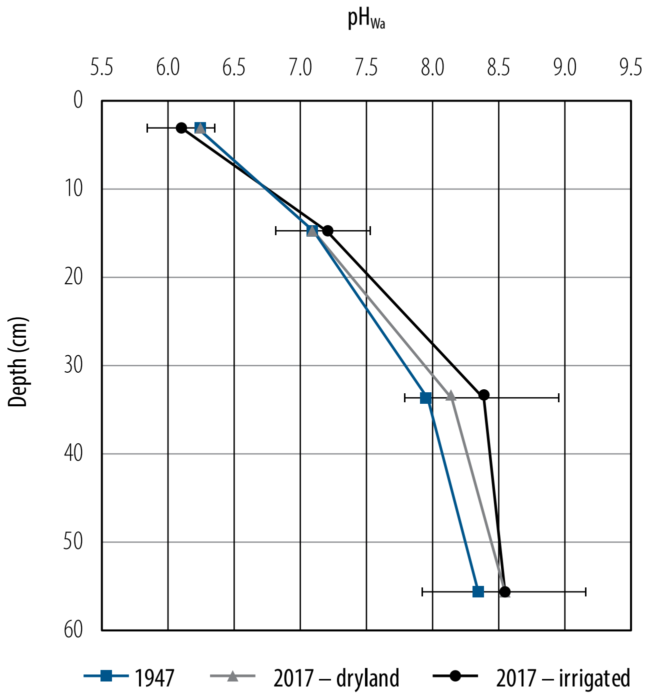

Figure 3. Average $\mathrm{pH}_{\mathrm{Wa}}$ for each sample group at the average depths of sampling. Error bars = 95% CI.

### Organic carbon

There was an estimated 0.4% more organic carbon in the surface soils of both dryland and irrigated sites in 2017 compared with the soils sampled in 1946–48. This difference is significant.

### Cation exchange capacity

There was no significant difference in cation exchange capacity (CEC) between 1946–48 and 2017, though CEC was generally lower in 2017 across both dryland and irrigated sites.

## Discussion

### Soluble salts

As the soil solution must remain electrochemically neutral, it is presumed the chloride leached from these profiles was replaced firstly by dissolution of solid gypsum and then secondly by dissolution of carbonates. The implications of this, particularly on soil structure, are unknown, but it can reasonably be expected that a reduction in the electrolyte effect with no concurrent reduction in the exchangeable sodium percentage will lead to dispersion and soil instability.

The initially high chloride content of Deniboota soils was thought to be due to a high water table in the district that had receded prior to sampling by CSIRO in 1946–48 (Johnston 1953). Much of this chloride appears to have been leached by rainfall over the past 70 years, while exchangeable sodium has remained largely unchanged (Figure 1). It is presumed that the soils now contain a mix of sodium salts of chloride, sulfate and carbonate, whereas in the 1940s, chloride would have been the dominant anion. Chloride mass balance modelling would enable long-term deep drainage rates to be estimated for these sites.

### Acidity

The finding of no appreciable change in pH is at odds with other studies that have observed low pH in a high proportion of irrigated soils in southern NSW (Dunstan 1984; Beecher and Lake 2004; North 2004). Strong leaching is a potential driver of soil acidity due to the loss of metal cations and their replacement with $H^+$. The original high levels of chloride salts, the high CEC, and the presence of carbonate and an alkaline trend in most profiles, would all help to buffer against increased acidity. The intensity of irrigated agriculture in the Deniboota Irrigation District is generally lower than in other southern NSW districts and this would help to slow acidification rates. Whilst this result is pleasing, the loss of chloride from all profiles may precede the dissolution and loss of carbonates if leaching continues, leaving these soils susceptible to acidification in the future.

### Organic carbon

The estimated increase in organic carbon could be due to a number of reasons, but the most likely is the difference in topsoil and land condition in 1946–48 compared with 2017. Widespread wind erosion occurred throughout the Riverina as a result of the 1942–45 drought, with Johnston (1952) reporting the loss of approximately 25 mm of top soil from Deniboota soils. This would undoubtedly have resulted in low soil organic carbon levels in topsoils in 1946–48.

Expanding this pilot project would provide a better baseline for soil carbon than is possible from just 12 locations where seasonal sampling effects are not able to be accounted for.

### Cation exchange capacity

A reduction in CEC and pH can indicate clay structure breakdown when soils are alternately reduced and oxidised; a process known as ferrolysis (Brinkman 1970). CEC was generally lower in 2017, but this was across both dryland and irrigated sites, indicating the difference was due to sampling or changes in analytical techniques since the 1940s, rather than irrigation. As there was no appreciable decline in pH, it appears unlikely ferrolysis is occurring in these soils.

The higher CEC measured in 1946–48 is more likely due to the method used to extract exchangeable cations (i.e. leaching with 1N $NH_4Cl$), which only provides a useful estimate of exchangeable bases for acidic and neutral, non-saline, non-calcareous and non-gypsiferous soils of low ionic strength (Rayment and Lyons 2011). Because all soils had an alkaline trend and high levels of salt and carbonate at depth in 1946–48, the CEC measured at that time would have been higher because of the inclusion of soluble as well as exchangeable bases in the analyte.

## Conclusion

This small pilot project has clearly demonstrated that it is possible to refind and geolocate the sites in the Murray irrigation districts that CSIRO sampled in the 1940s. While only 12 of the old sites were sampled in this study, there are at least 110 more sites recorded in the survey reports conducted in the Wakool, Berriquin, Pine Lodge, Deniboota, Jenargo and Denimein districts. Not every site has good location descriptions in the reports. However, original records exist with the CSIRO National Soils Archive and an ongoing collaboration with archive staff is seeking to identify these sites.

If all the old CSIRO sites can be geolocated, and the old and modern analytical methods correlated, then it will be possible to establish a baseline condition for agricultural soils in the central Murray Valley in the 1940s. This would provide an opportunity to assess the impact of modern, intensive agricultural practices on soil condition over a time and spatial scale not hitherto possible in Australia. An indication of the potential usefulness of this data is seen in the results from this project, which showed that all the soil profiles examined were leached of soluble salts over the past 70 years. Whilst this was expected for sites which had a history of irrigation, it was not expected at the dryland sites in an area with an average annual rainfall of 360 mm.

A more extensive resampling program across all the old CSIRO sites would provide valuable information to guide future management and RD&E investment decisions in the Murray Valley. For instance, the ability of rainfall to leach salts from profiles in the semi-arid climate of the Deniboota Irrigation District is encouraging with regard to prospects for long-term salinity management in southern NSW irrigation districts. However, the implications of this leaching and the consequent reduction in the electrolyte effect on the structure of soils which still contain appreciable amounts of sodium, needs to be ascertained. Additionally, the lack of change in pH at these 12 Deniboota sites is at odds with previous studies and needs further examination.

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## Acknowledgements

This pilot project was a partnership between Murray Local Land Services and NSW DPI under project MU9230, 'Soil condition and dust watch project – Assessing long term soil health trends under irrigation in the Murray Local Land Service area'.

The cooperation and assistance of the landholders involved in the project is gratefully acknowledged.

# Irrigation & climate

## Effect of sowing rate, nitrogen rate and application timing on grain yield and protein of short grain rice

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

### Key findings

- Very low plant populations can reduce grain yield, and increase grain protein and lodging. Sowing rates between 60 kg/ha and 120 kg/ha are recommended for Opus$^{\phi}$ and Koshihikari to achieve target plant populations of 75 to 150 plants/m$^2$.
- Koshihikari reached its highest grain yield with minimal lodging and lower grain protein when nitrogen (N) application was split between permanent water (PW) and panicle initiation (PI). Plan for a 50:50 split N application between PW and PI and then use the NIR Tissue Test at PI to fine-tune the PI application.
- Opus$^{\phi}$ has a higher yield potential with lower lodging risk than Koshihikari and can therefore tolerate higher N rates, but this can also increase grain protein. To ensure grain protein is at the required levels, plan for a 70:30 split between PW and PI and use the NIR Tissue Test at PI before applying additional N.

### Introduction

Short grain rice varieties are used to make sushi and require specific grain quality attributes. Grain protein content is an important quality attribute in short grain rice used for making sushi. Protein levels of paddy grain below approximately 6.9% are preferred, but high value markets require paddy protein levels below 6.4%.

Two rice experiments were established in the 2017–18 season to investigate the effect of plant population, N rate and application timing on grain yield and protein of Opus$^{\phi}$ and Koshihikari short grain rice varieties.

### Site details

The Opus$^{\phi}$ and Koshihikari experiments were located in adjoining fields at Rice Research Australia, Coree, 20 km west of Jerilderie. The soil was self-mulching medium clay. Both experiments used a fully randomised design with four replications. Plot size was 2.4 × 15 m. The 2017–18 season was warm with higher than average temperatures during both the vegetative and reproductive stages.

### Treatments

| | |
|---|---|
| **Rice varieties** | Opus$^{\phi}$ – a semi-dwarf short grain sushi variety.<br>Koshihikari – a premium Japanese short grain variety that commands a high premium. It is a tall variety that is susceptible to lodging at high N application rates. |
| **Sowing rates** | Both experiments were drill sown at 20 cm row spacing with sowing rates of 20, 60 and 120 kg/ha. |

**Nitrogen treatments**

Nitrogen was applied as urea at two application times:

1. to the dry soil before PW
2. into the flood irrigation at PI.

Ten N treatments were applied in each experiment using a combination of different rates and application timings. Table 1 shows the N rates (kg N/ha) applied to Opus$^{\Phi}$ and Koshihikari at PW and PI for each treatment.

Table 1. The N rate (kg N/ha) applied to Opus$^{\Phi}$ and Koshihikari at PW and PI for each treatment.

| Treatment | Opus | | Koshihikari | |
|---|---|---|---|---|
| | PW | PI | PW | PI |
| 1 | 0 | 0 | 0 | 0 |
| 2 | 0 | 60 | 0 | 40 |
| 3 | 0 | 120 | 0 | 80 |
| 4 | 0 | 180 | 0 | 120 |
| 5 | 60 | 0 | 40 | 0 |
| 6 | 60 | 60 | 40 | 40 |
| 7 | 60 | 120 | 40 | 80 |
| 8 | 120 | 0 | 80 | 0 |
| 9 | 120 | 60 | 80 | 40 |
| 10 | 180 | 0 | 120 | 0 |

The total N rates applied to Opus$^{\Phi}$ are higher than those applied to Koshihikari. Opus$^{\Phi}$ is a semi-dwarf variety with a high N requirement and yield potential, while Koshihikari is a tall variety that is highly susceptible to lodging at high N rates.

## Results

### Plant population

The 20, 60 and 120 kg/ha sowing rates achieved plant populations of 52, 140 and 216 plants/m$^2$ for Opus$^{\Phi}$ and 36, 91 and 156 plants/m$^2$ for Koshihikari. The Koshihikari experiment was located in an area of the field that had topsoil removed during landforming, which resulted in reduced establishment.

### Grain yield

Sowing rate did not significantly affect grain yield in the Opus$^{\Phi}$ experiment. The 20, 60 and 120 kg/ha sowing rates produced 11.77, 11.80 and 11.69 t/ha respectively, when averaged across N treatments.

However, in the Koshihikari experiment the 20 kg/ha sowing rate produced a significantly lower grain yield (7.35 t/ha) than the 60 kg/ha and 120 kg/ha sowing rates at 8.69 t/ha and 8.83 t/ha respectively, when averaged across N treatments. At the 20 kg/ha sowing rate, Opus$^{\Phi}$ established 52 plants/m$^2$ while Koshihikari established only 36 plants/m$^2$.

Higher rates of total applied N increased grain yield in both Opus$^{\Phi}$ and Koshihikari (Table 2). For each total applied N rate applying all that N at PW resulted in higher grain yield compared with when the same N rate was all applied at PI for both varieties (Table 2).

Table 2. Grain yield (t/ha at 14% moisture), paddy grain protein content (%) and lodging score (1 = standing, 10 = flat) for the nitrogen treatments averaged across sowing rates. A. Opus$^{\Phi}$ and B. Koshihikari.

**A. Opus**

| Nitrogen PW – PI (kg N/ha) | Grain yield (t/ha) | Grain protein (%) |
|---|---|---|
| 0 | 9.36 | 5.60 |
| Total N = 60 | | |
| 0 / 60 | 10.35 | 5.86 |
| 60 / 0 | 11.47 | 5.90 |
| Total N = 120 | | |
| 0 / 120 | 11.37 | 6.09 |
| 60 / 60 | 12.40 | 6.09 |
| 120 / 0 | 12.81 | 6.33 |
| Total N = 180 | | |
| 0 / 180 | 11.73 | 6.36 |
| 60 / 120 | 12.88 | 6.54 |
| 120 / 60 | 12.85 | 6.60 |
| 180 / 0 | 12.30 | 6.64 |
| l.s.d. ($P<0.05$) | 0.63 | 0.17 |

**B. Koshihikari**

| Nitrogen PW – PI (kg N/ha) | Grain yield (t/ha) | Grain protein (%) | Lodging score (1 to 10) |
|---|---|---|---|
| 0 | 5.56 | 6.09 | 1.0 |
| Total N = 40 | | | |
| 0 / 40 | 5.82 | 6.10 | 1.0 |
| 40 / 0 | 7.76 | 5.87 | 1.1 |
| Total N = 80 | | | |
| 0 / 80 | 6.67 | 6.19 | 1.1 |
| 40 / 40 | 9.06 | 5.92 | 1.5 |
| 80 / 0 | 9.72 | 6.16 | 2.6 |
| Total N = 120 | | | |
| 0 / 120 | 7.99 | 6.23 | 2.0 |
| 40 / 80 | 9.74 | 6.20 | 2.7 |
| 80 / 40 | 10.37 | 6.24 | 2.8 |
| 120 / 0 | 10.20 | 6.54 | 4.2 |
| l.s.d. ($P<0.05$) | 0.85 | 0.19 | 0.6 |

At the highest total N rate, the split N treatments produced the highest grain yield for both Opus$^{\Phi}$ and Koshihikari (Table 2), but not significantly different from when all the N was applied at PW.

As total N application extends above the optimal, split N applications often produce the highest grain yield, particularly when there are cold temperatures during the reproductive period. Cold temperatures interact with high N levels to increase grain sterility. In the 2017–18 season, temperatures remained warm during the reproductive period resulting in little difference in grain yield between the split treatments and when all the N was applied at PW.

There was no significant ($P<0.05$) interaction between sowing rate and N treatment for grain yield in either variety.

### Grain protein

The 20 kg/ha sowing rate produced a significantly ($P<0.05$) higher grain protein content (6.23%) compared with the 60 kg/ha and 120 kg/ha sowing rates (6.10% and 6.13%) for Opus$^{\Phi}$, when averaged across N treatments.

For Koshihikari, the 20 kg/ha sowing rate produced a significantly ($P<0.05$) higher grain protein content (6.27%) than the 60 kg/ha sowing rate (6.13%) and both had similar grain protein to the 120 kg/ha sowing rate (6.21%).

The increased rate of total applied N produced a higher grain protein content in Opus$^{\Phi}$, but the trend was less pronounced for Koshihikari (Table 2). At the highest total N rate, applying all the N at PW increased grain protein content above when it was all applied at PI, for both Opus$^{\Phi}$ and Koshihikari (Table 2).

Applying N as a split between PW and PI generally resulted in lower grain protein levels than when all the N was applied at PW for both Opus$^{\Phi}$ and Koshihikari (Table 2).

### Lodging

There was no lodging in the Opus$^{\Phi}$ experiment, with all treatments fully standing at harvest.

In the Koshihikari experiment, lodging was significantly ($P<0.05$) increased with a higher sowing rate and higher total rate of applied N. Lodging was also increased when all the N was applied at PW compared with the same total N rate split between PW and PI (Table 2).

## Conclusions

- The 20 kg/ha sowing rates resulted in low plant populations, which led to increased grain protein content in both Opus$^{\Phi}$ and Koshihikari.
- Growers should aim for a plant population between 75 plants/m$^2$ and 150 plants/m$^2$ to maximise grain yield, minimise grain protein content and reduce lodging.
- The higher total rate of applied N increased grain yield and grain protein content for both Opus$^{\Phi}$ and Koshihikari. When lower rates of N are applied, it should be all applied at PW, but as the total N rate is increased, a split application between PW and PI provides maximum grain yield with lower grain protein content.
- To keep grain protein at a level suitable to access high value markets, it is important not to apply excessive N at PW and use the NIR Tissue Test to assess crop N levels at PI before applying additional N.
- Using red edge imagery at PI to determine zones for variable rate N application at PI would provide more consistent grain protein levels across the field. Further research would target reducing the variability of both grain yield and protein levels across a field by using remotely sensed red edge maps and zoned variable rate PI N applications.

## Acknowledgements

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

Thank you to Rice Research Australia personnel, Russell Ford, Antony Vagg and Ben Heaslip for their support with this project.

# Soil moisture network for better irrigation decisions in the Murray Valley

Alex Schultz, Sam North and Don Griffin (NSW DPI, Deniliquin)

## Key findings

- Farmers in the Murray Valley show strong interest in an irrigation soil moisture network.
- A cost effective soil moisture network is possible with live soil moisture data easily assessable by growers.

## Introduction

Recent results from the Murray and Murrumbidgee Valleys showed that 64% of monitored crops produced lower yields than expected from the volume of irrigation water applied ('Soils under an irrigated environment' project, ICF00008). Yield is lost at a rate of 1 t/ha for every five days of moisture stress and/or waterlogging between late August and mid October.

In most cases moisture stress occurs because the first spring irrigation is too late. It is important to note that the key to identifying these periods of potential stress is to monitor soil moisture and schedule irrigations to prevent moisture stress.

Both Victoria and South Australia monitor soil moisture using soil sensor networks using capacitance sensors with a focus on dryland systems. This project developed and trialled technology that enabled a soil moisture monitoring network in irrigated systems that used soil water potential sensors to be implemented cost effectively.

The project was designed to demonstrate to winter crop irrigators the advantages of irrigation scheduling and its potential to increase yields. It had two main objectives:

1. pilot the concept of a soil moisture network in an irrigated district to gauge acceptance and uptake
2. test the technology and its viability.

## Method

Six sites within the Murray Irrigation Ltd area were selected that represented a range of climate, soil, and irrigation systems. Fields growing wheat were given preference when selecting sites to ensure a standard crop was being represented at each site.

Two irrigation systems were selected: border check and overhead sprinkler. These are common systems in the Murray Valley for irrigating wheat. Soil type at the sites, although important, was not prioritised over the geographic location. Crop, soil and irrigation type are listed in Table 1, and the site locations shown in Figure 1.

Figure 1. Map showing site locations. Table 1 provides additional detail.

Table 1. Details of each site monitored. Barley was selected at the Deniliquin site because wheat crops under sprinkler irrigation were not available.

| Map reference | Site | Crop | Soil type | Irrigation type |
|---|---|---|---|---|
| A | Moulamein West | Wheat | Sandy loam | Centre pivot sprinkler |
| B | Moulamein East | Wheat | Self-mulching clay | Border check |
| C | Deniliquin | Barley | Billabong clay | Linear move sprinkler |
| D | Blighty | Wheat | Red–brown earth | Border check |
| E | Finley | Wheat | Red–brown earth | Linear move sprinkler |
| F | Berrigan | Wheat | Red–brown earth | Border check |

Soil water (matric) potential sensors (Irrometer Watermark™ 200SS) were installed as they measure the suction (in kPa) required by plants to extract water from the soil. They have an advantage over other soil moisture sensors as they do not need to be calibrated for different soil types, ensuring that readings from all sites are comparable. All sites were installed by 6 August 2018. Crop growth stage and tiller count were recorded at this time, and a photo of the crop was taken to help other irrigators assess how the monitored site compared with their own.

Two depths (three replicates of each) were measured at each site: 15 cm and 30 cm at the overhead sprinkler sites and 30 cm and 45 cm at the border check sites. Because plants experience drought stress when the matric potential at the bottom of the active root zone exceeds –60 kPa, the shallower depths – readings from the 15 cm at overhead sprinkler sites, and 30 cm readings at border check sites – were used for the suggested irrigation triggers.

Telemetry, developed within the project, allowed the soil sensor network and live access to the data to be cost effectively implemented.

WiFi-enabled microcontrollers (Electric imp001) were used to pull data from Irrometer 900M loggers and post the data to Google sheets.

A public website (http://murrayvalleysoilmoisture.site/) was built to host the graphs and data from Google sheets and to make this data available to growers. Figure 2 shows an example of how the data was presented on the website. The predicted time for the next irrigation was displayed in both a table and also as a line drawn in the graph. This was calculated by finding the slope (rate of decline) between the most recent reading and the 24-hour reading before this (two readings 24 hours apart). The slope was then extrapolated to the trigger point of –60 kPa; the point of interception was used as the forecast irrigation date. All the calculations were done in a linked Google sheet allowing an automatically recalculated forecast every time a new soil moisture reading was uploaded.

The website also included basic paddock information such as the previous crop, soil type and sowing/top dress time and rate to enable other growers to compare the monitored crops with their own.

Google analytics was used to gauge the acceptance and uptake of the soil sensor network. This allowed important usage metrics to be gathered such as users to the site, number of times they revisited the site and total page views.

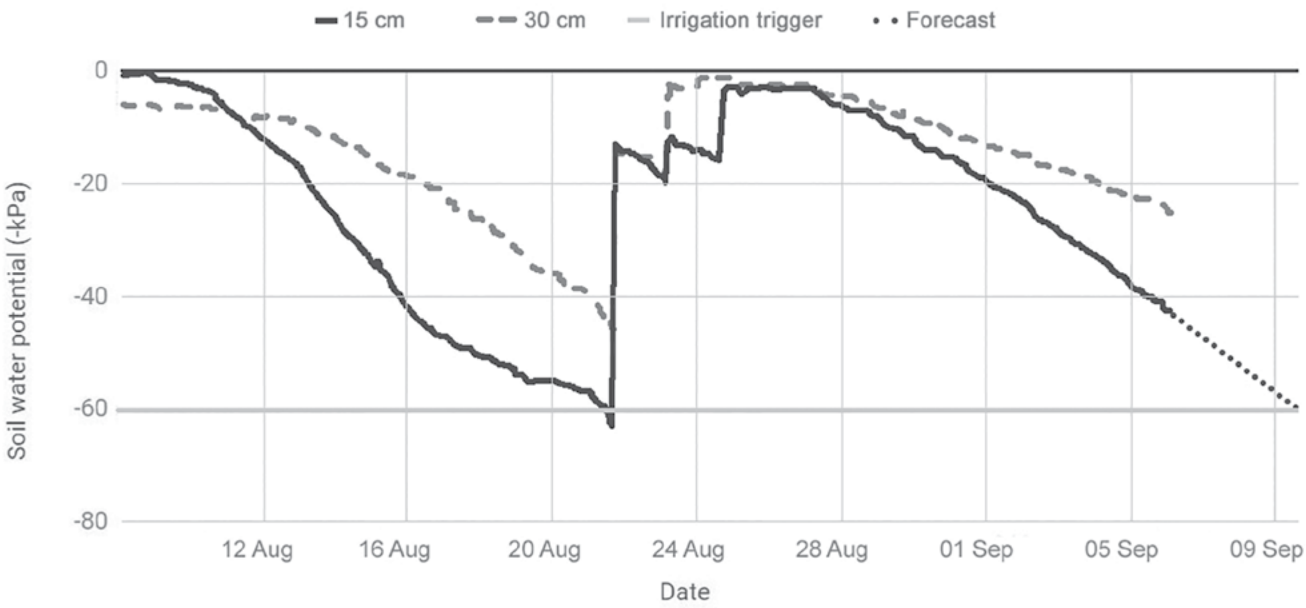

Figure 2. An example of a soil water potential chart from an overhead irrigation site displayed on the website.

## Results

The website that hosted the data from the soil monitoring sites had 1,619 page views by 112 users from when the website went online (8 August 2018) through to the end of October. The average session lasted just over five minutes, in which time the user looked at five pages/sections.

The cost-effective telemetry meant that there were no subscription fees, which can be as high as $30/month/site through commercial providers. The only ongoing cost was for a data plan, which was $70 per six months for each site.

## Discussion

This pilot was run in 2018, a year that received below average rainfall (Finley NSW received 125 mm, considerably less than the long-term average of 390 mm). Due to the dry season, soil moisture monitoring was not required to schedule the first irrigation – crops were irrigated as soon as water was available through the supply channel.

It was anticipated that the website would be publicised by the Murray Local Land Services extension network amongst irrigators. However, this was not done as irrigators did not need it to trigger the first irrigation, as well as small issues with the technology early after implementation. Despite not being actively publicised, the website still reached 112 users who, on average, visited the site three times, showing that there is interest in this type of information. This indicates that growers possibly see value in the soil network to schedule subsequent irrigation, and the experiment would have benefited from the network website being publicised.

The soil moisture network and associated technology developed for this project was effective. However, there were some issues early after deployment due to the telemetry in low reception locations increasing the power consumption. Larger solar panels and external antennas resolved the issue, ensuring reliable data transmission, increasing the confidence in the technology.

If a soil moisture network similar to the one used in this project was made available permanently, and it was adopted by growers, there is the potential to lift irrigated wheat yield by 1 t/ha through reduced waterlogging and drought stress. The network also creates the opportunity to add live agronomic messages about each crop to remind growers of key actions related to growth stages, making it a valuable resource for irrigators.

## Acknowledgements

This experiment was part of the 'Soil sensor network for better irrigation decisions in the Murray Valley' project, P-05851, June 2018–March 2019, with joint investment by Murray Local Land Services and NSW DPI.

A sincere thank you to James Brinkhoff (Deakin University) for helping to develop the telemetry used and also to the six cooperators who allowed their crops to be monitored.

# Other research

## Benefits of lucerne/perennial grass mixtures in cropping rotations

Richard Hayes, Dr Guangdi Li and Dr Mark Norton (NSW DPI, Wagga)

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### Key findings

- The most productive pasture swards over five years were sown to a mixture of phalaris, lucerne and sub clover.
- Only swards that included phalaris maintained groundcover >70% in all years, including periods of drought.
- Phalaris swards reduced annual grass weed incursion through competition by up to 7-fold compared with pure legume swards.
- Lucerne/perennial grass mixtures produced ~35% more legume biomass than swards sown only to sub clover.
- Lucerne's winter activity had little effect on its productivity and persistence.

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### Introduction

Cultivars of phalaris and cocksfoot, well-suited for use in crop rotations in drier environments, were first released in southern Australia during the 1970s. Cereal grain yields, after a perennial grass-based pasture phase, are comparable with pastures based on lucerne or annual legumes (Dear et al. 2004). In spite of this, few perennial grass species are used across the grain belt of south-eastern Australia.

A five-year field experiment was conducted near Ariah Park to assess the compatibility of temperate perennial grasses grown in mixtures with lucerne and/or sub clover in a typical medium rainfall cropping environment, and to assess the effects on productivity, ground cover and grass weed incursion attributable to the perennial grass.

This paper is a summary of a more detailed report that was recently published following the conclusion of this experiment (Hayes et al. 2018).

### Site details

| | |
|---|---|
| **Location** | 15 km north of Ariah Park |
| **Soil type** | Brown dermosol |
| **Experiment period** | Sown 7 May 2010; final sampling of herbage mass, June 2014. |
| **Annual rainfall** | 2010 – 745 mm; 2011 – 675 mm; 2012 – 569 mm; 2013 – 366 mm; 2014 – 414 mm. Long-term annual average for that site – 475 mm. |

## Treatments

The experiment included 18 treatments with three replicates. Plot size was 6 × 4 m. There were six perennial grass treatments sown in mixtures with one of three legume combinations.

### Perennial grass cultivars and sowing rates

Three phalaris cultivars and two *Hispanic* cocksfoots were compared with pure legume treatments (nil perennial grass) (Table 1). Phalaris was sown at 2.5 kg/ha, or at 1.5 kg/ha in mixtures with lucerne. Cocksfoot was sown at 3 kg/ha, or at 1.8 kg/ha in mixtures with lucerne.

### Legume cultivars and sowing rates

All treatments were sown with a mixture of the annual legumes subterranean clover at 2.7 kg/ha (cvv. Seaton Park and Urana in equal proportions by weight), and eastern star clover cv. Sothis at 1.3 kg/ha. Lucerne cultivars with high winter activity and low winter activity (in equal proportions by weight) were compared with nil lucerne (annual legume only or annual legume/perennial grass mixture) treatments. Lucerne was sown at 2.5 kg/ha, or at 1.0 kg/ha in mixtures with a perennial grass.

Table 1. Description of cultivars sown in the experiment.

| Species | Cultivar/line | Description |
|---|---|---|
| Phalaris (*Phalaris aquatica* L.) | Atlas PG | Winter-active perennial habit with substantial but incomplete summer dormancy |
| | Holdfast | Relatively summer-active, later maturing and with low levels of summer dormancy |
| | Sirolan | Relatively summer-active, earlier maturing and with low levels of summer dormancy |
| Cocksfoot (*Dactylis glomerata* L. ssp. *hispanica* Roth.) | Kasbah | Winter-active perennial habit with complete summer dormancy |
| | Moroccan | Winter-active with high level of summer dormancy |
| Lucerne (*Medicago sativa* L.) | Stamina 5 | Low winter-activity (LWA) rating (5) |
| | Venus | Low LWA rating (5) |
| | 54Q53 | Very low LWA rating (3) |
| | SARDI 10 | Very high LWA rating (9–10) |
| | Silverado | Very high LWA rating (9) |
| | Cropper 9.5 | Very high LWA rating (9.5) |
| Subterranean clover (*Trifolium subterraneum* L.) | Urana | Winter-growing annual habit, mid-season maturity, delayed seed softening characteristics |
| | Seaton Park | Winter-growing annual habit, early–mid-season maturity, low hard seed levels |
| Eastern star clover (*Trifolium dasyurum* C. Presl) | Sothis | Winter-growing annual habit, early–mid-season maturity, delayed seed softening characteristics |

## Results

### Pasture productivity and composition

Sirolan phalaris yielded the highest cumulative dry matter (DM) during the experiment period and yielded significantly more grass biomass than Atlas PG phalaris and both cocksfoots (Table 2). The lucerne productivity more than doubled when perennial grasses were excluded from the mix, in part reflecting the higher sowing rates of lucerne in those treatments. There was no difference in biomass contributed by other legumes among all treatments, which predominantly comprised naturalised burr medic. Cumulative weed biomass was generally least in mixes that included phalaris.

Table 2. Cumulative herbage dry matter (t/ha) under different pasture mixes over five years.

| Species | Cultivar | Lucerne winter activity | Cumulative herbage dry matter (t/ha) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Perennial grass | Lucerne | Sown annual legume | Other legumes | Weeds | Total DM |
| Phalaris | Atlas PG | High | 16.4 | 8.0 | 2.4 | 7.0 | 5.9 | 39.8 |
| | | Low | 14.9 | 6.3 | 1.9 | 7.5 | 4.7 | 35.3 |
| | | Nil | 19.8 | – | 4.5 | 3.2 | 5.7 | 33.3 |
| Phalaris | Holdfast | High | 18.4 | 7.1 | 4.0 | 4.2 | 4.3 | 38.0 |
| | | Low | 17.5 | 6.2 | 2.2 | 8.0 | 3.8 | 37.7 |
| | | Nil | 23.0 | – | 3.1 | 7.2 | 3.7 | 37.1 |
| Phalaris | Sirolan | High | 21.3 | 7.4 | 2.2 | 6.6 | 4.9 | 42.5 |
| | | Low | 20.1 | 8.1 | 2.2 | 6.2 | 4.2 | 40.9 |
| | | Nil | 26.9 | – | 2.8 | 4.8 | 4.3 | 38.7 |
| Cocksfoot | Kasbah | High | 6.1 | 7.4 | 3.5 | 5.8 | 9.2 | 32.1 |
| | | Low | 6.5 | 8.3 | 3.1 | 5.5 | 6.7 | 29.9 |
| | | Nil | 10.9 | – | 4.1 | 5.7 | 6.6 | 27.3 |
| Cocksfoot | Moroccan | High | 6.7 | 7.3 | 2.7 | 8.3 | 6.2 | 31.1 |
| | | Low | 6.7 | 7.8 | 2.4 | 8.5 | 5.3 | 30.7 |
| | | Nil | 10.6 | – | 2.8 | 8.5 | 5.3 | 27.2 |
| Lucerne | Nil | High | – | 17.2 | 3.5 | 7.6 | 7.3 | 35.6 |
| | | Low | – | 14.2 | 3.4 | 7.5 | 7.0 | 32.1 |
| Subclover | Nil | Nil | – | – | 5.7 | 5.2 | 10.7 | 21.7 |
| l.s.d. ($P = 0.05$) | | | 5.14 | 4.18 | 1.88 | – | 2.54 | 4.77 |

### Ground cover

Ground cover in autumn during years two, three and five was generally between 80% and 95% for all treatments. The proportion of exposed bare soil, the converse of ground cover, was highest for all treatments in year four, reflecting the drier seasonal conditions from September 2012 to April 2013 and ranged between 25% and 38% (Figure 1). During that period, only the treatments that included phalaris remained above 70% total ground cover. Throughout the experiment period, autumn ground cover was usually lowest in the pure legume or Moroccan cocksfoot treatments, although this trend was reversed in the final year due to the early emergence of annual grass weeds.

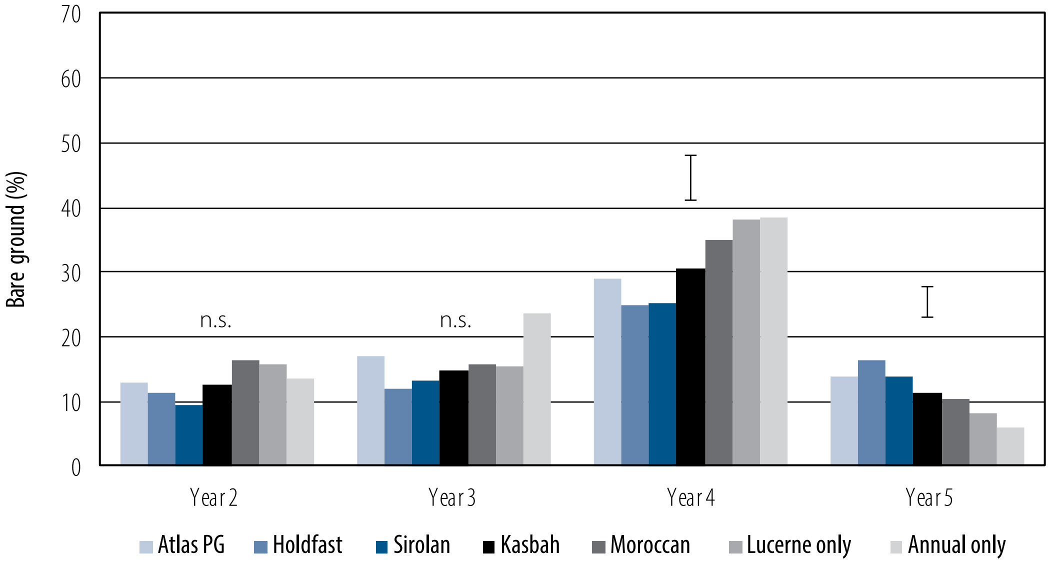

Figure 1. Bare ground under different pasture mixes sampled in autumn in years 2–5 (2011–2014). Vertical bar represents least significant difference between treatment means at $P = .05$; n.s. indicates no significant difference ($P>0.05$).

### Annual species regeneration

Regeneration of sub clover peaked in year two ranging between 360 plants/$m^2$ and 1,200 plants/$m^2$ across all treatments, with density observed to be roughly double in the nil grass treatments compared with the phalaris swards; it was generally intermediate in the cocksfoot swards. Regeneration of eastern star clover beyond year one was negligible throughout the experiment period. Burr medic seedling regeneration peaked in year five with all treatments observed to have over 700 plants/$m^2$ emerging in autumn 2014.

Regeneration of the naturalised burr medic was generally highest in the Moroccan cocksfoot swards during the experiment. The density of annual grass weed seedlings emerging in the final year of experimentation differed according to pasture treatment. Annual grass weed incursion was generally lowest in the cvv. Sirolan (average 173 plants/$m^2$) and Holdfast (200 plants/$m^2$) phalaris swards, and highest in the treatments not containing a perennial grass. Density was more than double in the annual-only treatment (1,262 plants/$m^2$) compared with the lucerne-only treatments (558 plants/$m^2$), but lucerne winter activity had little effect on annual grass weed invasion.

## Discussion

More diverse mixtures are commonly shown to be more productive due to enhanced resource-use efficiency, particularly where multiple functional plant types (e.g. legumes and grasses; annuals and perennials) are represented (Picasso et al. 2011).

This study showed that pasture productivity and persistence was maximised where a mixture of well-adapted cultivars from multiple species was included in the sward. In all cases, total cumulative biomass was reduced where lucerne was excluded from the perennial grass-based swards. The annual-only sward, which excluded all perennial species, was the least productive sward over the life of the experiment by a considerable margin.

Our experiment demonstrated that adding Sirolan phalaris increased cumulative pasture biomass by up to 25% compared with lucerne/clover pastures, and almost doubled biomass production compared with the annual legume sward. This demonstrates a significant opportunity for farmers in similar environments to increase pasture productivity by adding phalaris to their existing lucerne pastures in cropping rotations. The experiment also demonstrated a decreased annual grass weed burden following five years of a Sirolan phalaris-based pasture. The number of annual grass weeds emerging at the end of the pasture phase was between threefold and sevenfold greater in lucerne-based and annual legume-based swards, respectively, compared with the Sirolan phalaris swards due to reduced competition of grass weeds by the legumes. Moreover, only the phalaris treatments were able to maintain >70% ground cover in autumn of every year during the experiment period.

Most of the perennial grass/annual legume swards generated a similar amount of cumulative legume biomass over the experiment period (~10 t/ha) to that observed in the annual legume pasture sward. Including perennial grasses therefore might not necessarily represent a compromise in biological nitrogen inputs when compared with pure annual legume pastures. The Sirolan phalaris/annual legume swards were an exception, only producing ~7 t/ha of legume biomass, most of which comprised the naturalised burr medic. The reduced legume productivity in this treatment is undoubtedly attributed to the increased competition by cv. Sirolan, which has previously been demonstrated to be a strong competitor with annual species such as subterranean clover (Dear et al. 1998).

When lucerne was added to the perennial grass swards, cumulative legume biomass increased to ~16 t/ha, approximately 35% more than that observed in the annual legume sward. This clearly demonstrates the great potential to increase legume biomass in a perennial grass-based pasture simply by adding lucerne, although legume biomass in these treatments was not as great as the ~25–28 t/ ha of cumulative legume biomass observed in lucerne swards without a perennial grass.

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## Acknowledgements

Joint investment by the NSW Department of Primary Industries, the Future Farm Industries Cooperative Research Centre and the Grains Research and Development Corporation under the EverCrop project, CSA 00044.

The authors are grateful to Geoff and Leanne Tidd, Ariah Park, for allowing access to their land and for assisting with various aspects of the experiment. We acknowledge the contribution of Richard Lowrie, Justin Tidd, Jeff McCormick, Matthew Gardner and Craig Lihou for their technical assistance.

# Baking study: Investigating the quality of some historical and modern Australian wheat varieties

Denise Pleming (NSW DPI, Wagga Wagga) and Qura tul Ain Riaz (Functional Grains Centre, Charles Sturt University, Wagga Wagga)

## Key findings

- Targeting improvements in key quality attributes is producing superior baking varieties in Australian wheat breeding programs.

## Baking study rationale

### Variety selection

A set of 172 historical and modern wheat varieties released between 1860 and 2015 were grown at Collingullie, NSW in 2016. From these, a set of 39 baking-quality varieties were selected. Even though it was regarded as a weak dough type, Ghurka was included due to its importance as a widely grown variety in southern Australia in the 1930s. Modern soft grained varieties were excluded. The selected samples underwent large scale milling and dough testing and were then assessed for baking quality.

### Baking quality

To be regarded as having good baking quality in the modern context, a wheat variety must possess a number of key attributes – not only superior baking performance – that combine to make it attractive to wheat processors. These attributes include a:

- high extraction rate (yield of flour as percentage of grain weight milled)
- high water absorption (amount of water as a percentage of flour weight to produce dough of a specific consistency)
- strong but extensible dough (producing a gluten network that can trap and expand around gases produced during fermentation stage of bread-making)
- bright white flour colour (flour yellowness in Australian wheats is regarded as a quality defect).

These qualities form the basis of specifications for the Australian Prime Hard (APH) premium wheat grade.

### Test baking methods

The Australian wheat classification system includes three different baking methods: rapid dough, straight dough, and sponge and dough (S&D). Varieties are assessed for performance in one or more of these methods depending upon the classification grade being sought.

To attain an APH grade, varieties must perform satisfactorily in the S&D and straight dough baking methods. Due to long fermentation times, these methods favour a dough with greater gluten strength.

In this study, a modified version of the straight dough baking method was applied, and the historical varieties' performance compared with modern varieties released with an APH classification grade in southern NSW.

## Materials and methods

Wheats were milled using a Buhler MLU-202 laboratory test mill. Flours were assessed for dough water absorption (Perten DoughLAB 2500), and dough strength and extensibility (Brabender extensograph 8600).

Baking used a two-hour fermentation method, adapted from the standard Australian classification straight dough testing method. Doughs (50 g flour basis) were mixed in a DoughLAB at 120 rpm until optimum gluten was developed, divided into two 40 g dough pieces and fermented in sealed containers at 30 °C. After 95 minutes, the doughs were gently knocked down and run through a Domex bun moulder, and returned to sealed containers for a further 25 minutes fermentation. Doughs were again run through bun moulder, and placed in open square tins for proofing at 85% relative humidity (RH) and 34 °C for 45 minutes. Loaves were baked for 15 minutes at 215 °C, removed from the tin and cooled for 45 minutes, when loaf volume (rapeseed displacement) was determined.

The following day a central 20 mm slice was removed from each loaf and crumb colour measured using a Minolta chromameter CR200 (with an 8 mm head) before being subjected to a standard texture profile analysis (Stable Microsystems TA-XT2) using 50% compression.

From the original set of 39 varieties that underwent baking, this paper reports on the baking quality of historic wheat varieties (defined as those released before 1967 when the Australian Wheat Board (AWB) first introduced classification grades) compared with 12 modern varieties awarded an APH grade on release, as listed in Table 1.

Table 1. Varieties included in baking study in order of release.

| Variety name | Release date |
|---|---|
| Steinwedel | 1890 |
| Gluyas Early | 1898 |
| Pusa4 | 1916 |
| Ghurka | 1924 |
| Ranee | 1924 |
| Dundee | 1927 |
| Gabo | 1945 |
| Insignia | 1946 |
| Stockade | 1960 |
| Festiguay | 1963 |
| 1967: AWB Australia-wide grading system introduced | |
| Timgalen | 1967 |
| Cook | 1977 |
| Banks | 1979 |
| Janz | 1988 |
| Batavia | 1991 |
| Chara | 1999 |
| EGA Gregory | 2004 |
| Bolac | 2006 |
| LongReach Spitfire | 2010 |
| Wallup | 2011 |
| Suntop | 2012 |
| LongReach Lancer | 2013 |

## Results and discussion

### Significance of wheat grading

From the 1890s through to the 1960s, the only quality measure applied to the Australian wheat crop were regional standards of fair average quality (f.a.q.). Based purely on bushel weight alone (now known as hectolitre or test weight), f.a.q. standards were determined each year from grower-supplied samples and used as the basis to trade wheat both interstate and overseas. Since no premium was paid for milling or baking quality, there was no incentive to grow wheats better than f.a.q. and accordingly yield remained the major driver. By the 1950s, technical developments in the bread making industry meant there was greater emphasis placed on wheat and flour quality in both domestic and overseas markets. The *Wheat Research Act 1957* enabled state based wheat research funding, and by 1967 the AWB had introduced an Australia-wide wheat grading system, thus forming the basis of the modern Australian wheat classification system based on varietal segregation (eligibility) and protein content.

### Quality improvement

APH is the premium export grade, and eligible varieties should possess very good overall quality. Comparing historical and modern varieties means we now better understand how the emerging quality targets in breeding programs has affected the varieties that make up the Australian wheat crop.

A number of key quality attributes and crumb texture characteristics are listed in Table 2, along with the change in average values between the historical and modern wheat groups. All parameters registered a positive change, indicating comprehensive improvement in quality over time as breeding programs sought to deliver varieties suited to discerning markets. Flour extraction (FE) rates in particular have improved greatly, a response to the dollar value placed on this trait by flour millers. Insignia FE was lowest of all varieties at just 66.1%, while Chara$^{\phi}$, EGA Gregory$^{\phi}$ and Suntop$^{\phi}$ exceeded 76%.

Table 2. Changes in key quality traits and bread crumb texture parameters over time.

| Quality trait | Historical average | Modern average | Overall average |
|---|---|---|---|
| Flour extraction (%) | 70.6 | 75.1 | 73.0 |
| Dough strength (Rmax, BU) | 306 | 435 | 367 |
| Dough extensibility (cm) | 17.5 | 19.7 | 18.7 |
| Bake water absorption (%) | 59.6 | 61.5 | 60.7 |
| Loaf volume (cc) | 132 | 144 | 139 |
| Crumb yellowness (b) | 13.4 | 12.6 | 13.0 |
| Crumb firmness (g force) | 494 | 445 | 467 |
| Crumb resilience (area ratio) | 0.24 | 0.27 | 0.25 |

### Individual variety performance

Although all traits showed improvement in average values, these improvements were not uniform, with individual varieties in both groups either underperforming or outperforming in particular traits. The early variety Pusa4, for example, had exceptional dough strength. Timgalen, the first APH variety released, compares poorly in most traits with the later releases, but did have what, at the time, was considered good dough strength, as indicated by an extensograph Rmax of 360 BU (Figure 1).

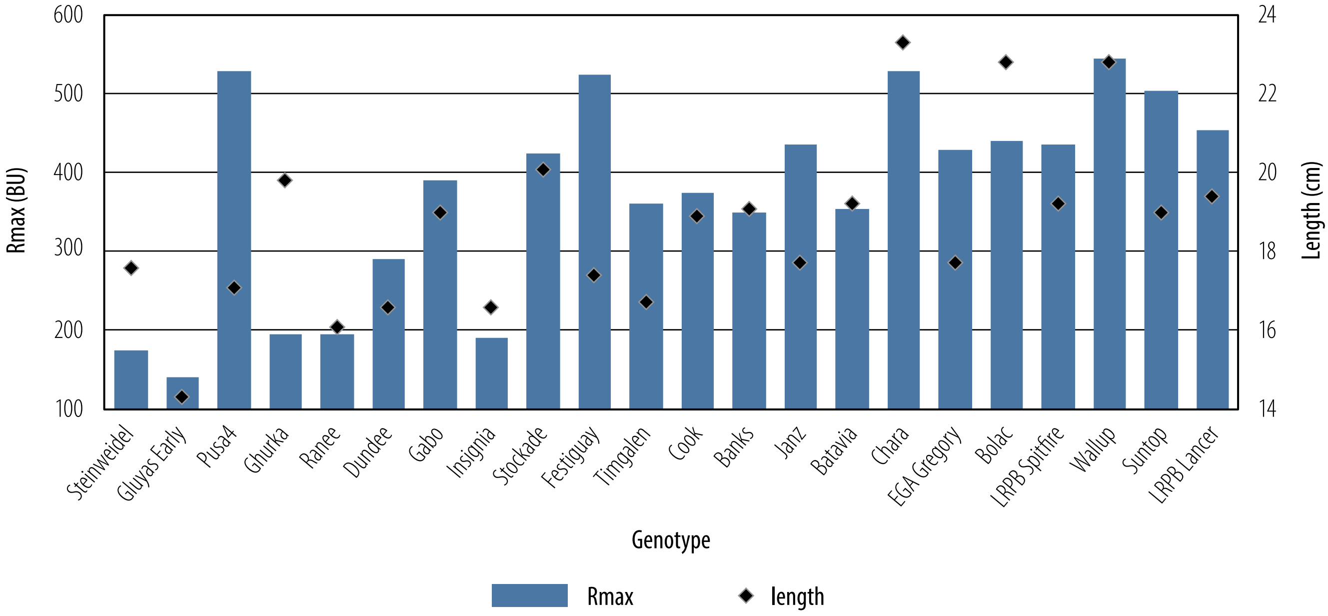

Figure 1. Dough strength (Rmax) and extensibility (length) in year-of-release order.

By 1999 however, the release of Chara$^{\phi}$ with an Rmax of 530 BU illustrates the new target for APH dough strength as Australian wheat breeders responded to market demand. Even the less than desirable bake water absorption (BWA) of 59.6% was overlooked as the imperative of increased strength was pursued. Chara$^{\phi}$ and the early APH release Timgalen aside, the modern varieties show consistently high BWA in accordance with market requirements (Figure 2).

The average loaf volume increased in the modern varieties but Janz, EGA Gregory$^{\phi}$, LongReach Spitfire$^{\phi}$ and especially Suntop$^{\phi}$ appeared to underperform in this baking study, while Bolac$^{\phi}$ produced the greatest loaf volume of all varieties. The historical variety Ghurka had an unexpectedly high loaf volume given its very weak dough strength, while the high dough strength of Pusa4 was not balanced with extensibility as illustrated in Figure 1, resulting in low loaf volume (Figure 3).

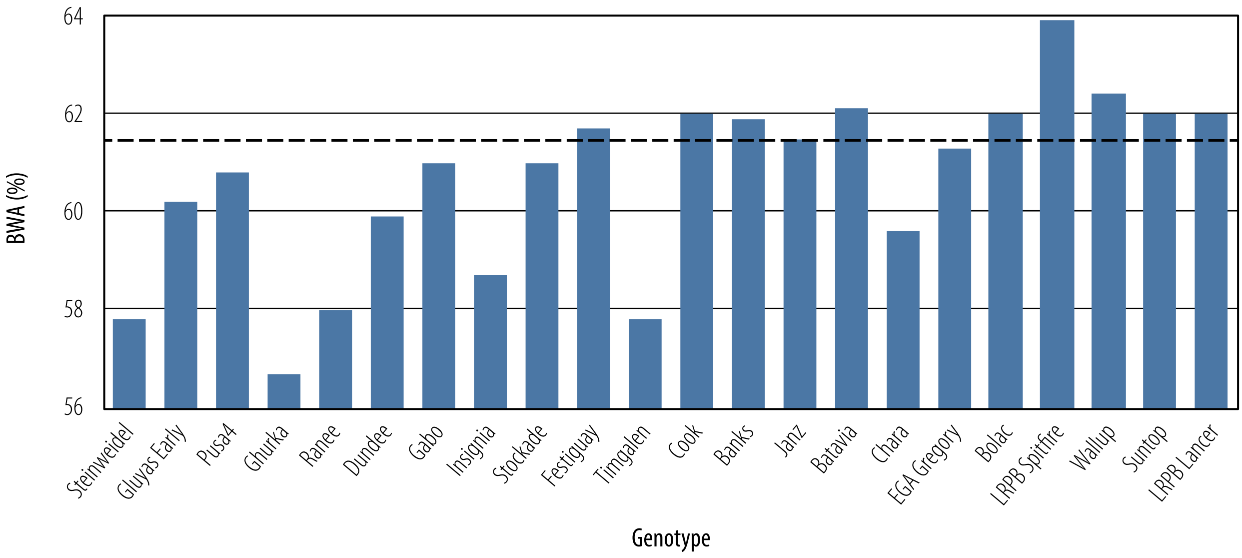

Figure 2. Bake water absorption in year-of-release order (dotted line = average of modern varieties).

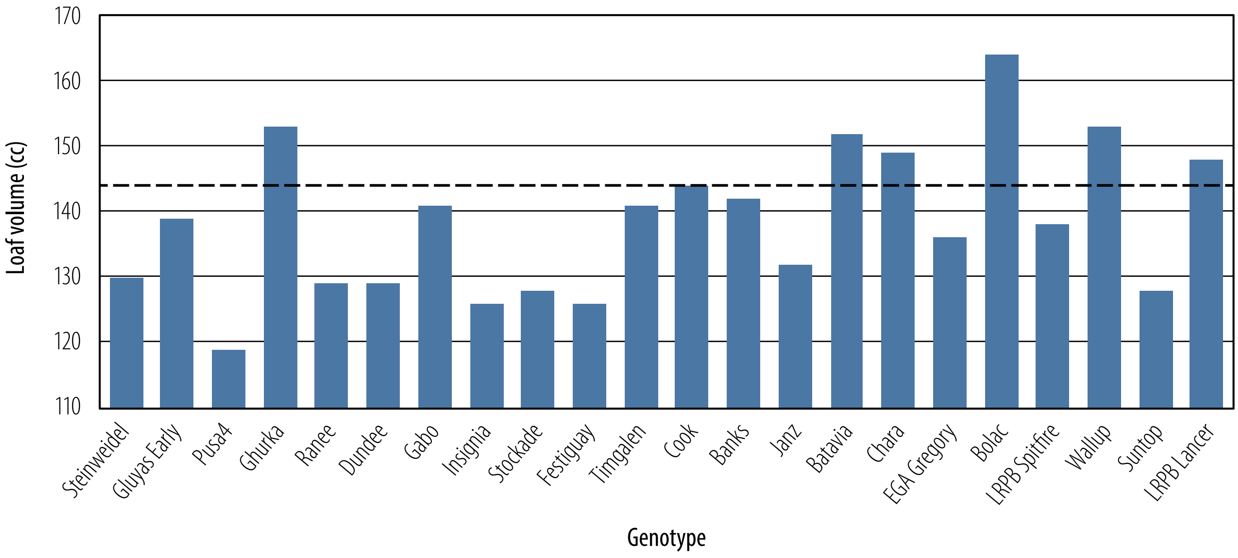

Figure 3. Loaf volume in year-of-release order (dotted line = average of modern varieties).

### Best performing varieties

Using the overall average in each quality trait as the benchmark, Bolac$^{\phi}$, Wallup$^{\phi}$ and LongReach Lancer$^{\phi}$ were the best performing modern varieties, exceeding the average in all eight traits. Of the historical varieties, Gabo was the best performer exceeding the average in five of the eight traits. Released in 1945, Gabo is credited with beginning Australia's reputation as a supplier of high quality baking wheat. Through targeted improvement in key quality attributes, Australian breeding programs have continued to produce superior baking quality wheats, shown by the modern varieties' improved performance observed in this study.

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## Acknowledgements

This baking study was performed as a NSW DPI contribution to the PhD thesis of Qura tul Ain Riaz 'Protein composition and quality of historic and modern Australian wheat varieties', 2016–19.

The technical assistance of Natalie Taber, NSW DPI, Wagga Wagga is gratefully acknowledged.

# Quinoa varieties and sowing window best suited for the Riverina – Leeton Field Station 2018

David Troldahl (NSW DPI, Yanco)

## Key findings

- Choose a sowing window to avoid heat or frosts during flowering.
- WA V2 was consistently the best suited quinoa variety for Riverina conditions.

## Introduction

Quinoa (*Chenopodium quinoa* Willd) can be grown in Australia as either a summer or winter crop and it is seen as a useful fit within existing cropping programs depending on soil type, rainfall and environment. The experiments carried out by NSW DPI at the Leeton Field Station (LFS) are part of a national project 'Quinoa as a new crop in Australia', a joint investment between Agrifutures and state departments of primary industry or departments of agriculture. Other experiment sites are in South Australia (Naracoorte), the Northern Territory (Katherine and Alice Springs) and Western Australia (Cunderdin, Eradu, Esperance, Geraldton, Katanning and Kununurra).

The project purpose is to evaluate the best sowing time for growing quinoa in southern NSW, which variety is best suited to summer irrigated cropping and to learn more about the agronomy, nutritional and herbicide needs to grow this crop and to develop best practices under summer irrigated conditions in the process.

This is the second year of experiments at LFS, evaluating varieties by sowing date (three dates) to identify the best sowing window for the Riverina. The experiment evaluated six different varieties to identify the best performing variety for the Riverina area under irrigation and on a heavy grey self-mulching soil typical of the surrounding irrigation area. This soil is very different from the lighter soils on which quinoa is normally grown in its native South America, or compared with the other national quinoa project evaluation sites.

The Western Australian Department of Primary Industries and Regional Development (WA DPIRD), who are leading this project, selected the varieties for Australian conditions. The six varieties for this experiment were selected based on their performance in the Riverina environment from last year's experiment.

## Site details

| | |
|---|---|
| **Location** | Leeton Field Station |
| **Soil type** | Grey self-mulching soils |
| **Previous crop** | Fallow, last sowing date quinoa previous season. |
| **Starter fertiliser** | Fertiliser was applied pre-sowing under rows, 110 kg/ha Granulock Z (11% nitrogen [N], 21.8% phosphorus [P], 4 % sulfur [S], 1% zinc [Z]). |
| **Sowing method** | Precision cone seeder, four rows at 30 cm apart onto 1.8 m beds.<br>Seeds were dropped onto the soil surface and covered using individual chains dragged behind the sowing boot, then followed by a press wheel. |
| **Irrigation method** | Furrow irrigation post sowing.<br>Following irrigations were timed using evapotranspiration figures to calculate irrigation needs. |

## Treatments

| | |
|---|---|
| **Varieties** | Six varieties were selected from the 2017 experiment as best suited to the Riverina:<br>• BEW (WA)<br>• CD (Variety sourced in Riverina)<br>• 2017 V2 (WA)<br>• 2017 V4 (WA)<br>• 2017 V6 (WA)<br>• 2017 V7 (WA).<br>One variety, BEW, is likely to be released as a commercial variety by WA DPIRD. Seed for five of the varieties was provided by WA DPIRD. The sixth variety was from seed kept from the 2017 evaluation experiments grown at LFS, due to the unavailability of fresh seed from Western Australia. |
| **Sowing date (SD)** | The different sowing dates were to evaluate the best sowing window for quinoa in the Riverina.<br>SD1: 27 October 2017<br>SD2: 20 November 2017<br>SD3: 19 December 2017 |

These experiments were sown at 7 kg/ha or the equivalent as some varieties had lower germination rates.

## Results

### Sowing date

Plant establishment was significantly better than in 2017 (Figure 1).

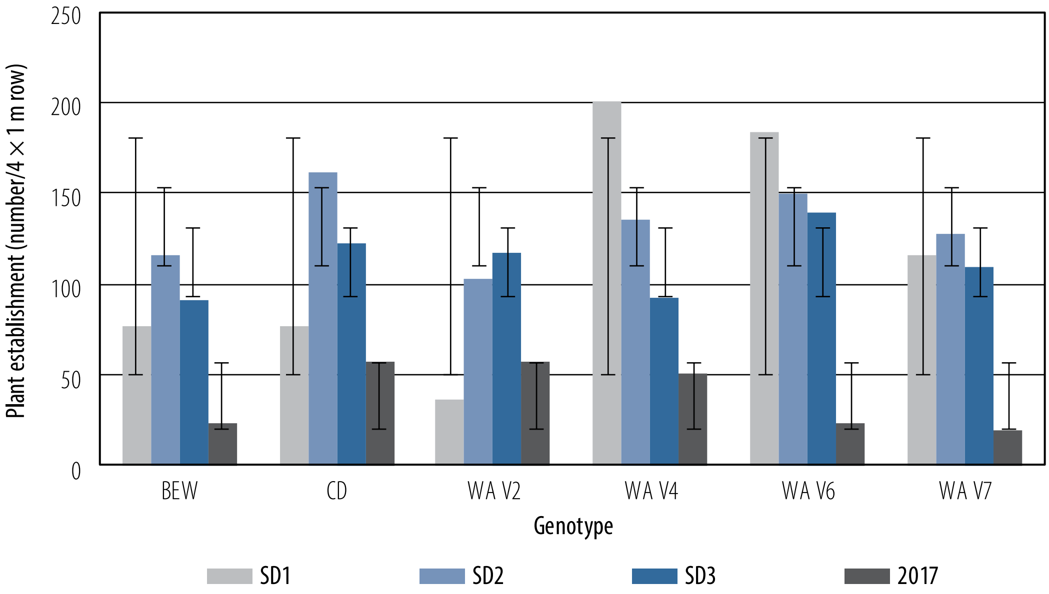

Figure 1. Plant counts late 2017 sowing compared with March 2017 sowing. Average of three replicates. Number of plants per metre in four rows (one bed).

Quinoa is susceptible to low and high temperatures at flowering. The three sowing dates in the late 2017 experiments encountered differing numbers of days above 34 °C, which appears to be the temperature above which flowering abortion occurs (Figure 2).

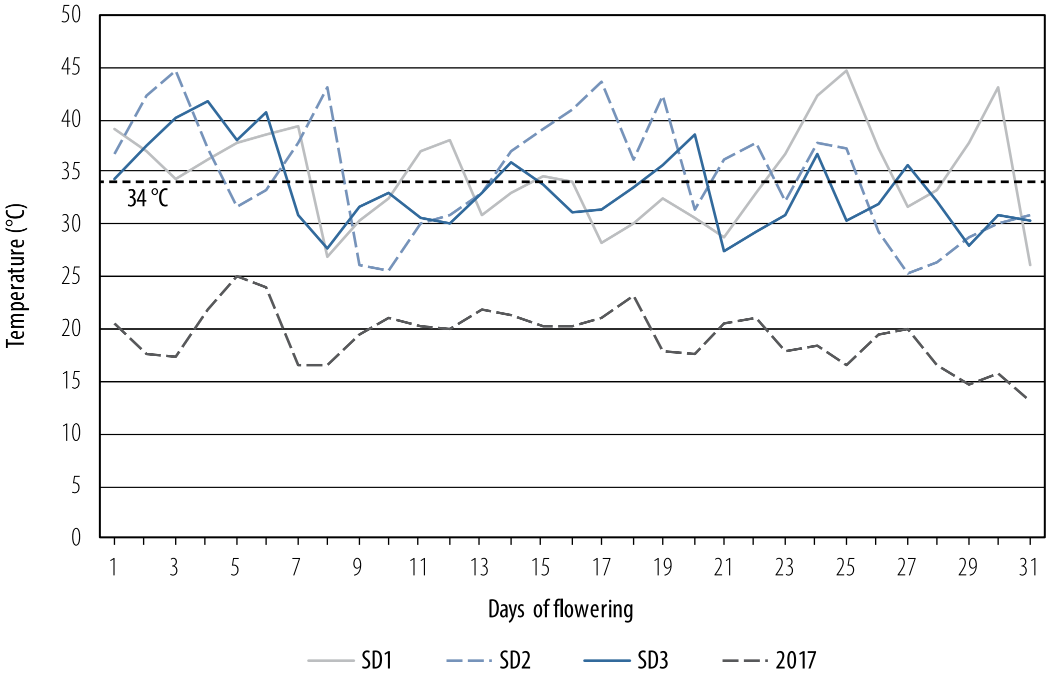

Figure 2. Peak daily temperatures experienced during the flowering period for three sowing dates in late 2017 and a single sowing date in March 2017. The dashed line indicates critical temperature (34 °C) above which flowers abort.

The yields from the experiments varied enormously across the sowing dates, and also between varieties (Figure 3; Table 1). The high temperatures (above 34 °C) over consecutive days appears to have led to high floret sterility and hence lower yields.

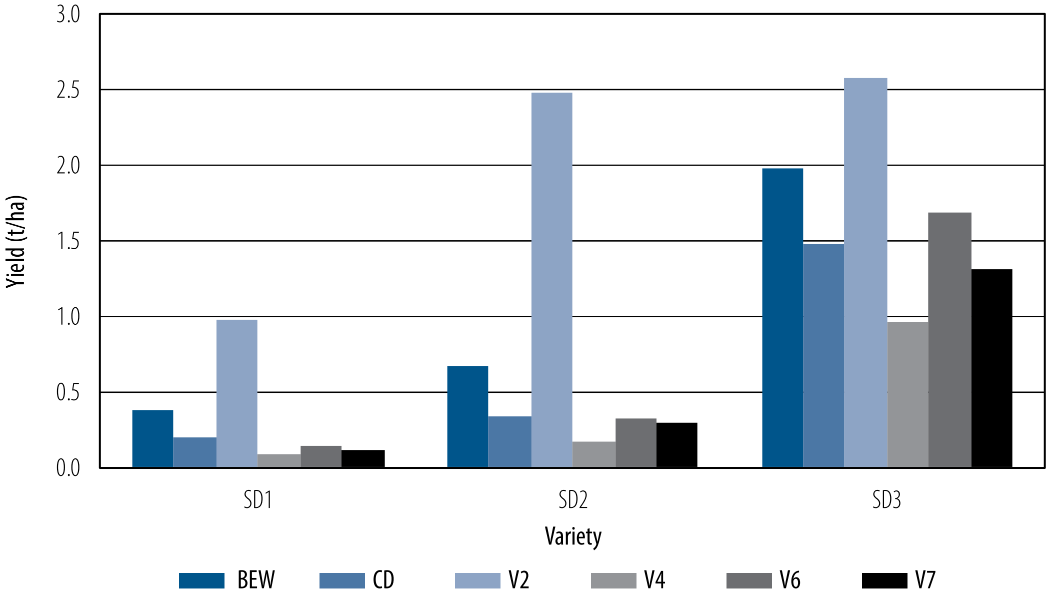

Figure 3. Yield of different varieties for each of the three sowing dates in late 2017. Significant difference within sowing dates is indicated by different letters (*P*<0.05) in Table 1.

Table 1. Grain yield (t/ha) for each variety for three sowing dates in late 2017. Significant difference within sowing dates is indicated by different letters (*P*<0.05).

| | BEW | CD | WA V2 | WA V4 | WA V6 | WA V7 |
|---|---|---|---|---|---|---|
| SD1: 27 October | $0.38^{b}$ | $0.19^{bc}$ | $0.97^{a}$ | $0.08^{c}$ | $0.15^{bc}$ | $0.11^{bc}$ |
| SD2: 20 November | $0.68^{b}$ | $0.33^{b}$ | $2.48^{a}$ | $0.17^{b}$ | $0.32^{b}$ | $0.29^{b}$ |
| SD3: 19 December | $1.98^{ab}$ | $1.47^{bc}$ | $2.57^{a}$ | $0.96^{c}$ | $1.68^{bc}$ | $1.31^{bc}$ |

## Conclusion

This experiment is very important for understanding the growing conditions on different sowing dates and challenges for quinoa crops in south-eastern Australia. The experiment has indicated that there are preferred sowing windows for the crop to achieve the best yields in the Riverina. The experiment also suggests that the WA V2 variety better tolerates high temperature periods during flowering than the other varieties.

Quinoa, as a crop, is suitable to be grown in the Riverina, but must be sown from late December to mid March to avoid temperature extremes at flowering. The December sowing date achieved the best yields for all varieties compared with the November and October sowing dates. This could be due to fewer days over 34 °C, with most of these early in the flowering period, which could, in turn, explain the better yields in this sowing date. This experiment was irrigated when an evapotranspiration of approximately 75 mm was reached.

A December to mid March sowing date would also coincide with later water allocations and would allow opportunist crops to be sown. The later sowing date could also mean less irrigations; experiments sown in March 2017 needed only two irrigations to achieve a yield of approximately 2.0–2.5 t/ha (Troldahl 2018). The viability of quinoa as a crop in the Riverina relies on market price which is currently down from a high of approximately $4,000/tonne to $1,000/tonne, and having a demand for the product.

Developing an agronomy package for quinoa in the Riverina that identifies the best growing practices along with nutritional needs, irrigation requirements and pest and weed management options, will be one of the outcomes from this project. The experience gained from two years of experiments where some failures occurred has identified that quinoa needs to be sown on or near the surface and just covered to achieve establishment. Young quinoa is also susceptible to attack from flea beetle. These observations, as well as published data, will be compiled into a best practice growing guide for quinoa in the Riverina.

## Reference

Troldahl D 2018. Quinoa growing in NSW: Sowing rates and varieties best suited for the Riverina. D Slinger, T Moore and C Martin (eds). *Southern NSW research results 2018*. NSW Department of Primary Industries, pp. 152–155.

## Acknowledgements

This experiment was part of the 'Quinoa as a new crop in Australia – stage 2' project, PRJ-010057, 2016–18, with joint investment by NSW DPI and AgriFutures.

Thank you Owen O'Callaghan for technical support and Rachelle Ward for literature review and discussion. Thanks also to Mario Dantuono (WA DPIRD) for biometric support.