Department of Primary Industries

Southern NSW research results 2018

RESEARCH & DEVELOPMENT – INDEPENDENT RESEARCH FOR INDUSTRY

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Department of Primary Industries

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Southern NSW research results 2018

RESEARCH & DEVELOPMENT – INDEPENDENT RESEARCH FOR INDUSTRY

an initiative of Southern Cropping Systems

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Cover images: Main image–soybean seed increase block at Leeton Field Station, part of the Australian Soybean Breeding Program, Mathew Dunn, NSW DPI; inset left–tagged canola plants in *Effect of heat stress on canola yield: A novel method of imposing heat stress in the field environment* (p 78), Dr Rajneet Kaur Uppal, NSW DPI, Wagga Wagga; inset centre–cracked rice grains in *Cracking and breakage in rice grains: implications for the rice industry* (p156) Dr Mark Talbot, formerly NSW DPI; inset right– paired open and closed clip cages with green peach aphid on a canola plant in *Assessing the effect of natural enemies on insect pests in canola* (p 108), Dr Jo Holloway, NSW DPI, Wagga Wagga.

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Foreword

NSW Department of Primary Industries (NSW DPI) welcomes you to the Southern NSW research results 2018. 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, extensive livestock, pastures, water and irrigation in southern NSW.

NSW DPI, in collaboration with our major funding 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, Condobolin and Cowra 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:

- germplasm improvement
- agronomy and physiology
- farming systems management
- soil and nutrient management
- water use efficiency
- crop sequencing
- plant protection
- integrated weed management
- water productivity
- livestock genetics and breeding
- livestock production
- animal health and welfare
- climate adaptation
- supply chains and market access.

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
Southern NSW
NSW Department of Primary Industries

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Irrigation & climate

Other research

Seasonal conditions 2017

Michael Cashen (Research Officer, Climate Applications and Digital Agriculture)

Climate summary

Condobolin Agricultural Research and Advisory Station

Average minimum temperatures were below the long-term average (LTA) from April through to September (Figure 1) at Condobolin with severe frosts causing damage in all crops. Average maximum temperatures were above the LTA from June to October with temperatures ~2 °C higher in September and October. The very low minimum temperatures in winter followed by the very high maximum temperatures in spring meant that there was not an ideal window for crops to flower to avoid temperature stress.

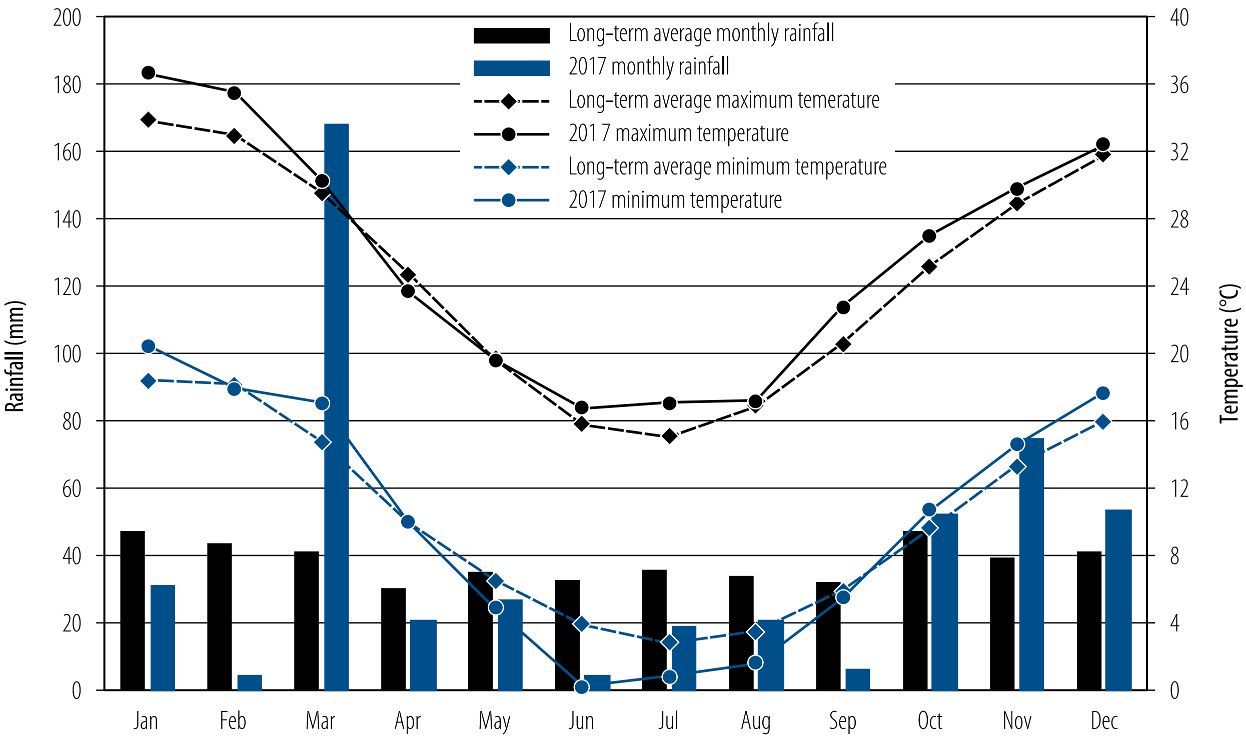

Figure 1. Monthly temperature and rainfall data for Condobolin Agricultural Research and Advisory Station in 2017.

With significant rainfall in March 2017, soil profiles at Condobolin (Figure 1) were full at sowing and, with some follow up rain in late autumn, crop establishment was good. This was followed by a relatively dry growing season (April to September), resulting in reduced crop growth and low disease pressure. There was a wetter than average finish in October, which was too late to increase grain yield.

Yanco Agricultural Institute

Average minimum temperatures were slightly below the LTA from mid April through to September (Figure 2) with temperatures ~3 °C below average in June at Yanco. There were a few heavy frosts recorded during spring at YAI causing some stem frost damage in cereals, and pod and seed abortion in canola. Average maximum temperatures were above the LTA from April through to October with temperatures ~1 °C higher in September and October. The higher maximum temperatures in the spring meant there was slightly higher than normal heat stress during the grain filling period at this site.

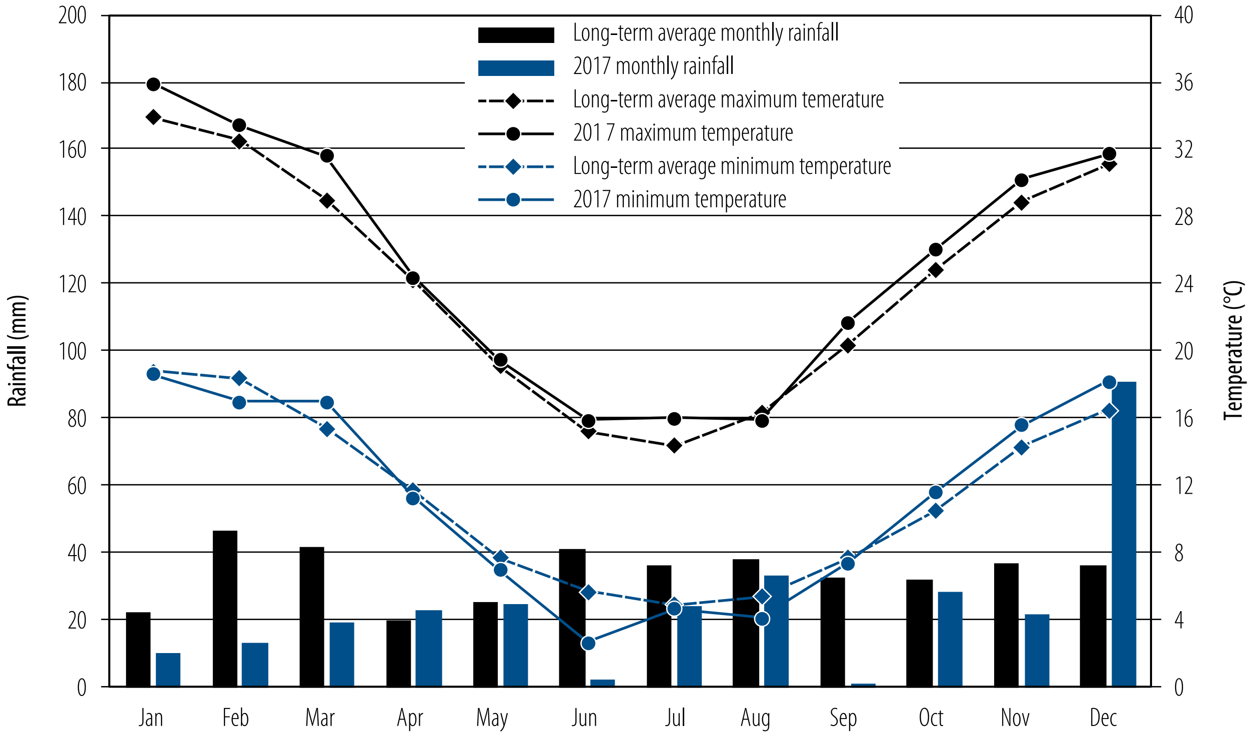

Figure 2. Monthly temperature and rainfall data for Yanco Agricultural Institute in 2017.

There was a promising start to the 2017 growing season with average rainfall recorded during April and May, which allowed the early winter crops to be sown. June was very dry, which retarded early growth and restricted the prospects for later sowings. Growing conditions in spring were extremely dry with no rain recorded at Yanco from the middle of August to mid October. The drier than average winter and spring resulted in below average grain yields. The high rainfall in December was too late to improve yields and caused some grain quality downgrading.

Wagga Wagga Agricultural Institute

Average minimum temperatures were well below the LTA from April through to September at Wagga Wagga: June minimum temperatures were 3.4 °C below the LTA. Early-developing cereal varieties suffered severe stem frost damage and early canola had high rates of seed abortion. Average maximum temperatures were higher in 2017 than the LTA for the entire growing season, with temperatures 2.8 °C higher in September and 3.5 °C higher in October. This meant there was no window for crops to flower to completely avoid both frost and heat stress.

The 2017 growing season started slightly drier than normal with almost no rain during June, which reduced early vegetative growth. Rainfall conditions improved from July onwards with near average rainfall in every month except for September. Above average rainfall late in the season helped later flowering crops produce close to average grain yields, especially pulses. Rainfall in early December caused some grain quality downgrading.

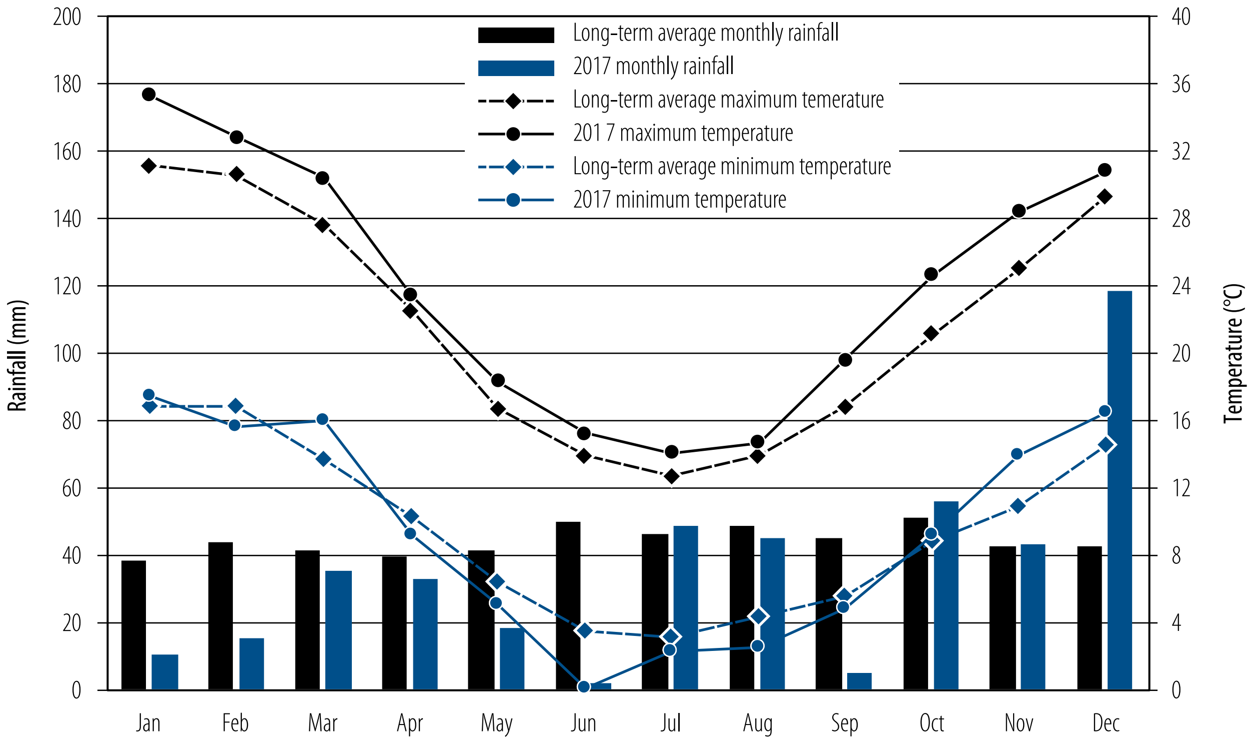

Figure 3. Monthly temperature and rainfall data for Wagga Wagga Agricultural Institute in 2017.

Disease

Crop disease development during the 2017 season in southern NSW was driven by carry-over inoculum loads from 2016 and the dry winter and spring conditions. Crop surveys showed the most commonly occurring foliar diseases in wheat paddocks in southern NSW were septoria tritici blotch (STB) and yellow leaf spot. The dry conditions influenced the amount of cereal rusts, with stripe rust only found in four of the surveys. For barley, the most common diseases were scald and the spot form of net blotch (SFNB). Overall disease severity was low, but for STB and SFNB the percentage of in infected plants in 11–15% of paddocks reached levels of 50% or more, which under more favourable rainfall conditions would have required growers to implement control measures.

Drier than average winter and spring conditions also restricted disease development in oilseed and pulse crops. However, frequent frosts favoured widespread outbreaks of bacterial blight in field pea crops in winter. Lower levels of blackleg in canola were recorded due to the drier winter conditions. Outbreaks of sclerotinia stem rot were restricted to those districts where the disease frequently occurs, in contrast to the widespread outbreaks in 2016. The drier than average spring conditions, with shortened periods of leaf wetness, curbed potential foliar disease outbreaks. This resulted in a reduced need for foliar fungicide applications in crops such as canola and faba bean.

Acknowledgements

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

Agronomy – cereals

Influence of anti-lodging plant growth regulators on root activity in barley – Wagga Wagga 2017

Jessica Simpson (NSW DPI Wagga Wagga and Charles Sturt University, Wagga Wagga); Dr Felicity Harris (NSW DPI); Dr Sergio Moroni (Charles Sturt University, Wagga Wagga); Hayden Petty (NSW DPI Wagga Wagga and Charles Sturt University, Wagga Wagga)

Key findings

- Plant growth regulator (PGR) application at the recommended time of early stem elongation (Z31) did not alter root or shoot growth in the barley cultivar (cv) Compass$^{\phi}$.
- When PGRs were applied during early growth stages (Z12–13) root growth was inhibited or unchanged depending on the active ingredient applied and the application method.
- When PGRs were applied early and when applied as a soil drench they inhibited root growth, but when applied at the recommended time for controlling stem height, PGRs had no effect on root growth.

Introduction

Plant growth regulators (PGRs) are chemicals that regulate stem elongation and reduce plant height in cereals (Berry et al. 2000; Acuña et al. 2015). PGRs are used in farming systems that are susceptible to lodging, such as in high rainfall areas or under intensive management (e.g. irrigation, high nitrogen rates). There have been indications that PGRs might potentially modify plant characteristics, such as root growth, in addition to reducing the internode length of stems and shortening plant height (Cooke, Hoad & Child 1983; Berry et al. 2004). However, results have been inconsistent and are often dictated by the influence of PGR type, environment, growth stage of application, and cultivar.

The aim of this experiment was to investigate the effect of two commonly used PGRs on root growth. It was hypothesised that if root growth modification occurred due to PGR application it would be a result of either the PGR altering the allometric balance between roots and shoots; a modification of the allocation of photoassimilates between the root and shoot as a consequence of inhibiting shoot growth; or a translocation of PGR from the point of application to the roots to directly influence root growth.

Methodology

The experiment was conducted in glasshouse facilities at Charles Sturt University, Wagga Wagga NSW, to investigate the influence of two gibberellin-inhibiting PGRs: Moddus®Evo (250 g/L trinexapac ethyl) and Errex 750 (582 g/L chlormequat chloride) on root growth. One barley variety, cv. Compass$^{\phi}$, was evaluated at two specific growth stages: early vegetative (Z12–13), and at early stem elongation (Z31), which is the recommended application time on the label.

PGRs were applied as either a soil drench or foliar spray to plants growing in PVC pots (100 mm diameter, 500 mm height) at two specific stages: the two- to three-leaf stage (Z12–13) or at the beginning of stem elongation (Z31) using a split-split randomised design, blocked by replication with four replicates. The rate of application of both PGRs was based on the highest label recommended rate to maximise the possibility of a response from the plants. Moddus®Evo was applied at 1 g active ingredient (ai)/L, which is equivalent to 400 mL/ha at 100 L water rate.

Errex 750 was applied at 7 g ai/L, which is equivalent to 1300 mL/ha at 100 L water rate. An untreated control, in which water was applied in place of chemical, was also included.

Multiple harvests were conducted from the date of application of the PGR treatments up to 20 days after treatments (DAT) to explore how soon plant growth was modified and to investigate more specifically the plant's response to the PGR over time. Shoots were removed at soil level and, depending on PGR timing, had either leaf extension (Z12–13) or stem height (Z31) measured. Tiller number, growth stage, and leaf area were also recorded. Soil was removed as an intact core and split into 10 cm increments for root washing. A selection of treatments was scanned for root length and diameter using WinRhizo. Shoots and roots were dried at 60 °C for dry weight determination. WinRhizo uses a computer program and image acquisition components to analyse root characteristics such as morphology (length, area, volume) and architecture.

Results

PGRs had varying effects on plant growth modification in cv. Compass(b barley. The effect of PGR application was only significant 20 DAT at the final harvest; as a result data is shown from the final harvest only.

PGR applied at the beginning of stem elongation (Z31); the label recommended time of application

Applying Moddus®Evo and Errex 750 at the recommended time of early stem elongation (Z31) had no significant effects on plant height, shoot dry matter (DM) production, root DM, or tiller appearance from either PGR in either treatment (data not shown).

PGR applied at the two- to three-leaf stages (Z12—13) of vegetative growth

When Moddus®Evo was applied during early growth stages (Z12–13) it significantly inhibited root and shoot DM in both treatments (52% and 61%, respectively of the untreated control) (Table 1). Foliar application of Moddus®Evo did not affect leaf extension rate, however, when applied as a soil drench, leaf extension rate was slower when compared with the untreated control (data not shown).

Table 1. The effect of applying PGRs during early (Z12–13) plant growth on mean tiller appearance (tiller number/day), shoot dry matter [DM] (grams), and root DM.

PGR	Application method	Tiller appearance (tiller/day)	Shoot DM (grams)	Root DM (grams)
Untreated control	Soil drench	0.38	6.31	1.71
	Foliar application	0.26	4.93	1.75
	Mean	0.32	5.62	1.73
Errex 750 (ai chlormequat chloride)	Soil drench	0.40	5.45	2.24
	Foliar application	0.35	5.87	2.32
	Mean	0.38	5.66	2.25
Moddus® Evo (ai trinexapac ethyl)	Soil drench	0.15	2.27	0.50
	Foliar application	0.32	4.59	1.39
	Mean	0.23	3.43	0.90
l.s.d. chemical		ns	1.53**	0.91*
l.s.d. application method		ns	ns	ns
l.s.d. interaction		0.16*	ns	ns

Note: ** *P*<0.01; * *P*<0.05; ns: not significantly different.
'Means' indicate the average of chemical regardless of application method (two application methods used; either soil drench or foliar application). Least significant differences (l.s.d.) shown for main effects and the interaction of [application method × chemical].

Tiller appearance was significantly affected by both PGR type and application method. A soil drench of Moddus®Evo reduced tiller appearance by 47%, however, a foliar application of Moddus®Evo did not reduce tiller appearance compared with the untreated control (Table 1).

Applying Errex 750 during early growth stages did not significantly influence root DM, shoot DM, or leaf area (Table 1).

Summary

Applying Moddus®Evo and Errex 750 at the recommended time of early stem elongation (Z31) were ineffective on root and shoot growth. When applied during early growth stages (Z12–13), Moddus®Evo significantly inhibited shoot DM, root DM, and the rate of tiller appearance. Results from applying Errex 750 during early growth stages was inconsistent, but overall did not significantly influence root and shoot growth.

In this study, only one barley cultivar (cv. Compass[Φ]) was evaluated. However, it is likely that the effect of PGRs on plant growth parameters would interact with cultivar with respect to growth stage, plant type, and environmental conditions. Therefore, further research is needed to determine which Australian barley cultivars respond to PGR application by reducing their shoot height before it will be possible to adequately quantify whether PGRs also affect root growth.

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Acknowledgements

This experiment was part of the project 'Building capacity in southern grains region', DAN201 2017–18, and 'Management of barley and barley cultivars for the southern region', DAN00173 2013–18, with joint investment from GRDC and NSW DPI. This experiment was conducted in collaboration with Charles Sturt University as part of the Agricultural Science course.

The technical assistance of Hugh Kanaley, Han Nguyen, Kerry Schirmer, Jack Zyhalak, John Broster, Cameron Copland, Danielle Malcolm, Jhoana Opena, Greg McMahon and Sharni Hands is gratefully acknowledged.

Influence of nitrogen and plant growth regulator application on grain yield of barley – Marrar 2017

Jessica Simpson, Dr Felicity Harris, Hugh Kanaley and Danielle Malcolm (NSW DPI, Wagga Wagga)

Key findings

- Plant growth regulators (PGRs) had minimal effects on the plant height of different barley varieties.
- PGRs reduced some lodging, however, this occurred predominantly in the taller cultivar (cv) prone to lodging (cv. Compass⁽ᴰ⁾).
- Neither PGR nor nitrogen (N) application increased grain yield.
- PGRs should be strategically applied, taking into account the interaction between cultivar, seasonal conditions, and application timing.

Introduction

Crop lodging presents a significant risk in cereal production and can severely reduce grain quality and yield by up to 80% (Berry et al. 2004) whilst ultimately increasing production costs. PGRs are applied in situations where lodging risk is high in order to shorten the plant height (internodes) and reduce lodging.

The primary objective of PGRs is to decrease plant height to reduce lodging, however, this can also indirectly increase grain yield. If the crop is not lodged, the effect of PGR application on yield is more variable. The influence of varying levels of N and PGR timing on the grain yield of four elite barley cultivars, including the recently released RGT Planet⁽ᴰ⁾, was investigated at Marrar in 2017.

Site details

Location	'Pine Grove', Marrar NSW
Soil type	Red chromosol
Previous crop	Canola
Sowing	Direct drilled with DBS tines, 250 mm row spacing, GPS auto-steer system
Target plant density	150 plants/m^2
Sowing date	10 May 2017
Soil pH_{Ca}	4.5 (0–10 cm) 4.9 (10–30 cm)
Mineral N at sowing	172 kg N/ha (150 cm depth)
Fertiliser applied	80 kg/ha mono-ammonium phosphate (MAP) applied at sowing (N: 10, P [phosphorus]: 22, K [potassium]: 0, S [sulfur]: 2) Variable rates of urea (N: 46) applied as per experiment treatments
Weed control	Pre-emergent (9 May): Diuron® 900 WDG at 350 mL/ha + Bouncer® at 350 g/ha Post-emergent (11 Aug): LVE MCPA 570 at 400 mL/ha + Paradigm™ at 25 g/ha + Uptake™ spraying oil at 500 mL/100 L water
Disease management	Seed treatment: Hombre® Ultra at 2 mL/kg In-crop (11 Aug): TILT®Xtra at 500 mL/ha
Pest management	Aphids (16 Oct): Aphidex® WG 500 at 150 g/ha

In-crop rainfall 194 mm (Apr–Oct) (long-term average is 293 mm)

Treatments

A complete factorial design consisting of treatment combinations of cultivars, applied N and plant growth regulators were included.

Cultivar	The barley (*Hordeum vulgare* L.) cultivars used were Compass$^{\phi}$ (with weak straw strength and medium-tall height), La Trobe$^{\phi}$ (with moderately good straw strength and medium height), Rosalind$^{\phi}$ (with good straw strength and medium height) and RGT Planet$^{\phi}$ (with good straw strength and medium height).
Nitrogen	Nitrogen was applied as either nil, 40 kg N/ha at sowing, 40 kg N/ha at sowing and 40 kg N/ha at GS22, or 40 kg N/ha at sowing and 80 kg N/ha at GS22.
PGR	The PGR applied was Moddus®Evo at 200 mL/ha. PGRs were applied at GS30, GS31–32, or a double application at GS30 and GS37–39. An untreated control was also included.

Results

Plant height and lodging score

One application of PGR at GS31–32 significantly reduced the height of La Trobe$^{\phi}$ and Rosalind$^{\phi}$ by 1.7 cm and 3.3 cm, respectively (Figure 1A). A double application also reduced the height of Compass$^{\phi}$, La Trobe$^{\phi}$ and Rosalind$^{\phi}$ by 1.4, 2.0, and 2.1 cm respectively (Figure 1A). The effect of Moddus®Evo on barley plant height in this experiment was small. In comparison, studies on wheat using Moddus®Evo found plant height was reduced by up to 26% (decreases of up to 20 cm compared with the untreated control) (Rajala & Peltonen-Sainio 2002; Matysiak 2006).

Lodging increased with additional N in all varieties (data not shown). Lodging was highest in Compass$^{\phi}$, a variety that is known to lodge. In comparison, lodging in RGT Planet$^{\phi}$ was minimal (Figure 1B). In two varieties (Compass$^{\phi}$ and Rosalind$^{\phi}$), PGR treatments caused a small decrease in lodging severity; in other varieties (La Trobe$^{\phi}$ and RGT Planet$^{\phi}$) the PGR had no effect (Figure 1B).

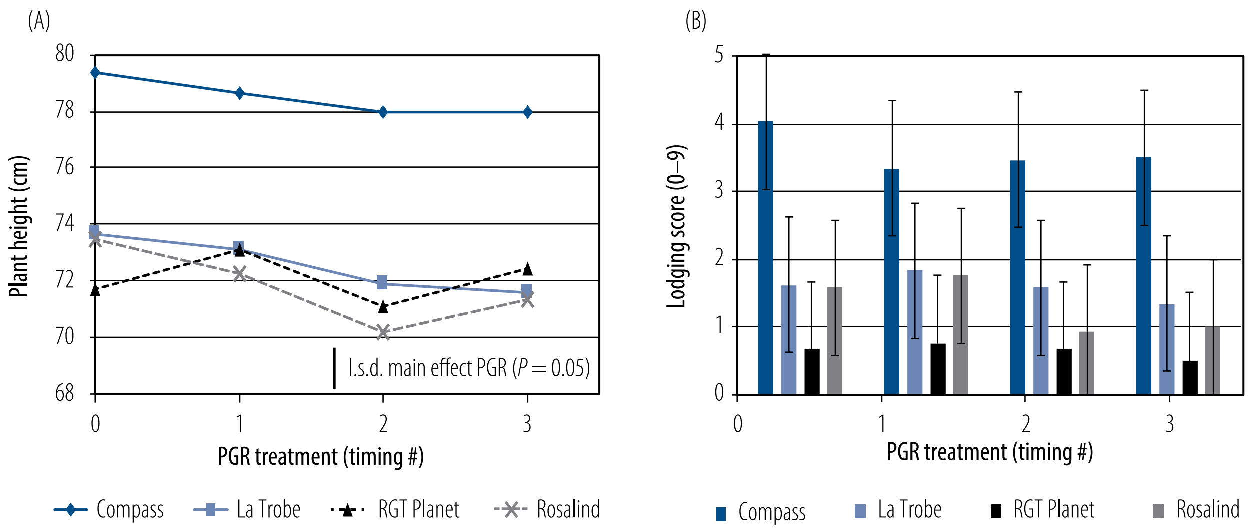

Figure 1. Plant height (A) and lodging score (B, 0 = no lodging to 9 = completely lodged) for combination of treatment factors (cultivar and PGR application timing) at Marrar, 2017.
Note: PGR application 0 = nil, 1 = GS30, 2 = GS31–32, and 3 = GS30 + GS37–39.
Bars on graph (B) are 2 × SE.

Grain yield and protein

Without additional N applications RGT Planet$^{\phi}$ had the highest yield (5.9 t/ha) and La Trobe$^{\phi}$ had the lowest yield (4.9 t/ha) (Figure 2A). Applying additional N at 40–80 kg/ha did not significantly increase yield. At the highest N rate (120 kg/ha additional N) yield was depressed by up to 12.5% (Figure 2A). However, N application directly increased grain protein concentration (Figure 2B). There was a significant difference in grain protein concentration in cultivars, with Rosalind$^{\phi}$ having the highest protein content and RGT Planet$^{\phi}$ the lowest. Grain protein content increased up to 5.3% with additional N (Figure 2B). There was no significant effect from any PGR application on grain yield.

In this experiment it is likely that the crop experienced post-anthesis water stress, as Marrar received ~100 mm less rainfall in the growing season than the long-term average. Hence, when additional N was applied it reduced grain yield. High soil N levels can lead to increased vegetative growth, which can exhaust soil water, resulting in water stress and lower grain yields (Van Herwaarden 1998). Screenings were generally low; however, they did increase with applied N (Figure 3). At the highest N rate RGT Planet$^{\phi}$ had the highest level of screenings at 4.1% and La Trobe$^{\phi}$ had the lowest at 2.8% (Figure 3). High N rates and low water availability at grain filling can result in pinched grain (high level of screenings) with high protein concentration (Van Herwaarden 1998).

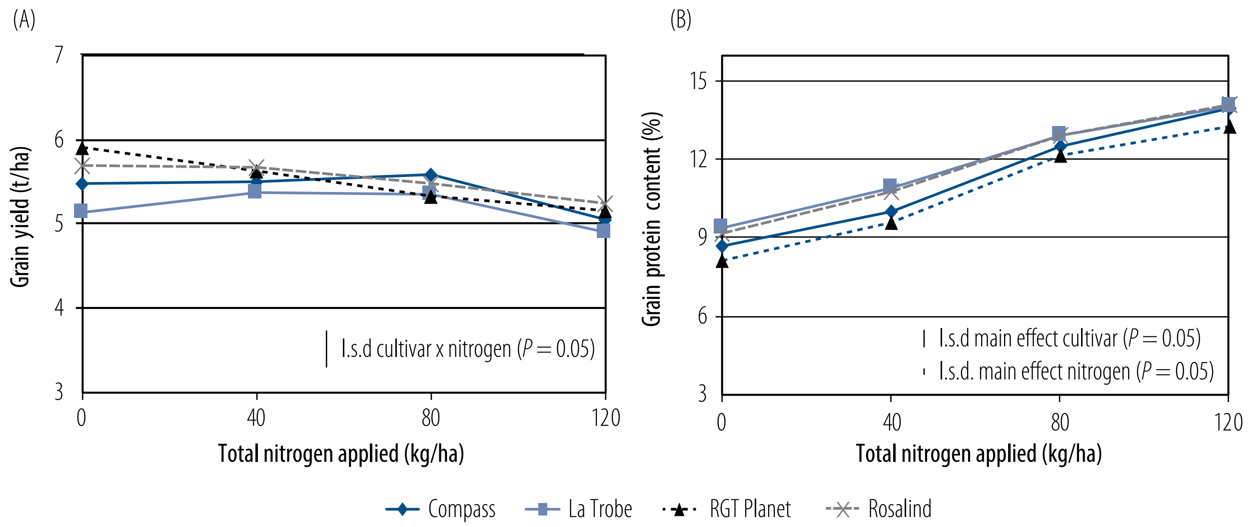

Figure 2. Grain yield (A) and grain protein content (B) for combination of treatment factors (cultivar and total nitrogen applied) at Marrar, 2017.

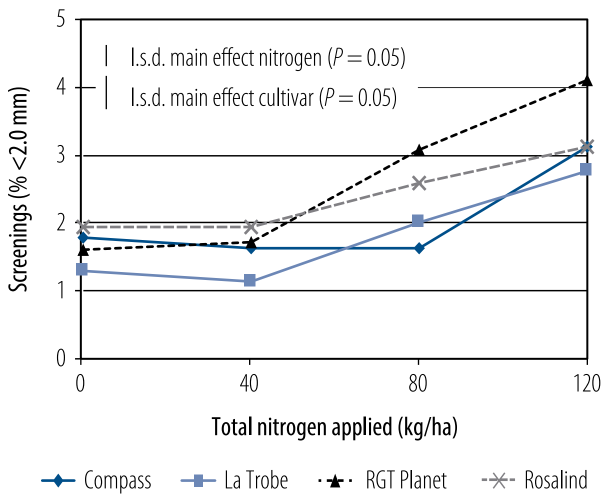

Figure 3. Screenings (grain passing through 2.0 mm sieve) for combination of treatment factors (cultivar and total nitrogen applied) at Marrar, 2017.

Summary

PGRs had minor effects on the height of these barley varieties. PGRs did mitigate some lodging however, mainly in the taller barley cultivar (Compass[(D)]). There was no effect on grain yield, but 2017 was a dry season and N application also did not increase yield. Strategically applying PGRs where lodging risk is high might offer some opportunities for increasing grain yield. However, in this experiment, these barley varieties did not respond to PGRs in terms of stem shortening to the same extent as other research studies where PGRs were applied to wheat. It needs to be clarified whether Australian barley varieties differ from each other in their responsiveness to PGR application. If varieties don't respond substantially, then the chance of yield improvement is not high. Further research should be conducted to determine the potential for PGRs to protect crops in high rainfall or irrigated areas and on specific varieties.

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Acknowledgements

This experiment was part of the project 'Management of barley and barley cultivars for the southern region', DAN00173, 2013–18, with joint investment by GRDC and NSW DPI.

We acknowledge the technical support of Hayden Petty, Cameron Copland, Warren Bartlett, Greg McMahon and Sharni Hands.

Sowing date influence on the phenology and grain yield of barley – Wagga Wagga 2017

Dr Felicity Harris, Hugh Kanaley, Greg McMahon and Cameron Copeland (NSW DPI, Wagga Wagga); David Burch (NSW DPI, Condobolin); Dr Kenton Porker (SARDI); Dr Ben Trevaskis (CSIRO)

Key findings

- Varietal options for early sowing (pre 25 April) in barley is limited by the availability of commercial winter genotypes.
- Genotypes with alternative development patterns showed variation in phasic development in response to sowing date.
- High grain yields were achieved across a range of genotype × sowing date combinations and through varied yield components.

Introduction

The adaptation and yield potential of barley depends on matching genotype phenology and sowing time to ensure heading date and grain formation occurs at an optimal time, with minimal exposure to abiotic stresses. Recently, early heading date has been positively correlated with grain yield in barley, and there has been a breeder focus on genotypes with rapid development. This experiment was conducted to evaluate phenology and yield responses of some commercial barley genotypes compared with some novel genetic lines, with respect to sowing date to investigate opportunities for genotypes with alternative development patterns in southern NSW.

Site details

Location	Wagga Wagga Agricultural Institute
Soil type	Red chromosol
Previous crop	Canola
Sowing	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}	4.5 (0–10 cm)
Mineral nitrogen (N)	145 kg N/ha at sowing (1.8 m depth)
Fertiliser	80 kg/ha mono-ammonium phosphate (MAP) (sowing) 40 kg N/ha (applied as urea at sowing)
Weed control	Knockdown: glyphosate (450 g/L) 1.2 L/ha Pre-emergent: Boxer Gold® 2.5 L/ha In-crop: Precept® 500 mL + Lontrel™ 750 SG 40 g/ha (12 July) LVE MCPA (570 g/L) 400 mL/ha + Paradigm™ 25 g/ha (9 August)
Disease management	Seed treatment: Hombre® Ultra 200 mL/100 kg Flutriafol-treated fertiliser (400 mL/ha) In-crop: Prosaro® 300 mL/ha (6 July, 9 August)
In-crop rainfall	222.8 mm (April–October) (long-term average – 355 mm)

Treatments

Sixteen near isogenic lines (NILs) were used that contained different combinations of vernalisation and photoperiod genes derived from ultra-early barley genotype WI4441 (developed by Dr Ben Trevaskis, CSIRO), three French winter genotypes (Secobra Research) with strong vernalisation, and five commercial genotypes with varied development were sown on three dates, 21 April, 8 May and 26 May in 2017.

Results

Phenology and grain yield

There was substantial variation in flowering date for the genotypes sown across the three Sowing dates. Optimum grain yield is achieved when genotypes are matched with sowing date to ensure appropriately timed flowering. In 2017, the genotypes and sowing date combinations that flowered in mid September to early October generally had the greatest yields (Figure 1). In southern NSW, this response is common, generally driven by the high risk of frost damage early, and heat and moisture stress later.

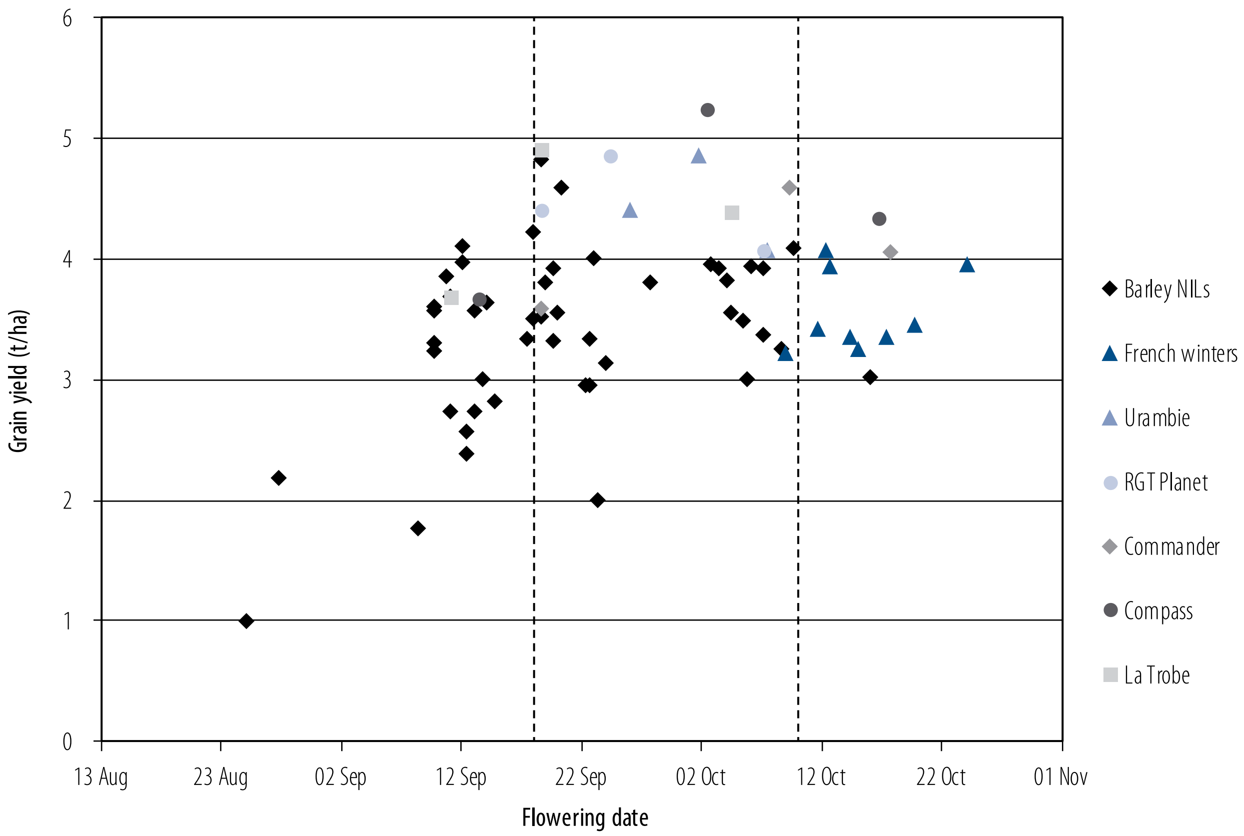

Figure 1. Relationship between flowering date and grain yield of genotypes sown 21 April, 8 May and 26 May at Wagga Wagga in 2017. Dashed lines indicate optimal flowering period.

Experiments conducted from 2014 to 2017 indicated that sowing of many spring varieties, such as La Trobe⊕ and Compass⊕, in mid May achieved optimal flowering times. However, the increased photoperiod of Commander⊕ means it flowers slightly later than the faster-developing genotypes, whilst Urambie⊕ is suited to earlier sowing due to its vernalisation response, and is relatively stable in its flowering response across sowing dates (Figure 2).

RGT Planet⊕ is a longer-season spring genotype that offers an alternative phenology pattern (minimal vernalisation response coupled with weak photoperiod response), in which its vegetative period is slightly longer than spring types, with an extended reproductive phase (Figure 2). RGT Planet⊕ has shown some flexibility across sowing dates and is capable of being sown earlier than most other fast-developing commercial spring genotypes, however, it can flower later than optimal when sown in late May due to its weak photoperiod response.

The NILs were all relatively quick to flower (Figure 1), however, the genetic variation in phenology responses indicated there could be alternative development patterns suitable for achieving optimal flowering time in southern NSW worth exploring.

The French winter lines had later flowering dates compared with the current commercial genotypes, indicating a stronger vernalisation response compared with Urambie⁽ᵈ⁾. Despite flowering outside the optimal window, they achieved relatively high stable grain yields across the sowing dates (Figure 1), which highlights opportunities for slower-developing barley genotypes that might be better suited to an earlier April sowing.

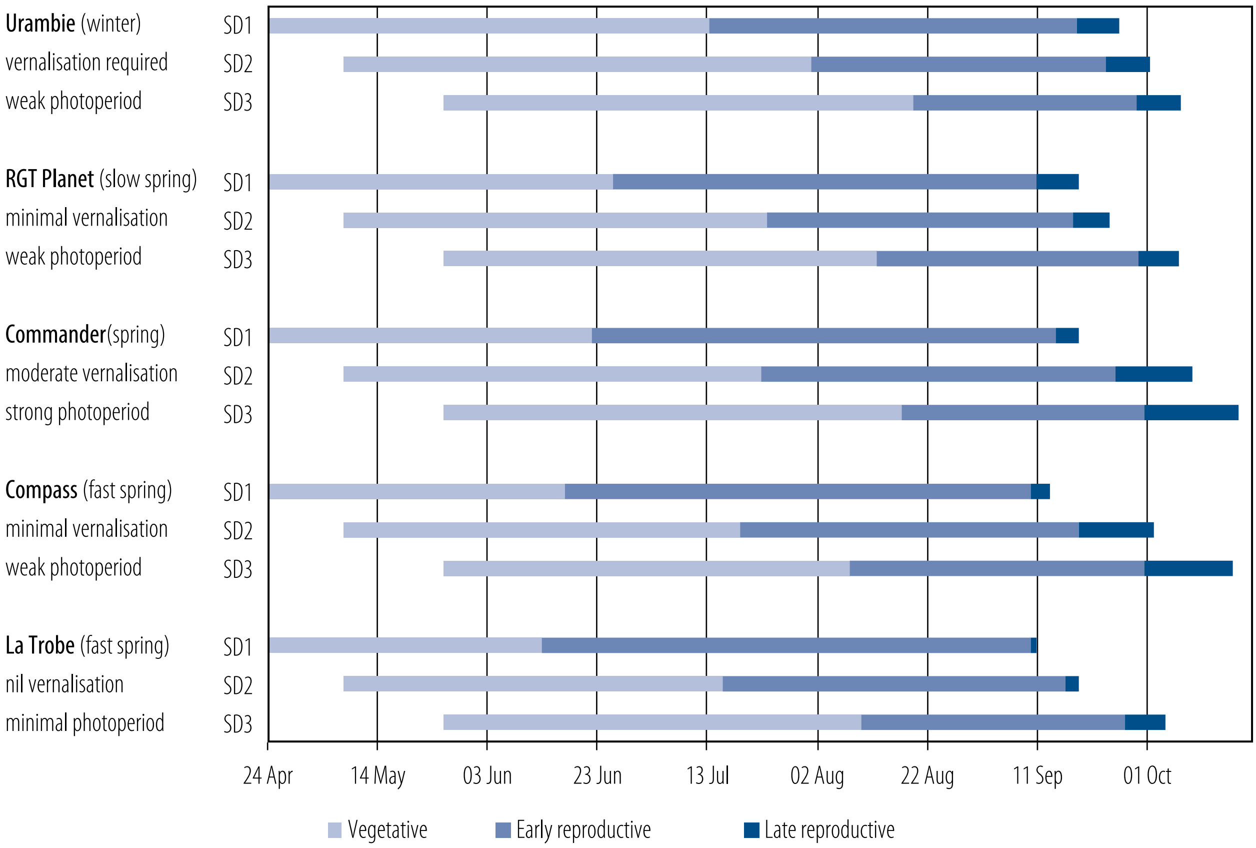

Figure 2. Sowing date influence on phasic development of selected genotypes sown on 21 April (SD1), 8 May (SD2) and 26 May (SD3) at Wagga Wagga in 2017. Vegetative phase: sowing to start of stem elongation (GS30); early reproductive phase: stem elongation (GS30) to awn peep (GS49); late reproductive: awn peep (GS49) to flowering (GS65).

Grain yield components

Results from the 2017 field experiment indicated that relative to the site mean, grain yield was predominately driven by increased grain number responses in most varieties (Figure 3A). However, there was varied influence of grain weight on yield improvement among genotypes for the three sowing dates (Figure 3b). RGT Planet⁽ᵈ⁾ and Compass⁽ᵈ⁾ maintained a relatively high grain number and weight across most sowing dates. In contrast, Urambie⁽ᵈ⁾ had a trade-off between grain number and grain weight at all sowing times, as did La Trobe⁽ᵈ⁾, which achieved its highest yield from the 8 May sowing date.

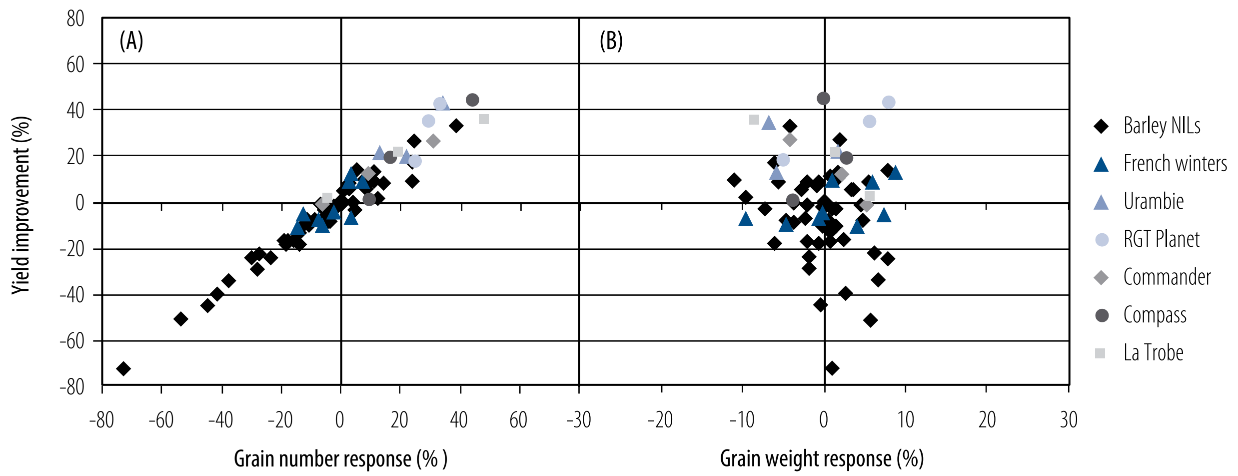

Figure 3. Relationship between yield improvement and its components (A) Grain number (grains/m²), and (B) average grain weight (mg). Data is expressed as a percentage of the site mean.

In 2017, harvest index (HI, ratio of grain yield to biomass) was maintained under high biomass levels (Figure 4). An analysis of the grain yield components shows that barley genotypes vary in their ability to achieve yield in response to sowing time. For example, La Trobe⁽ᵈ⁾ had the highest grain yield from sowing date 8 May, which was largely attributed to a high number of spikes/m² whilst maintaining grains/spike and moderate grain weight. In contrast, RGT Planet⁽ᵈ⁾ had its highest grain yield from an earlier 21 April sowing date, achieved through a high spike density coupled with high grain weights, with moderate grains/spike.

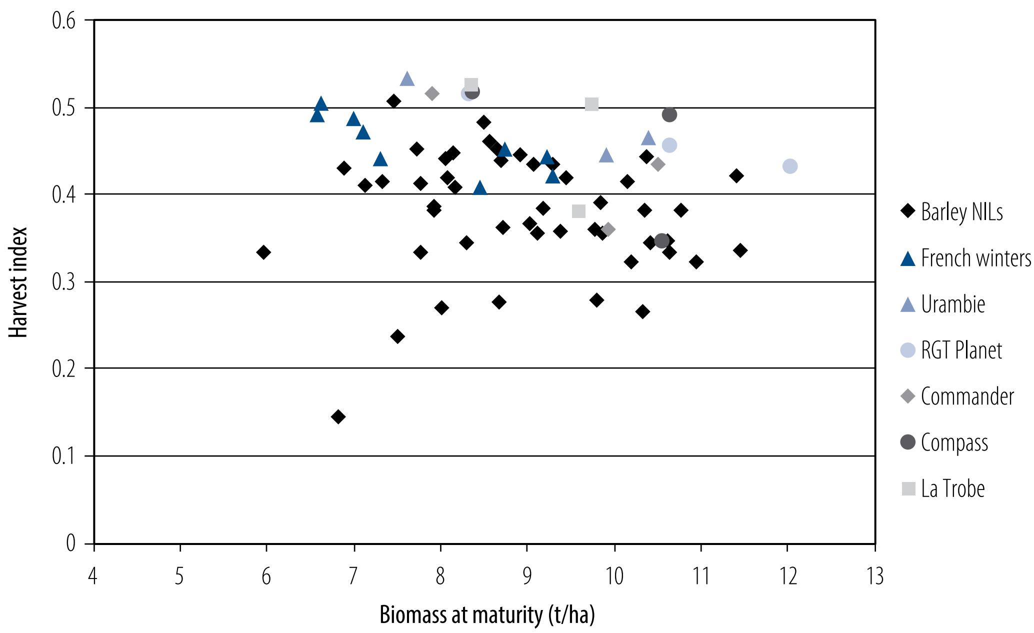

Figure 4. Relationship between harvest index and biomass at maturity of genotypes sown 21 April, 8 May and 26 May at Wagga Wagga in 2017.

Summary

Our data suggested there is scope for exploring alternative development genes for more varied phenology patterns in barley to support earlier sowing; currently these options are limited. There are differences in flowering date and yield development in response to sowing date in the barley NILs, French winter lines, and commercial varieties that growers can exploit. Urambie⁽ᵈ⁾ and RGT Planet⁽ᵈ⁾ offer opportunities for earlier sowing compared with other spring varieties best suited to mid May sowing in southern NSW. However, RGT Planet⁽ᵈ⁾ does not have a vernalisation requirement like Urambie⁽ᵈ⁾ and growers should be cautious when considering sowing earlier than May in frost-prone environments. Compared with other cereals, barley is an adaptive crop, capable of achieving high stable grain yields across a range of genotype × sowing date combinations, and through varied yield components. However, matching variety and sowing time to achieve flowering at an appropriate time for the growing environment is the most effective management strategy for optimising grain yields.

Acknowledgements

This experiment was part of the project 'Management of barley and barley cultivars for the southern region', DAN00173, 2013–18, a joint investment by GRDC and NSW DPI.

We acknowledge NSW DPI for their site cooperation at Wagga Wagga Agricultural Institute.

Sincere thank you for the technical support of Jessica Simpson, Hayden Petty, Mary Matthews, Dylan Male, Kathleen Bernie and Eliza Anwar.

Effect of sowing date on the phenology and grain yield of sixteen barley varieties – Condobolin 2017

David Burch, Nick Moody and Blake Brangwin (NSW DPI, Condobolin)

Key findings

- Frost and terminal drought were key determining factors on barley grain yield and development at Condobolin in 2017.
- Selecting sowing date and varietal phenology maximised grain yield by timing flowering for the first week of September at Condobolin.
- Grain plumpness, as indicated by screenings and retention, can be adversely affected by late sowing dates in the absence of spring rainfall.

Introduction

Phasic development varies widely between barley varieties, affecting flowering times and subsequent grain yield. This field experiment assessed the performance of 16 commercially available barley varieties sown on three dates at the Condobolin Agricultural Research and Advisory Station in 2017. The effects from sowing date on flowering date and yield for each variety is reported.

Site details

Location	Condobolin Agricultural Research and Advisory Station
Soil type	Red–brown chromosol
Previous crop	Eight months fallow following lucerne pasture
Fallow rainfall	323 mm (16 November–17 April)
In-crop rainfall	99 mm (17 May–17 October)
Soil nitrogen	43 kg/ha (0–60 cm, January 2017)
Starter fertiliser	70 kg/ha MAP (mono-ammonium phosphate) (11% nitrogen [N], 22.7% phosphorus [P], 2% sulfur [S]) at sowing
In crop management	380 g Achieve® herbicide on 20 June for grass weed control 1000 mL Precept® on 26 June for broadleaf weed control

Treatments

Varieties	AGTB0015, Banks$^{\phi}$, Biere$^{\phi}$, Bottler$^{\phi}$, Commander$^{\phi}$, Compass$^{\phi}$, Fathom$^{\phi}$, Hindmarsh$^{\phi}$, IGB1512, La Trobe$^{\phi}$, RGT Planet$^{\phi}$, Rosalind$^{\phi}$, Spartacus CL$^{\phi}$, Urambie$^{\phi}$, Westminster$^{\phi}$, WI4952
Sowing date (SD)	SD1: 24 April SD2: 12 May SD3: 25 May

Results

Grain yield and phenology

There were 84 frosts throughout the growing period at Condobolin, with 26 nights recording temperatures of below –2 °C. Frost and low rainfall were the major limitations to crop yield.

There were significant effects observed between varieties (P<0.001), and sowing dates (P = 0.003) (Table 1). The 12 May (mid season) sowing date had the greatest grain yield overall, with a mean yield of 1.68 t/ha. The late season sowing was the lowest yielding with a mean of 1.50 t/ha.

Table 1. Grain yield and flowering date of 16 barley varieties from three sowing dates at Condobolin, 2017.

Variety	SD1: 24 April 2017		SD2: 12 May 2017		SD3: 25 May 2017	
	Grain yield (t/ha)	Flowering date (GS55)	Grain yield (t/ha)	Flowering date (GS55)	Grain yield (t/ha)	Flowering date (GS55)
AGTB0015	1.86	28 Aug	1.73	9 Sep	1.69	16 Sep
Biere	1.45	12 Aug	1.48	30 Aug	1.36	10 Sep
Bottler	1.94	8 Sep	1.57	17 Sep	1.48	21 Sep
Commander	1.85	9 Sep	1.95	20 Sep	1.79	25 Sep
Compass	1.78	25 Aug	1.90	10 Sep	1.59	22 Sep
Fathom	1.72	24 Aug	1.86	8 Sep	1.86	15 Sep
Hindmarsh	1.11	20 Aug	1.55	8 Sep	1.36	14 Sep
Banks	1.81	11 Sep	1.72	18 Sep	1.38	23 Sep
IGB1512	0.99	18 Aug	1.73	8 Sep	1.71	16 Sep
La Trobe	1.61	20 Aug	1.82	8 Sep	1.54	17 Sep
RGT Planet	1.88	4 Sep	1.56	12 Sep	1.56	18 Sep
Rosalind	1.36	17 Aug	1.38	7 Sep	0.95	23 Sep
Spartacus CL	1.32	19 Aug	1.61	7 Sep	1.46	18 Sep
Urambie	1.74	17 Sep	1.41	22 Sep	1.39	26 Sep
Westminster	1.60	17 Sep	1.68	22 Sep	1.18	26 Sep
WI4952	1.48	7 Sep	1.96	10 Sep	1.73	17 Sep
Mean (SD)	1.59	31 Aug	1.68	13 Sep	1.50	21 Sep
l.s.d. (*P*<0.05) sowing date 0.09 t/ha; variety 0.24 t/ha						

The mid May sowings yielded significantly better than the early- and late-sown treatments overall, although varieties AGTB0015, Bottler⁽ᵈ⁾, Banks⁽ᵈ⁾, RGT Planet⁽ᵈ⁾ and Urambie⁽ᵈ⁾ all yielded significantly higher when sown on 24 April. All varieties, except Fathom⁽ᵈ⁾ and RGT Planet⁽ᵈ⁾, incurred a yield penalty from the later sowings compared with the mid season. Fathom⁽ᵈ⁾ demonstrated the greatest yield stability over the three sowing dates. This experiment and experiments in previous years indicate that for the central west of NSW, the target flowering window is the last week of August to the first week of September in order to avoid frost-induced yield losses and ensure sufficient soil moisture for grain fill (Figure 1). It is important to note that decisions on varieties and sowing dates require knowledge of multi-year trends, as a single season might not represent the typical regional growing environment.

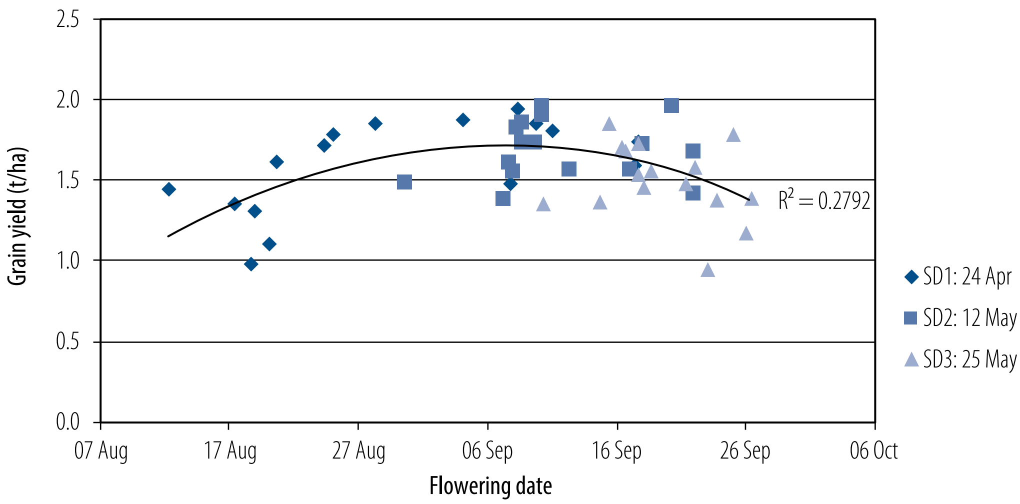

Figure 1. Flowering date and grain yield of 16 barley varieties sown on three dates at Condobolin in 2017.

Grain quality

There were significant differences between sowing dates and varieties for grain protein, test weight, screenings (<2.2 mm) and retention (>2.5 mm) with a significant interaction occurring in all quality components apart from grain protein. The grain quality results for all varieties averaged across sowing dates are displayed in Table 2.

Agronomy—cereals

Table 2. Average grain quality parameters of 16 barley varieties sown on three dates at Condobolin in 2017.

Variety	Protein (%)	Hectolitre weight (kg/hL)	Screenings (% <2.2 mm)	Retention (% >2.5 mm)	Thousand grain weight (g)
AGTB0015	12.4	68.12	4.80	68.09	37.54
Biere	13.2	71.39	3.57	71.81	37.84
Bottler	11.8	69.83	3.33	76.83	36.71
Commander	12.0	69.75	2.13	85.95	40.08
Compass	12.3	67.38	3.67	69.37	40.75
Fathom	12.5	70.52	4.12	67.05	34.80
Hindmarsh	12.1	69.94	8.34	48.91	31.06
Banks	12.4	71.42	5.54	52.97	35.10
IGB1512	12.5	69.48	2.46	76.50	36.33
La Trobe	12.0	70.25	4.52	66.41	35.09
RGT Planet	11.8	69.90	5.34	64.84	37.59
Rosalind	12.7	69.92	5.45	68.60	36.26
Spartacus CL	12.9	71.37	2.46	76.99	35.86
Urambie	12.8	69.97	21.05	16.89	35.92
Westminster	13.0	73.34	3.22	62.79	36.73
WI4952	12.1	70.14	2.82	80.30	35.67
l.s.d. ($P = 0.05$)	1.2	0.31	1.18	3.75	0.78

In order to achieve malt status, 70% of grain must be >2.5 mm in plumpness (retention), and <7% narrower than 2.2 mm (screenings). Figure 2 charts the change in retention and screening over sowing dates and illustrates the effect from later sowing dates on grain quality. Due to poor rainfall conditions, later sowings significantly decreased grain plumpness. In the late sowing date, long season varieties Banks⁽ᵈ⁾, Bottler⁽ᵈ⁾ and Urambie⁽ᵈ⁾ were most affected. The varieties that maintained the largest grain size despite late sowing and moisture stress at grain fill were Compass⁽ᵈ⁾, Commander⁽ᵈ⁾, and WI4952, all three of which have genetically plump grain and are early–mid season types.

Yield components

Grain yield is a function of grain weight, grains per tiller, and the number of tillers per metre square. There were significant varietal and sowing date differences with interactions observed in number of tillers per metre square and thousand grain weight. There was no direct relationship between final grain yield and the three yield components. There was, however, a strong relationship between total grains per metre square and grain yield (Figure 3), indicating it is a varietal specific combination of tiller numbers and grains per tiller that are the major determinants of yield, with individual grain weight contributing to a lesser degree.

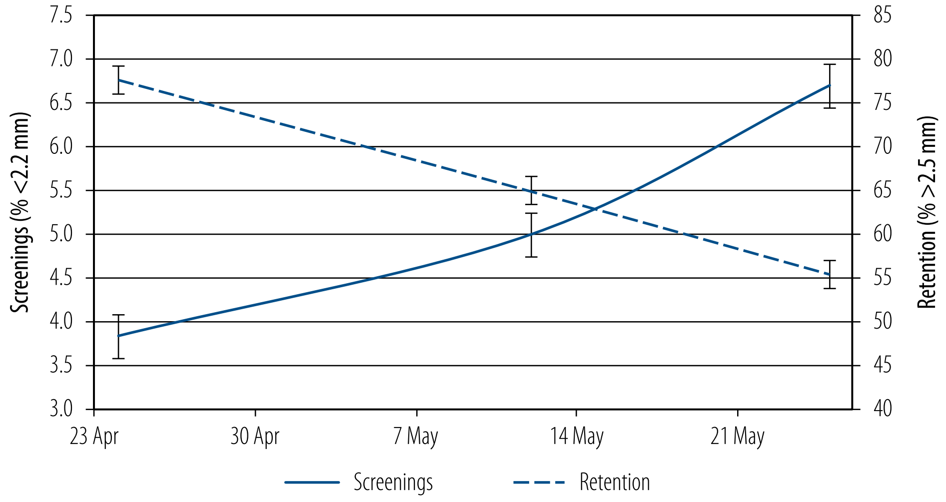

Figure 2. Effect of sowing date on barley grain screening and retention rates from 16 barley varieties sown at Condobolin in 2017.

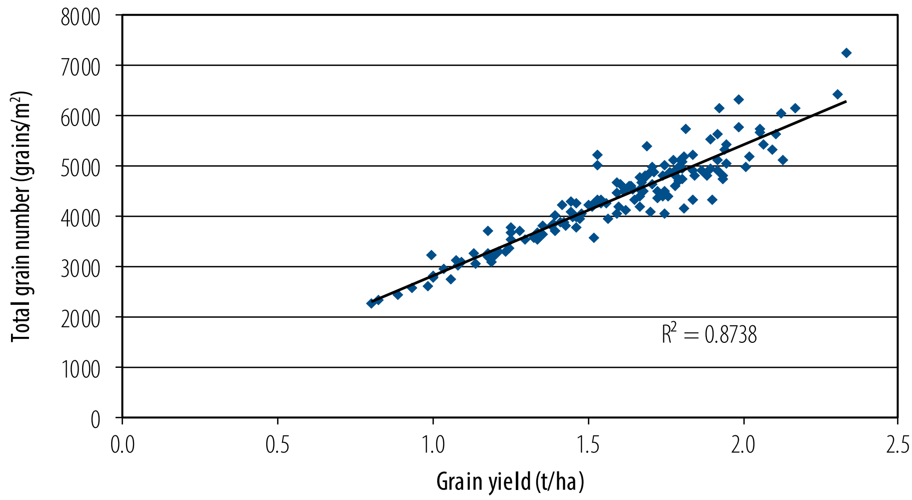

Figure 3. Individual grains per square metre vs total grain yield for 16 barley varieties sown at Condobolin NSW in 2017.

Conclusions

While early faster maturity varieties such as Hindmarsh⁽ᵖ⁾ and La Trobe⁽ᵖ⁾ and early sowing dates have predominated in the past several years, 2017 illustrated the risk of early flowering dates exposing the crops to frost damage during critical periods. By targeting a flowering period of early September, crops were provided with the best opportunity to avoid frost while ensuring sufficient time for grain fill in the event of moisture stress in spring.

Acknowledgements

This experiment was part of the project 'Management of barley and barley cultivars for the southern region,' DAN00173, 2013–18 with joint investment by GRDC and NSW DPI.

Thanks to the technical support of Daryl Reardon, Craig Ryan, Leisl O'Halloran and Susi Brangwin.

Comparison of four high-yielding barley varieties under different water regimes – Condobolin 2017

David Burch, Nick Moody and Blake Brangwin (NSW DPI, Condobolin)

Key findings

- Under the low rainfall conditions in 2017, there was no competitive advantage of newer barley varieties over the benchmark variety La Trobe⁽ᴾ⁾.
- Newer varieties such as Rosalind⁽ᴾ⁾, Compass⁽ᴾ⁾ and RGT Planet⁽ᴾ⁾ demonstrate a yield advantage in higher rainfall environments over La Trobe⁽ᴾ⁾.
- Under low rainfall conditions, La Trobe⁽ᴾ⁾ demonstrates superior retention and screenings compared with newer barley varieties.
- Feed variety Rosalind⁽ᴾ⁾ demonstrated excellent yield stability over a number of simulated rainfall scenarios.

Introduction

Since its commercial release in 2013, La Trobe⁽ᴾ⁾ barley has become the most widespread malting variety in the low and medium rainfall zones, due to consistently high yields and desirable malt characteristics. Since then, several barley varieties have entered the market, with comparable yield and quality characteristics, providing varietal alternatives for growers in the medium to low rainfall zone. This experiment assesses the performance of La Trobe⁽ᴾ⁾ barley against newly released barley varieties Compass⁽ᴾ⁾, Rosalind⁽ᴾ⁾, and RGT Planet⁽ᴾ⁾ under different irrigation treatments.

Site details

Location	Condobolin Agricultural Research and Advisory Station
Soil type	Red–brown chromosol
Previous crop	Eight months fallow following lucerne pasture
Fallow rainfall	322.6 mm (16 November–17 April)
In-crop rainfall	99 mm (17 May–17 October) (growing season average 209 mm)
Soil nitrogen	43 kg N/ha (0–60 cm, January 2017)
Starting fertiliser	70 kg/ha MAP (mono-ammonium phosphate) (11% nitrogen [N], 22.7% phosphorus [P], 2% sulfur [S]) at sowing
In crop management	380 g Achieve® herbicide on 20 June for grass weed control 1000 mL Precept® on 26 June for broadleaf weed control

Treatments

Varieties	La Trobe⁽ᴾ⁾ (malt), Compass⁽ᴾ⁾ (malt), Rosalind⁽ᴾ⁾ (feed), RGT Planet⁽ᴾ⁾ (undertaking stage two malt accreditation)
Irrigation	Four irrigation treatments were applied to the experiment, as described in Table 1. The growing season was divided into pre and post anthesis phases, assuming an anthesis date of 1 September. The rainfed treatment was naturally occurring rainfall, while full irrigation consisted of 120 mm additional water. Pre and post anthesis irrigation consisted of 60 mm of irrigation water applied either before or after anthesis (Table 1).

Table 1. Four irrigation treatments applied to four barley varieties at Condobolin NSW, 2017.

Irrigation timing	Rainfed (mm)	Pre-anthesis irrigation (mm)	Post-anthesis irrigation (mm)	Full irrigation (mm)
Pre-anthesis	93.0	153.0	93.0	153.0
Post-anthesis	6.2	6.2	66.2	66.2
Total	99.2	159.2	159.2	219.2

Results

Yield

There was a significant yield difference across irrigation treatments and variety, with a significant interaction between the two. La Trobe$^{\phi}$ was the lowest yielding variety overall, although there was no significant yield difference between varieties in the rainfed treatment (Table 2). The highest yielding varieties were Rosalind$^{\phi}$ and RGT Planet$^{\phi}$ in the fully irrigated treatment and RGT Planet$^{\phi}$ and Rosalind$^{\phi}$ in the pre-anthesis irrigation treatment.

Yield components

Grain yield is a factor of three components; grain weight, tiller number and number of grains per tiller. The main driver for grain yield in this experiment was total grains per square metre (Figure 1), with an r^2 value of 0.88 between grain yield and number of grains per square metre. This indicates that the greatest drivers of yield are tillers per square metre and number of grains per tiller. La Trobe$^{\phi}$ produced significantly more tillers than other varieties, with RGT Planet$^{\phi}$ producing the least. This difference was offset by RGT Planet$^{\phi}$ producing more grains per tiller and a higher grain weight.

There was a significant varietal effect from the irrigation treatment on grain number per tiller, thousand grain weight and tillers per square metre. Variety did not affect the number of grains per square metre, but was affected by irrigation treatment. When assessing yield stability in high and low available water environments, La Trobe$^{\phi}$ was the least affected with the smallest decrease in yield, grains per square metre, tillers per square metre and thousand grain weight. While RGT Planet$^{\phi}$ has demonstrated a capacity for high yields when moisture is available, it does not demonstrate a yield advantage over other varieties when moisture is limited.

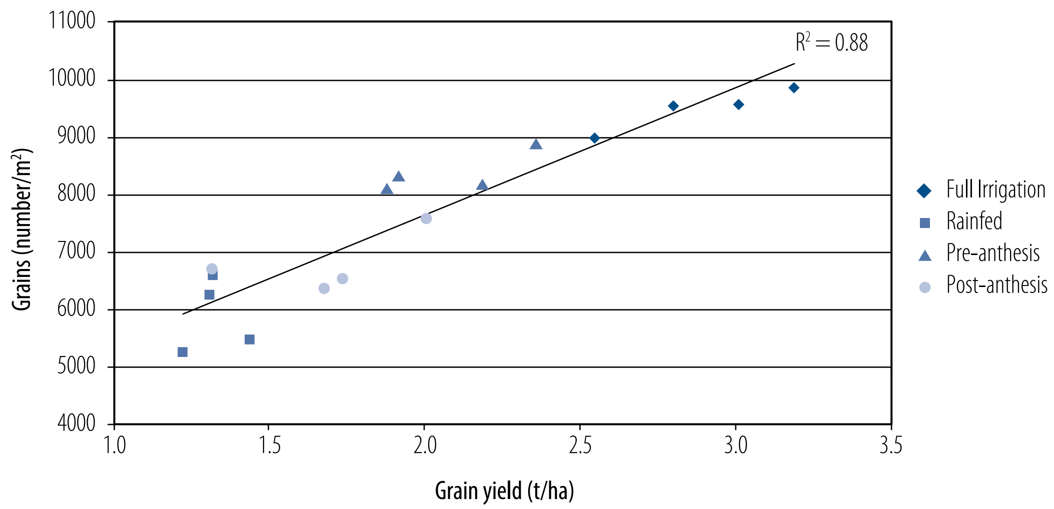

Figure 1. Relationship between grain number per square metre and total grain yield for four barley varieties treated with four irrigation practices.

Table 2. Grain yield and yield components of four barley varieties treated with different irrigation regimes.

Component	Variety	Irrigation treatment				
		120 mm irrigation	Rainfed	60 mm pre-anthesis	60 mm post-anthesis	Mean
Grain yield (t/ha)	Compass	2.80	1.31	1.92	2.01	2.01
	La Trobe	2.55	1.32	1.88	1.32	1.77
	RGT Planet	3.01	1.22	2.36	1.68	2.07
	Rosalind	3.19	1.44	2.19	1.74	2.14
	Mean	2.89	1.32	2.09	1.69	2.00
	l.s.d. ($P = 0.05$)	variety 0.14; irrigation 0.09; variety × irrigation 0.29				
Grain number (grains/m²)	Compass	9551	6277	8336	7584	7937
	La Trobe	8982	6601	8130	6701	7604
	RGT Planet	9586	5275	8899	6359	7530
	Rosalind	9879	5485	8189	6543	7524
	Mean	9500	5910	8389	6797	7649
	l.s.d. ($P = 0.05$)	variety 645; irrigation 643; variety × irrigation 1290				
Tiller number (tillers/m²)	Compass	558	375	492	619	511
	La Trobe	611	467	578	551	552
	RGT Planet	486	316	462	491	439
	Rosalind	612	429	630	514	546
	Mean	567	397	540	544	512
	l.s.d. ($P = 0.05$)	variety 52.4; irrigation 28.2; variety × irrigation 84.6				
Grain number (grains/tiller)	Compass	17.2	16.9	17.4	12.7	16.0
	La Trobe	15.2	14.2	14.3	12.2	14.0
	RGT Planet	19.8	16.8	19.2	13.1	17.2
	Rosalind	16.5	13.1	13.3	12.8	13.9
	Mean	17.1	15.3	16.0	12.7	15.3
	l.s.d. ($P = 0.05$)	variety 0.97; irrigation 0.72; variety × irrigation 1.94				
Grain weight (g/1000 grains)	Compass	49.3	38.5	42.4	42.7	43.2
	La Trobe	43.1	35.9	37.1	38.6	38.7
	RGT Planet	51.2	36.9	42.0	42.2	43.1
	Rosalind	46.6	36.9	39.7	39.9	40.8
	Mean	47.5	37.0	40.3	40.8	41.4
	l.s.d. ($P = 0.05$)	variety 0.59; irrigation 0.36; variety × irrigation 1.17				

Grain quality

There were significant differences between variety and irrigation treatments, with a significant interaction for protein, screenings, retention, test weight, harvest index and thousand grain weight. (tables 2 and 3). Compass⟨PBR⟩ and RGT Planet⟨PBR⟩ demonstrated the greatest capacity to suppress grain protein concentration, although this could have been in part due to protein being diluted as yield increased. When moisture stress occurred, RGT Planet⟨PBR⟩ demonstrated a significantly lower retention rate of 63%, below the required 70% retention rate for malt quality (Figure 2). Additionally, while there was no significant difference in screenings when irrigated, moisture stressed conditions resulted in significantly higher screenings in RGT Planet⟨PBR⟩ and Rosalind⟨PBR⟩ compared with La Trobe⟨PBR⟩ and Compass⟨PBR⟩ (Figure 3).

An analysis of thousand grain weight and screenings in the rainfed treatment is shown in Figure 4, indicating that screenings increased at a greater rate in RGT Planet⁽ᵈ⁾ compared with La Trobe⁽ᵈ⁾, at lower thousand grain weights. This suggests that at lower moisture availability, RGT Planet⁽ᵈ⁾ is at increased risk of high screenings compared with La Trobe⁽ᵈ⁾, even when grain weight is comparable.

There was a significant difference in grain protein concentration within the fully irrigated treatment, with La Trobe⁽ᵈ⁾ significantly higher than RGT Planet⁽ᵈ⁾, although there was no difference in the rainfed treatment between any of the varieties.

Table 3. Grain quality parameters for four barley varieties treated with four different irrigation regimes.

Parameter	Variety	Irrigation treatment				
		120 mm irrigation	Rainfed	60 mm pre-anthesis	60 mm post-anthesis	Mean
Grain protein (%)	Compass	12.3	13.5	12.3	14.8	13.2
	La Trobe	13.5	13.3	12.8	15.7	13.8
	RGT Planet	12.0	13.6	12.0	14.7	13.1
	Rosalind	12.4	13.8	13.3	15.0	13.6
	Mean	12.6	13.5	12.6	15.1	13.4
	l.s.d. ($P = 0.05$)	variety 0.4; irrigation 0.3; variety × irrigation 0.7				
Hectolitre weight (kg/hL)	Compass	65.9	62.3	63.8	65.1	64.3
	La Trobe	67.9	64.3	64.9	66.4	65.8
	RGT Planet	67.6	62.6	63.9	65.6	64.9
	Rosalind	67.2	63.7	64.8	65.4	65.3
	Mean	67.1	63.2	64.4	65.6	65.1
	l.s.d. ($P = 0.05$)	variety 0.35; irrigation 0.28; variety × irrigation 0.7				
Retention (% <2.5 mm)	Compass	98.5	85.3	90.8	94.2	92.2
	La Trobe	93.9	74.3	70.0	87.7	81.5
	RGT Planet	98.0	63.0	82.8	90.2	83.5
	Rosalind	96.8	73.3	81.0	88.8	85.0
	Mean	96.8	74.0	81.2	90.2	85.5
	l.s.d. ($P = 0.05$)	variety 1.8; irrigation 1.4; variety × irrigation 3.6				
Screenings (% <2.2 mm)	Compass	0.4	2.1	1.2	1.1	1.2
	La Trobe	0.7	2.9	4.6	1.6	2.5
	RGT Planet	0.5	4.1	2.0	2.1	2.2
	Rosalind	0.5	4.6	3.1	2.0	2.5
	Mean	0.5	3.4	2.7	1.7	2.1
	l.s.d. ($P = 0.05$)	variety 0.34; irrigation 0.29; variety × irrigation 0.69				
Harvest index	Compass	0.51	0.49	0.50	0.48	0.50
	La Trobe	0.53	0.52	0.51	0.52	0.52
	RGT Planet	0.54	0.47	0.52	0.47	0.50
	Rosalind	0.52	0.48	0.49	0.49	0.50
	Mean	0.53	0.49	0.51	0.49	0.50
	l.s.d. ($P = 0.05$)	variety 0.01; irrigation 0.01; variety × irrigation 0.02				

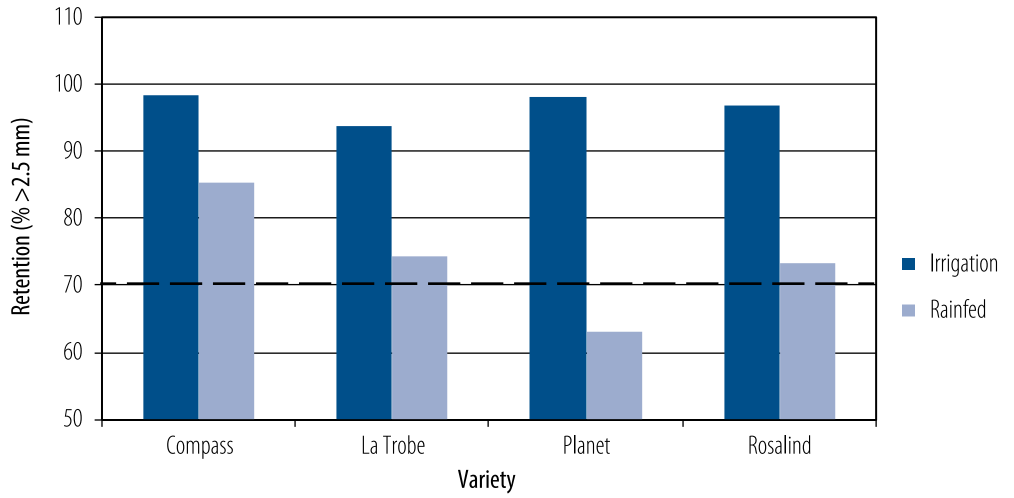

Figure 2. Retention rates (% >2.5 mm) of four barley varieties sown under rainfed and irrigated conditions. Horizontal dashed line represents minimum retention for malt accreditation at receival. l.s.d. ($P = 0.05$) variety 2.51%; irrigation 1.78%; variety × irrigation 3.53%.

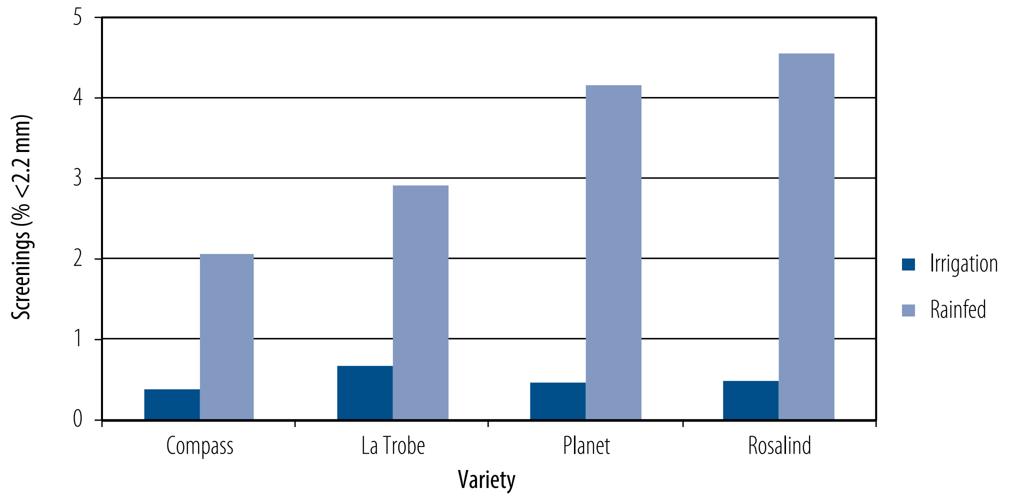

Figure 3. Screenings (% <2.2 mm) of four barley varieties under rainfed and irrigated conditions. l.s.d. ($P = 0.05$) variety 0.51%; irrigation 0.36%; variety × irrigation 0.72%.

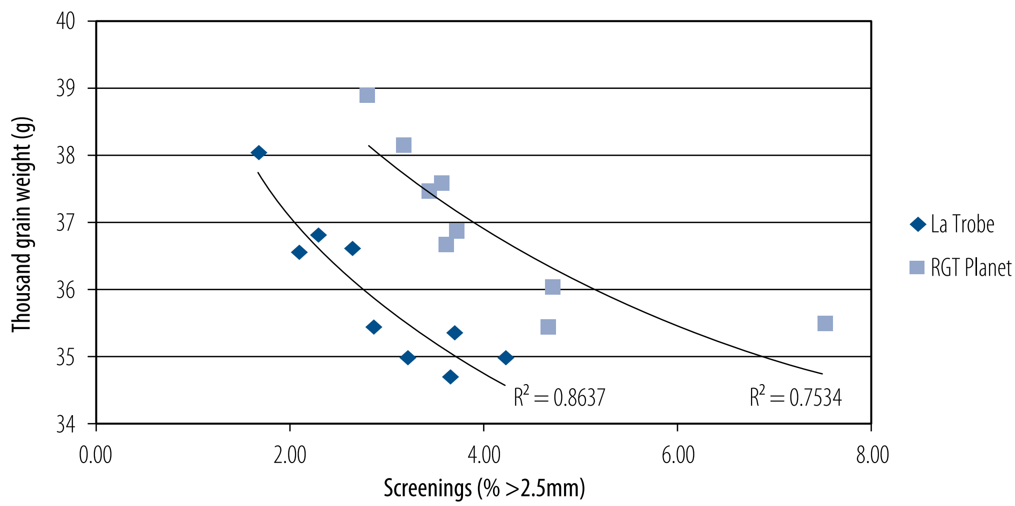

Figure 4. Relationship between thousand grain weight and screenings for La Trobe[⊕] and RGT Planet[⊕] barley grown under rainfed conditions.

Conclusions

New varieties such as Compass⌽, RGT Planet⌽ and Rosalind⌽ can demonstrate a yield and quality advantage over La Trobe⌽ given sufficient moisture. If sown in the central west of NSW where the probability of low rainfall is high, there is minimal competitive advantage over the benchmark variety of La Trobe⌽. Under higher rainfall scenarios, these newer varieties do provide greater yield potential.

It should be noted that at this time, only La Trobe⌽ and Compass⌽ can be accepted for malt.

Acknowledgements

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A sincere thankyou to Daryl Reardon, Craig Ryan, Leisl O'Halloran, Susi Brangwin, Tara Burns and Sarah Baxter for their technical assistance.

Effect of sowing date on the phenology and grain yield of thirty-two wheat varieties – Condobolin 2017

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

Key findings

- Frosts during flowering and stem elongation, and high moisture stress at grain fill presented the major limitations to grain yield at Condobolin in 2017.
- Early and mid season sowings had reduced yield in 2017, while late May sowings avoided frost damage during flowering.
- Medium to slow flowering varieties generally out-yielded faster flowering types, an atypical trend at Condobolin.

Introduction

In order to optimise grain yield, flowering times must be tailored to minimise frost risk at flowering and late season heat and moisture stress. The flowering time of any wheat cultivar is a combination of environment and the particular genetics of that variety. Australian wheat varieties have a broad range of phenology types, ranging from very fast early flowering, to very slow winter varieties, requiring long periods of vernalisation before flowering.

In order to maximise yield a grower must be able to match sowing time with varietal phenology, ensuring the crop flowers within its optimum window. This experiment evaluated the performance of 32 wheat cultivars for phenology, grain yield and quality at Condobolin, in 2017.

Site details

Location	Condobolin Agricultural Research and Advisory Station
Soil type	Red–brown chromosol
Previous crop	Eight months fallow following lucerne pasture
Fallow rainfall	322.6 mm (16 November–17 April)
In-crop rainfall	99 mm (17 May–17 October) (long-term growing season rainfall 209 mm)
Soil nitrogen	43 kg N/ha (0–60 cm, January 2017)
Starting fertiliser	70 kg/ha MAP (mono-ammonium phosphate) (11% nitrogen [N], 22.7% phosphorus [P], 2% sulfur [S]) at sowing
In crop management	380 g Achieve® herbicide on 20 June for grass weed control 1000 mL Precept® on 26 June for broadleaf weed control

Treatments

Varieties	see Table 1
Sowing date (SD)	SD1: 20 April SD2: 5 May SD3: 18 May

Table 1. Phenology types of the experiment varieties.

Phenology type	Variety
Winter (W)	EGA Wedgetail⦶, LongReach Kittyhawk⦶, Manning⦶, RGT Accroc⦶, Longsword⦶
Very slow (VS)	EGA Eaglehawk⦶, Sunlamb⦶, Sunmax⦶
Slow (S)	Cutlass⦶, Kiora⦶, Suntime⦶
Mid–slow (M–S)	Mitch⦶, LongReach Lancer⦶, Coolah⦶, DS Pascal⦶, EGA Gregory⦶, LongReach Trojan⦶
Medium (M)	Beckom⦶, Janz, Suntop⦶ Sunvale⦶, V09063-56
Fast (F)	Corack⦶, LongReach Mustang⦶, LongReach Reliant⦶, Mace⦶, Scepter⦶, LongReach Spitfire⦶, V08025-18
Very fast (VF)	Condo⦶, LongReach Dart⦶, Emu Rock⦶

Results

Flowering and grain yield

There were significant (*P*<0.001) differences between varieties and sowing dates, with medium to slow phenology types demonstrating a yield advantage over faster flowering varieties overall. Grain yields increased with later sowing dates, a trend not observed at Condobolin in the past two years (Menz et al. 2016; Menz et al. 2017).

There were frosts throughout the central west of NSW in 2017, with 84 nights falling below 2 °C between May and the end of September. Faster developing varieties flowered throughout this frost period, potentially affecting yield. One mechanism a wheat crop uses to recover from a frost event is producing secondary tillers. Due to low available moisture there was limited capacity for re-tillering and varieties that flowered during frosts were severely affected. Earlier frosts resulted in stem frost damage, as frost killed the developing head during the stem elongation period.

Varieties with slow, very slow or winter phenology were the highest yielding, with LongReach Kittyhawk⦶ (1.12 t/ha), Coolah⦶ (1.13 t/ha) and EGA Eaglehawk⦶ (1.29 t/ha) the top yielding varieties at SD1, SD2 and SD3 respectively (Table 2). It is important to note that this paper contains the results of one year of experiments and any sowing decisions should be based on multiple years of data.

Of all the varieties with fast to very fast phenology types, the only varieties to rank in the top 50% at any sowing date was LongReach Reliant⦶ (all sowing dates), LongReach Mustang⦶ (SD3) and V09063-56 (SD2 and SD3). In an environment with more available moisture, these fast types might have been more competitive due to increased grain filling time and capacity to re-tiller.

Peak yields were achieved by varieties flowering in the last week of September and the first week of October (Figure 1). Dry spring conditions such as those experienced in 2017 would normally favour earlier flowering varieties. However, frosts throughout August and September curbed potential yield.

Table 2. Grain yield and flowering date of 32 wheat varieties sown on three dates at Condobolin in 2017.

Variety	Sowing date					
	SD1: 20 April		SD2: 5 May		SD3: 18 May	
	Yield (t/ha)	Flowering date[1] (GS65)	Yield (t/ha)	Flowering date[1] (GS65)	Yield (t/ha)	Flowering date[1] (GS65)
Beckom	0.60 (20)	17 Sep	0.79 (17)	18 Sep	1.04 (15)	24 Sep
Condo	0.54 (23)	14 Sep	0.50 (31)	24 Sep	0.91 (26)	2 Oct
Coolah	0.91 (3)	26 Sep	1.13 (1)	02 Oct	1.04 (14)	2 Oct
Corack	0.40 (32)	14 Sep	0.53 (30)	24 Sep	0.81 (31)	29 Sep
Cutlass	0.53 (24)	17 Sep	0.75 (20)	24 Sep	1.24 (3)	4 Oct
LongReach Dart	0.57 (21)	14 Sep	0.64 (26)	20 Sep	0.89 (27)	26-Sep
DS Pascal	0.83 (8)	24 Sep	1.11 (2)	28 Sep	1.20 (6)	2 Oct
EGA Eaglehawk	1.05 (2)	2 Oct	1.07 (3)	2 Oct	1.29 (1)	4 Oct
EGA Gregory	0.78 (11)	24 Sep	0.98 (8)	24 Sep	1.24 (4)	2 Oct
EGA Wedgetail	0.91 (4)	2 Oct	0.61 (28)	2 Oct	0.98 (23)	2 Oct
Emu Rock	0.45 (28)	14 Sep	0.64 (27)	20 Sep	0.94 (25)	26 Sep
Janz	0.67 (17)	24 Sep	0.80 (16)	24 Sep	1.21 (5)	28 Sep
Kiora	0.89 (5)	2 Oct	0.79 (18)	4 Oct	1.15 (10)	4 Oct
LongReach Kittyhawk	1.12 (1)	2 Oct	0.98 (6)	2 Oct	1.03 (17)	2 Oct
LongReach Lancer	0.73 (14)	24 Sep	0.98 (7)	28 Sep	1.14 (11)	2 Oct
LongReach Reliant	0.74 (13)	17 Sep	0.96 (9)	28 Sep	1.25 (2)	28 Sep
Mace	0.51 (26)	18 Sep	0.66 (25)	24 Sep	0.89 (28)	30 Sep
Manning	0.48 (27)	17 Oct	0.41 (32)	17 Oct	0.50 (32)	17 Oct
Mitch	0.51 (25)	24 Sep	0.86 (13)	02 Oct	1.03 (18)	2 Oct
LongReach Mustang	0.42 (31)	17 Sep	0.74 (21)	24 Sep	1.09 (12)	30 Sep
Longsword	0.83 (9)	2 Oct	0.86 (12)	28 Sep	1.18 (8)	28 Sep
RGT Accroc	0.71 (15)	12 Oct	0.68 (24)	12 Oct	0.94 (24)	12 Oct
Scepter	0.61 (19)	18 Sep	0.74 (23)	2 Oct	1.00 (19)	2 Oct
LongReach Spitfire	0.44 (30)	17 Sep	0.54 (29)	28 Sep	0.84 (29)	30 Sep
Sunlamb	0.82 (10)	12 Oct	0.78 (19)	12 Oct	0.99 (20)	12 Oct
Sunmax	0.84 (7)	2 Oct	1.03 (4)	2 Oct	1.15 (9)	2 Oct
Suntime	0.67 (16)	24 Sep	0.84 (14)	4 Oct	0.82 (30)	4 Oct
Suntop	0.74 (12)	24 Sep	0.91 (10)	2 Oct	0.99 (21)	2 Oct
Sunvale	0.87 (6)	24 Sep	1.00 (5)	24 Sep	1.03 (16)	28 Sep
LongReach Trojan	0.66 (18)	18 Sep	0.90 (11)	24 Sep	1.08 (13)	27 Sep
V08025-18	0.44 (29)	14 Sep	0.74 (22)	18 Sep	0.99 (22)	24 Sep
V09063-56	0.55 (22)	24 Sep	0.83 (15)	28 Sep	1.19 (7)	24 Sep
Mean	0.68	24 Sep	0.80	29 Sep	1.03	1 Oct
l.s.d. (P<0.05) sowing date 0.05; variety 0.17						

[1] Flowering date was determined as the date 50% of anthers had extruded from the head (GS65).
Figures in parentheses are the yield ranking for each variety per sowing date.

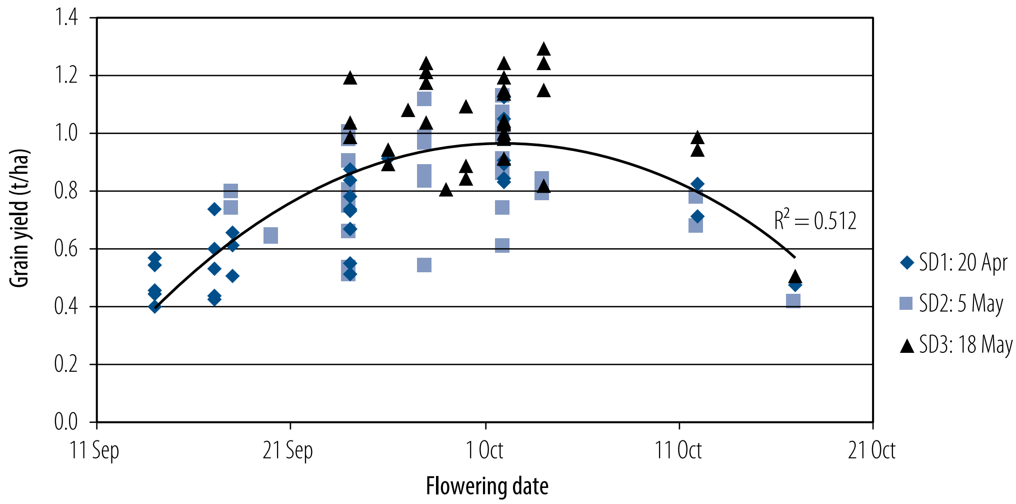

Figure 1. Flowering date and grain yield of 32 wheat varieties sown on three dates at Condobolin, 2017.

Grain quality

Grain protein concentration (GPC) decreased significantly with later sowing dates, although this could have been due to higher yields diluting available protein. Screenings increased with each sowing date, although the increase from SD1 to SD2 was not significant (Table 3). Test weights, not displayed here, had significant (*P*<0.001) differences between varieties and sowing dates, with test weights increasing over time. For wheat to be received at the highest three quality classifications (APH2, H1 or H2), hectolitre weights over 76 kg/hL must be attained. This was achieved in all varieties and sowing dates except for Corack⟂ and LongReach Spitfire⟂ (SD1) and Manning⟂ (SD2 and SD3). LongReach Spitfire⟂ demonstrated the greatest capacity for GPC, rating significantly higher than the average across all sowing dates, and a 22% higher grain protein than the average across all sowing dates. There was no significant difference between the screenings of SD1 and SD2, although there was a significant increase in SD3. The highest level of screenings was from Mitch⟂, with screenings 75% above the average, while the lowest was Longsword⟂, which was 42% lower than average. The varieties with screenings below 5% in all three sowing dates were Beckom⟂, EGA Wedgetail⟂, Janz, LongReach Lancer⟂, Sunlamb⟂, Suntop⟂, Sunvale⟂, LongReach Trojan⟂ and Longsword⟂.

Table 3. Protein (%) and screenings (% grain passed through a 2 mm slotted sieve) for 32 wheat varieties sown on three dates at Condobolin in 2017.

Variety	Sowing date					
	SD1: 20 April		SD2: 5 May		SD3: 18 May	
	Protein (%)	Screenings (%)	Protein (%)	Screenings (%)	Protein (%)	Screenings (%)
Beckom	14.5	4.64	13.9	4.28	12.9	5.00
Condo	15.3	7.20	14.9	7.71	14.1	8.10
Coolah	11.8	7.59	11.4	7.00	11.3	6.36
Corack	14.7	4.49	14.5	5.48	13.6	5.69
Cutlass	13.9	5.96	13.3	5.98	12.8	5.97
LongReach Dart	14.0	7.67	14.9	6.09	13.8	7.17
DS Pascal	13.5	3.98	12.7	4.29	12.8	5.16
EGA Eaglehawk	13.5	7.51	13.1	7.14	13.2	5.76
EGA Gregory	13.8	5.79	12.1	7.41	12.2	8.16
EGA Wedgetail	14.1	4.09	14.7	4.91	14.2	4.09
Emu Rock	14.6	6.51	14.3	6.53	14.1	6.96
Janz	14.5	3.49	13.9	3.04	13.1	3.75
Kiora	13.7	4.03	13.0	5.34	12.1	5.39
LongReach Kittyhawk	12.1	6.18	13.4	5.49	12.4	7.33
LongReach Lancer	14.5	4.15	13.5	4.40	13.4	4.80
LongReach Mustang	14.4	5.55	13.6	6.39	12.7	8.18
LongReach Reliant	14.2	8.19	13.0	7.07	12.0	7.83
Mace	14.8	4.40	13.5	5.13	13.5	4.91
Manning	14.6	6.49	15.0	4.86	14.7	6.40
Mitch	13.8	8.99	12.3	11.57	12.3	10.95
Longsword	15.2	1.72	13.6	3.00	13.5	2.70
RGT Accroc	13.8	7.45	14.1	5.75	14.2	6.44
Scepter	13.1	8.39	13.1	8.02	12.3	9.04
LongReach Spitfire	17.9	4.69	16.8	5.79	15.8	6.40
Sunlamb	15.1	4.55	15.0	4.37	14.6	4.63
Sunmax	13.3	7.00	12.3	7.70	13.0	6.96
Suntime	14.6	7.33	13.4	6.95	13.0	7.55
Suntop	13.9	4.02	13.3	4.47	13.6	3.83
Sunvale	14.4	2.73	13.8	3.63	13.4	4.52
LongReach Trojan	14.2	4.00	13.2	3.70	13.0	4.38
V08025-18	14.1	5.84	13.3	6.49	12.5	7.74
V09063-56	14.3	6.41	12.9	9.17	11.9	10.33
Mean	14.2	5.66	13.6	5.91	13.2	6.33
l.s.d. ($P<0.05$)						
sowing date	0.25	0.33				
variety	0.8	1.08				

Conclusions

Grain yield in 2017 was limited by frosts throughout the vegetative and flowering periods, and by moisture and heat stress during the grain filling period. Later season sowings, despite having a short grain filling period yielded greater than earlier sowings, which had suffered frost damage. Highest yields were obtained from sowings that flowered in the first week of October. Long season varieties LongReach Kittyhawk⁽ᶲ⁾, and EGA Eaglehawk⁽ᶲ⁾ and Coolah⁽ᶲ⁾ were the top yielding varieties, while fast flowering variety LongReach Reliant⁽ᶲ⁾ was competitive at later sowings. This trend is not coherent with experiments conducted in 2015 and 2016, and had record frosts during the growing season. Experiments will be undertaken in 2018 in order to further characterise the interactions of phenology on grain yield in the central west of NSW.

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Acknowledgements

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Thanks to the technical assistance of Daryl Reardon, Craig Ryan, Leisl O'Halloran, Tara Burns, Sarah Baxter and Susi Brangwin.

Honours study: The relationship between water-soluble carbohydrates and freezing resistance in wheat

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Key findings

- The incidence and severity of frost in southern NSW in 2017 had a significant effect on grain yield and quality.
- The concentration of sugars that could be manipulated in the plant at booting and ear-emergence contributed very little to the freezing point of plant sap.
- Higher yields were not observed under higher rates of nitrogen in the field, due to extreme frost conditions. However, increasing nitrogen rates increased tillering capacity, which contributed more regrowth to plants recovering from stem frost damage.

Introduction

Freezing and cold resistance is largely associated with vegetative growth, with the plant having the ability to recover and drive yield through regrowth (Eagles et al. 2016). As such, the growth stage that is most susceptible to freezing stress is that of reproductive development, due to tillering stopping during this stage and the direct effects on the fertility of emerging ears (Levitt 1980).

Whilst there have been significant research efforts into breeding frost resistant wheat varieties (Eagles et al. 2016), currently there are no resistant varieties commercially available. Therefore, growers rely on frost mitigation strategies such as sowing date, cultivar and paddock selection. It is known that plants naturally acclimatise to cold surroundings through solutes accumulating to lower the freezing point of tissues (Levitt 1980; GRDC 2016).

A glasshouse and field experiment were conducted to determine whether increased water-soluble carbohydrate (WSC) levels during pre-anthesis reproductive development would depress the freezing point of plant tissues to increase frost resistance.

Methodology

Experiments were conducted whereby plants that differed in WSC concentrations were subjected to freezing conditions during sensitive reproductive stages before anthesis. WSC levels were manipulated through shading (glasshouse) and varied nitrogen (N) fertiliser treatments (field) on one cultivar (cv. LongReach Dart⁽ᶲ⁾).

Glasshouse experiment

A shading stress was imposed under glasshouse conditions to limit photosynthetic activity and lower concentrations of WSC. The plants were shaded for two weeks before the growth stages of mid-booting (Z45) and 50% ear emergence (Z55), where plants were then exposed to a freezing event in the growth chambers at Charles Sturt University. Plant sampling occurred at Z45 and Z55 before freezing events for WSC (sucrose, glucose and fructose) and osmometry analysis. Grain weight and distribution were also measured to determine the effect of freezing on grain formation.

Field experiment

The field experiment involved varied rates of in-crop applied N, as high N is correlated with lowering WSC concentrations (van Herwaarden et al. 2003). LongReach Dart⁽ᶲ⁾ was sown on 10 April at Wagga Wagga Agricultural Institute. Plots were sown with 98 kg/ha mono-ammonium phosphate (MAP) using DBS tynes on 24 cm row spacings. Nitrogen was applied at Z31 (nil, 50 and 100 kg N/ha as urea) and Z37 (40 kg N/ha as liquid urea ammonium nitrate (UAN)). Plots were visually scored for frost damage at flag leaf emergence (Z37–39) and assessed for yield and grain characteristics at harvest.

Results

Glasshouse

Stem WSC concentrations were lowered significantly by shading only during the booting growth stage (Figure 1). The two-week shading period imposed to lower WSC concentrations resulted in the emerging ears becoming infertile, preventing grain production.

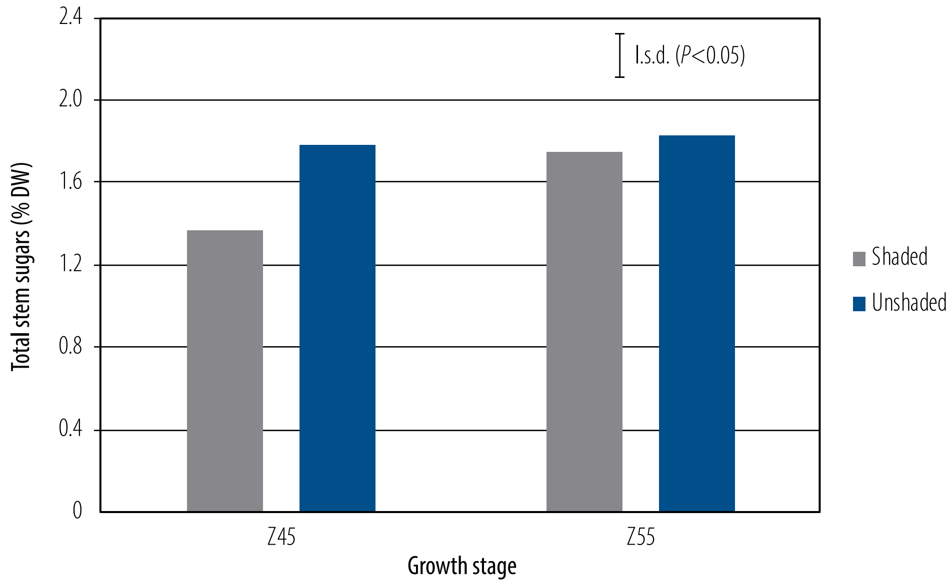

Figure 1. Total wheat stem sugars as a percentage of dry weight (DW) for the shaded and unshaded treatments for each timing treatment of booting (Z45) and ear emergence (Z55).

The mass of solutes within a solution, known as osmolality, can alter the freezing point. Hence, using shading to lower sugar concentrations in plant sap was expected to reduce solutes and increase the freezing point. However, the shading process stressed the plants, resulting in reduced growth and a measured increase in osmolality due to a reduced dilution effect. The calculated proportion of solutes to which the measured sugars contributed was not significantly different between shaded and unshaded treatments (Table 1).

Table 1. Stem osmolality and predicted freezing point for shaded and unshaded treatments at each wheat growth stage.

Treatment	Timing	Osmolality (mOsm/kg water)	Freezing point of solution (°C)	Predicted freezing point from sugars (°C)
Shaded	Z45	390.4	−0.7270	−0.1748
	Z55	417.3	−0.7753	−0.1748
Unshaded	Z45	353.1	−0.6561	−0.1745
	Z55	353.7	−0.6573	−0.1745
l.s.d. ($P<0.05$)		15.27	0.03167	n.s.

Note: ns: not significant.

A single freezing event, simulating a frost, significantly reduced grain number in the controlled environment growth chambers for the unshaded plants. The −4 °C treatment significantly lowered grain number from the control by approximately 15%, whilst the −8 °C treatment lowered grain number by ~50% (Figure 2). The severe grain loss experienced in the −8 °C treatment occurred when grains were being formed in the centre of the wheat spike (Figure 3).

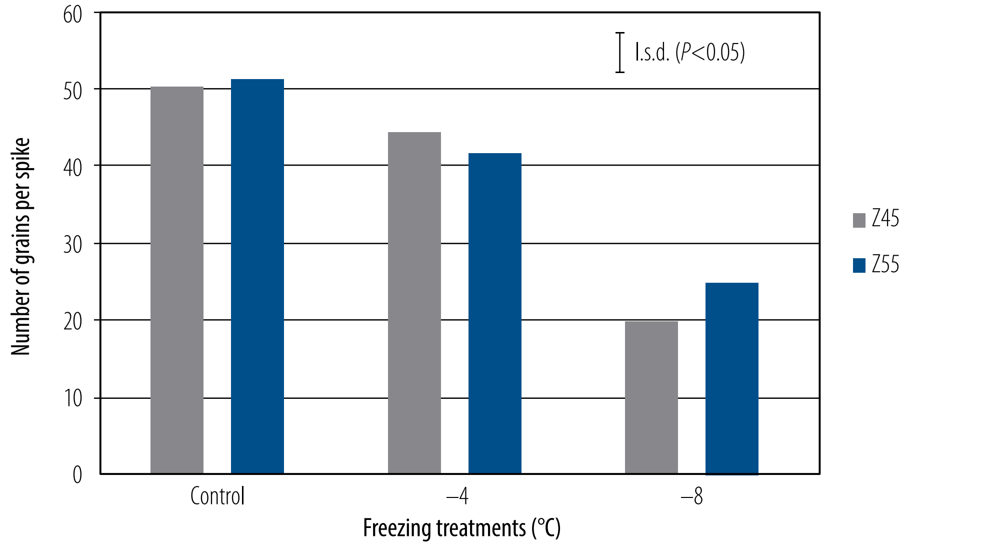

Figure 2. Average number of wheat grains per spike for the unshaded treatment. Presented is each timing, Z45 and Z55 for the temperature treatments control, –4 °C and –8 °C.

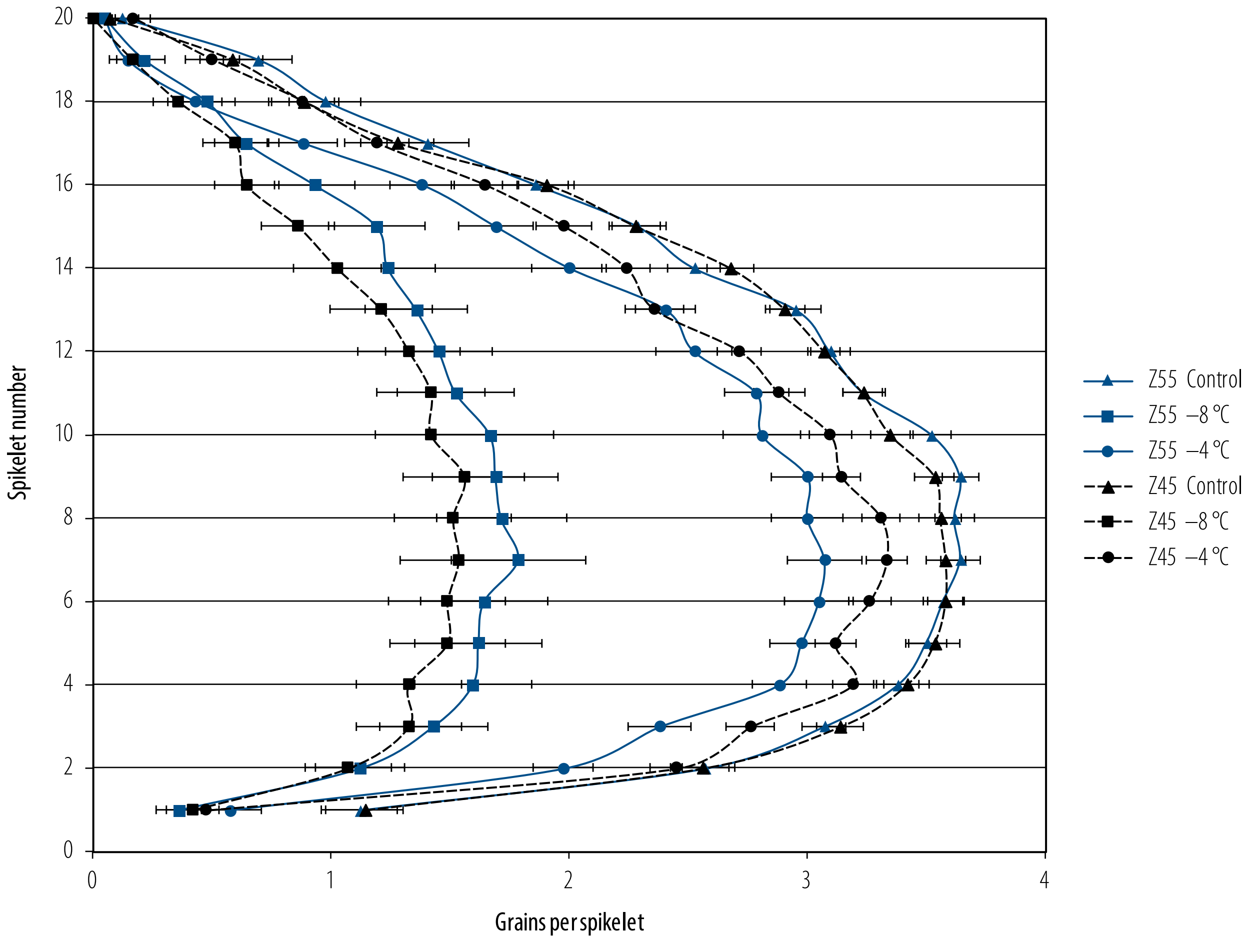

Figure 3. Average number of grains per spikelet for each location on the spike of the main stem for the unshaded treatment. The timing of the temperature treatments are Z45 (black) and Z55 (blue). Error bars represent standard error of the mean.

Field

The 2017 season was one of the coldest on record with 92 days below 0 °C and 63 below –2 °C measured in the crop canopy (Figure 4). LongReach Dart[⁽ᵇ⁾] is a spring wheat variety and develops quickly. For the purpose of this study, it was sown early to ensure frost exposure occurred during the developmental stages of booting and ear-emergence. As the 2017 frosts were so severe, the frost effect dominated, minimising any treatment effect on grain yield and quality.

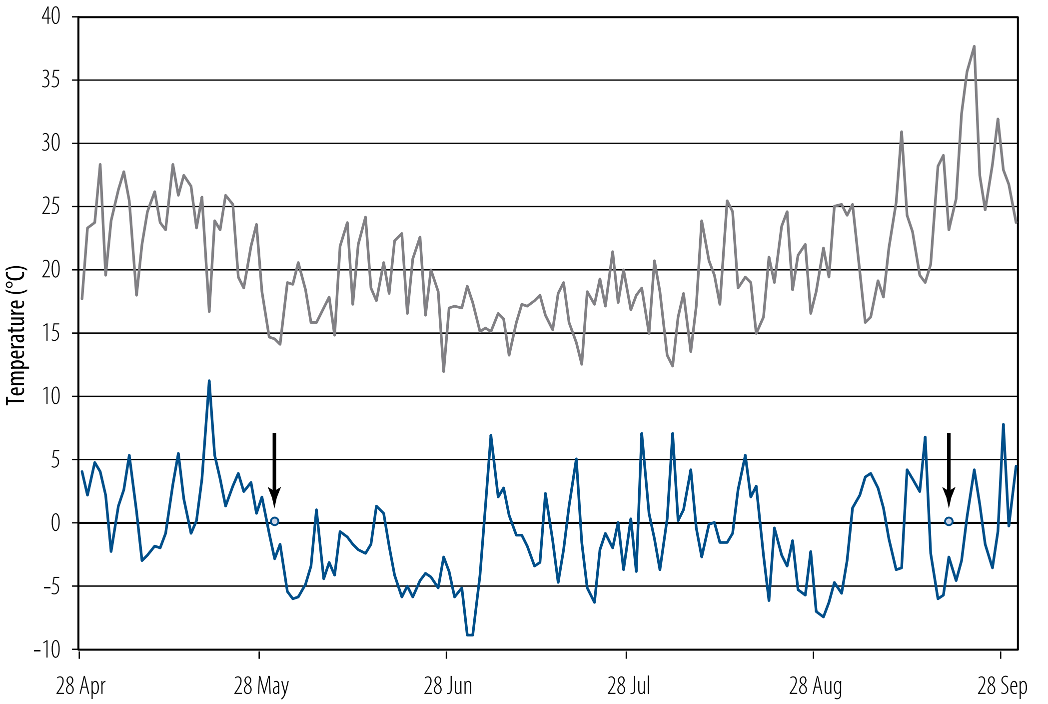

Figure 4. Maximum (grey) and minimum (blue) temperatures recorded at the experiment site at Wagga Wagga in 2017. Arrows indicate beginning of stem elongation (Z30) and 50% spike emergence (Z55) respectively.

The incidence and severity of frosts caused a significant level of stem frost. However, the wheat plants continued to regrow, capturing late rainfall in October and November, which enabled yields to be produced (averaging 2.66 t/ha) that would otherwise have been much lower. There were no significant differences in yield between the treatments. However, the proportion of tillers that produced a viable head was larger in the high N treatment. The higher N rates probably allowed for more regrowth to occur late in the season (Figure 5), leading to a visual increase in biomass and more leaf scorching from frost damage. Due to the number of severe frosts experienced in 2017 any treatment effect of the N on yield, which was intended to demonstrate resistance to frost, was nullified.

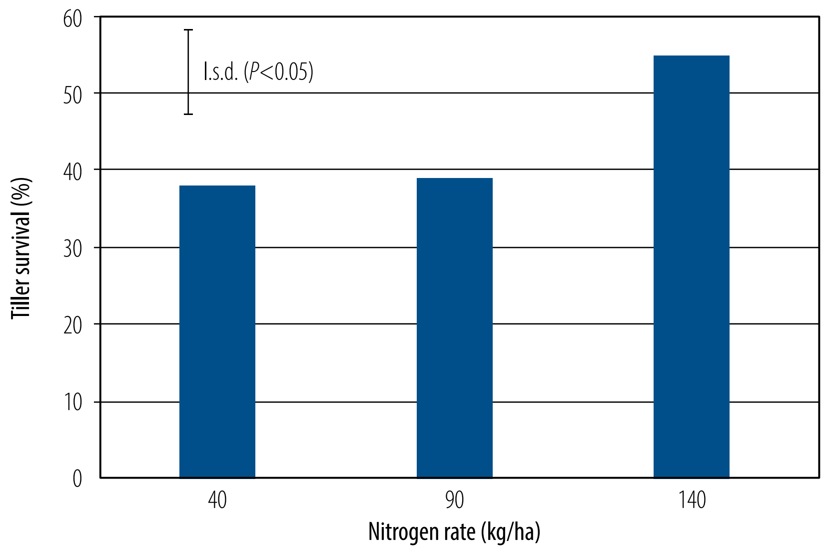

Figure 5. Proportion of viable tillers across nitrogen rates from the field experiment located at Wagga Wagga.

Summary

Frost is an environmental factor that cannot be avoided in cropping systems. However, a greater understanding of interactions could assist to identify different management techniques. From the perspective of glasshouse experiments, we were able to show that shading during the booting stage lowered WSC concentrations. However, the stress that this induced confounded the results by shading influencing a dilution effect. Data from the effect of one freezing event at booting and ear emergence provides insight into the threshold levels of frost as –8 °C led to a 50% grain loss per spike compared with –4 °C at 15%. The high frequency of frosts during the 2017 season seems to have removed any treatment effect from N on yield in the field experiment. The role that sugars (WSC) play in resisting freezing damage was shown to be minimal due to the small concentrations measured at booting and emergence. However, in regions of the world where crops must acclimatise to freezing conditions in order to survive snowfall, sugars play an integral part by lowering the freezing point of plant sap. Hence, more research surrounding cold acclimation in Australia needs to be carried out across an array of seasonal conditions to identify management techniques that growers can adopt to mitigate the effect of frosts in southern NSW.

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Sowing date influence on phenology and grain yield of wheat – Cudal 2017

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

Key findings

- Frost had a significant effect on phenology and grain yield responses in 2017.
- High grain yields were achieved through a range of sowing date × variety combinations, indicating that growers can optimise yield through various sowing options.
- Differences in pre-flowering development phases were observed among genotypes of similar maturity, resulting in a significant influence on grain yield responses in 2017.

Introduction

In 2017, field experiments were conducted across eight sites in the northern grains region (NGR) in central and southern QLD, northern, central and southern NSW to determine the optimal grain yield potential of wheat genotypes in the NGR. This paper presents results from the Cudal site (southern NSW) and discusses the influence of sowing date on the phenology and grain yield responses of a core set of 30 wheat genotypes.

Site details

Location	'Rutherfield', Cudal, NSW
Soil type	Red–brown chromosol
Previous crop	Canola
Sowing	Direct drilled with Horwood Bagshaw seeding units, spaced at 220 mm using a GPS auto-steer system.
Target plant density	140 plants/m^2
Mineral nitrogen (N)	115 kg N/ha at sowing (0.9 m depth)
Fertiliser	100 kg/ha mono-ammonium phosphate (MAP) (sowing) 100 kg/ha urea (sowing) 100 kg/ha urea (top dressed, 8 August 2017)
Weed control	Knockdown: glyphosate (450 g/L) 2 L/ha, Spray.Seed® 2 L/ha Pre-emergent: Triflur X 1.6 L/ha, Avadex Xtra® 1.6 L/ha, Sakura® 850 118 g/ha In-crop: Precept® 2 L/ha (14 June) Axial® 300 mL/ha, Adigor® 500 mL/100 L water (15 June)
Disease management	Seed treatment: Hombre® Ultra 200 mL/100 kg Flutriafol-treated fertiliser (400 mL/ha) Cogito® 300 mL/ha (14 June) Prosaro® 420 mL/ha (22 August)
Pest management	Aphidex® 200 g/ha (14 June)
In-crop rainfall	146 mm (April–October) (long-term average: 353 mm)

Treatments

Thirty wheat genotypes varying in maturity were sown on three sowing dates: 20 April, 5 May and 18 May 2017 (Table 1).

Table 1. Putative phenology types of the experiment genotypes.

Phenology type	Genotypes
Winter (W)	Longsword$^{\Phi}$ (fast), LongReach Kittyhawk$^{\Phi}$, EGA Wedgetail$^{\Phi}$, RGT Accroc$^{\Phi}$ (slow), Manning$^{\Phi}$ (slow)
Very Slow (VS)	Sunlamb$^{\Phi}$, EGA Eaglehawk$^{\Phi}$, Sunmax$^{\Phi}$
Slow (S)	Cutlass$^{\Phi}$, Kiora$^{\Phi}$, Suntime$^{\Phi}$
Mid - Slow (S-M)	Mitch$^{\Phi}$, LongReach Lancer$^{\Phi}$, Coolah$^{\Phi}$, DS Pascal$^{\Phi}$, EGA Gregory$^{\Phi}$, LongReach Trojan$^{\Phi}$
Mid (M)	Janz, Beckom$^{\Phi}$, Sunvale$^{\Phi}$, Suntop$^{\Phi}$,
Fast (F)	Scepter$^{\Phi}$, Corack$^{\Phi}$, LongReach Reliant$^{\Phi}$, Mace$^{\Phi}$, LongReach Mustang$^{\Phi}$, LongReach Spitfire$^{\Phi}$
Very fast (VF)	Condo$^{\Phi}$, LongReach Dart$^{\Phi}$, Tenfour

Results

Phasic development

Optimum grain yield is achieved when genotypes are matched with sowing date to ensure flowering occurs at an appropriate time. In southern NSW, this response is commonly driven by the high risk of frost damage early, and heat and moisture stress later. Generally, the genotype and sowing date combinations that flower early to mid October at Cudal have the highest grain yields. As with the Wagga Wagga site, early stem frost damage resulted in significant tiller losses and late regrowth, which resulted in variable maturity within plots, and delayed the recorded flowering date in 2017. The Cudal site recorded 37 days below 0 °C (13 days below –2 °C) from June to September. The frost events affected flowering time, with the flowering window spanning from 18 September to 24 October for the Cudal site. As a result, significant variation in grain yields for genotype × sowing date combinations were observed, even when flowering occurred on the same day (Figure 1). For example, LongReach Trojan$^{\Phi}$ (mid spring type) sown on 20 April, flowered on 6 October and recorded 2.49 t/ha; while Scepter$^{\Phi}$ (fast spring type) that was sown on 18 May flowered the same day as LongReach Trojan$^{\Phi}$ yet recorded 5.59 t/ha.

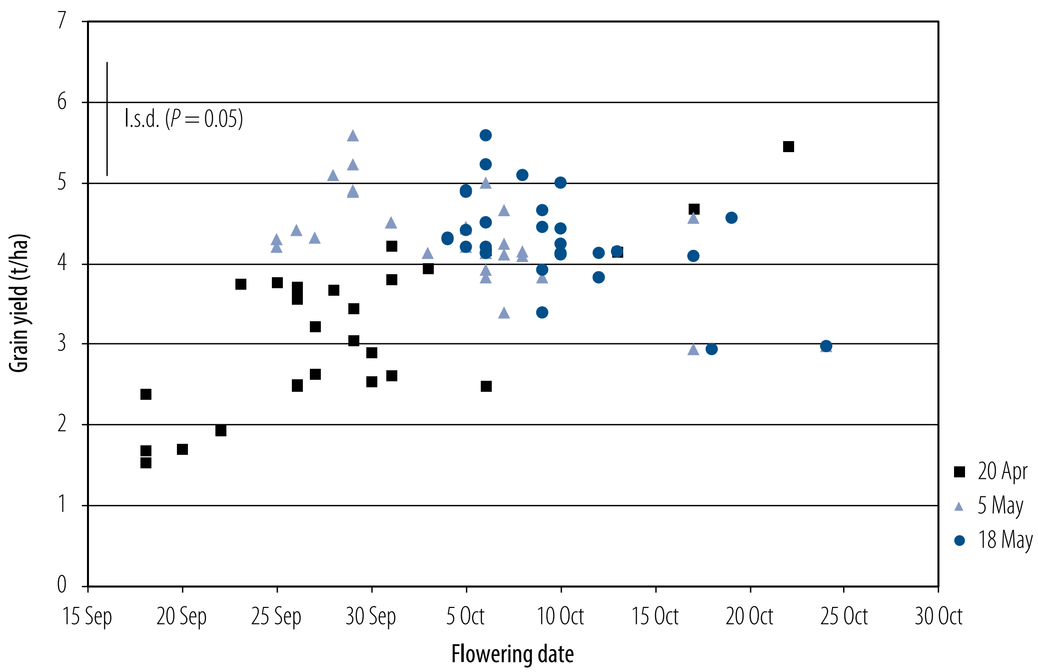

Figure 1. Relationship between flowering date and grain yield for 30 genotypes sown on 20 April, 5 May and 18 May at Cudal, 2017.

There is variation in the vernalisation and photoperiod responses among the 30 genotypes, hence differences in the phase duration of genotypes in response to sowing date were observed (Figure 2). Faster-developing, spring types (with minimal response to vernalisation), progressed quickly when sown in late April. For example, LongReach Mustang$^{\Phi}$, Condo$^{\Phi}$ and Scepter$^{\Phi}$ sown on 20 April 2017 at Cudal started stem elongation (GS30) between 15–20 June. However, when the winter type EGA Wedgetail⁽ᴰ⁾ was sown on the same day (20 April), it reached GS30 a month later on 20 July (Figure 2) due to a prolonged vegetative phase associated with its vernalisation requirement. Winter types with a strong vernalisation and photoperiod response, such as RGT Accroc⁽ᴰ⁾, had an extended vegetative and reproductive period (Figure 2).

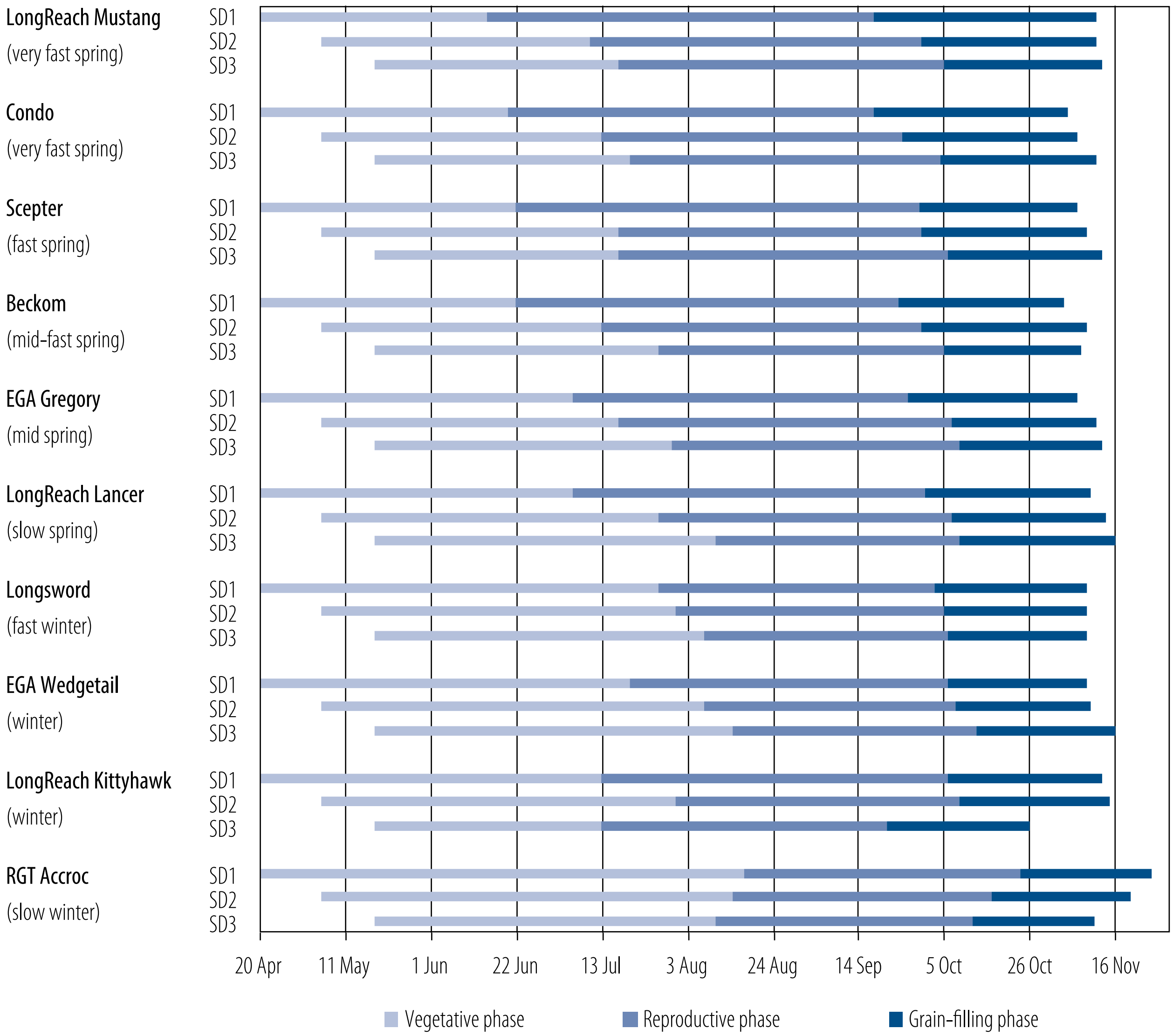

Figure 2. Sowing date influence on phasic development of selected genotypes sown on 20 April (SD1), 5 May (SD2) and 18 May (SD3) at Wagga Wagga, 2017. Vegetative phase (sowing to GS30); reproductive phase (GS30 to flowering); grain-fill phase (flowering to maturity).

Grain yield

In 2017, as with the Wagga Wagga site, winter and long-season genotypes achieved high yields from early sowing and were relatively stable across sowing dates at the Cudal site (Table 2). This is likely due to the extended vegetative phase, which reduced exposure to frosts during early reproductive development and resulted in flowering at an optimal time for the season. In contrast, faster developing genotypes, when sown early, were exposed to several frosts during stem elongation through to flowering, which significantly reduced yield potential.

Table 2. Grain yield of genotypes across three sowing dates at Cudal in 2017. Percentage of sowing date mean in parentheses. Highest yielding genotype shaded grey in each sowing date.

Genotype	Grain yield (t/ha)					
	SD1: 20 Apr		SD2: 5 May		SD3: 18 May	
Beckom	3.77	(118)	4.85	(99)	4.92	(114)
Condo	2.40	(76)	4.42	(90)	4.32	(100)
Coolah	3.05	(96)	5.64	(115)	4.15	(96)
Corack	1.72	(54)	4.30	(88)	5.09	(118)
Cutlass	2.65	(83)	5.24	(107)	5.01	(116)
LongReach Dart	1.69	(53)	4.05	(83)	4.21	(98)
DS Pascal	4.23	(133)	4.66	(95)	4.25	(99)
EGA Eaglehawk	3.94	(124)	5.69	(116)	4.13	(96)
EGA Gregory	3.56	(112)	5.19	(106)	4.66	(108)
EGA Wedgetail	2.49	(78)	5.06	(103)	4.16	(97)
Janz	3.78	(119)	5.40	(110)	4.13	(96)
Kiora	2.90	(91)	4.48	(91)	4.1	(95)
LongReach Kittyhawk	4.17	(131)	4.58	(93)	3.84	(89)
LongReach Lancer	2.54	(80)	4.83	(98)	3.40	(79)
LongReach Mustang	1.68	(53)	4.79	(98)	4.89	(113)
LongReach Reliant	3.23	(102)	4.63	(94)	5.24	(122)
LongReach Trojan	2.49	(78)	4.69	(96)	4.51	(105)
Longsword	3.94	(124)	5.31	(108)	4.22	(98)
Mace	2.62	(82)	4.74	(97)	4.33	(101)
Manning	5.46	(172)	4.60	(94)	2.98	(69)
Mitch	3.68	(116)	5.29	(108)	3.83	(89)
RGT Accroc	4.68	(147)	5.19	(106)	4.56	(106)
Scepter	3.45	(109)	5.62	(115)	5.59	(130)
LongReach Spitfire	1.94	(61)	4.96	(101)	4.47	(104)
Sunlamb	4.15	(130)	4.64	(94)	2.93	(68)
Sunmax	2.51	(79)	5.79	(118)	4.44	(103)
Suntime	3.69	(116)	4.38	(89)	4.52	(105)
Suntop	3.71	(117)	4.85	(99)	3.93	(91)
Sunvale	3.81	(120)	4.90	(100)	4.13	(96)
Mean	3.18	(100)	4.91	(100)	4.31	(100)
l.s.d.						
sowing date	0.38					
genotype	0.82					
sowing date × genotype	1.42					

Genotype yield responses varied across the three sowing dates (Figure 3). Generally, slow developing genotypes had a positive yield response when sown early, (indicated by negative slope), while faster developing, spring genotypes had a positive yield response when sown later (indicated by positive slope). In 2017, winter types, such as Manning$^{\phi}$ (strong vernalisation response) and LongReach Kittyhawk$^{\phi}$ (mid vernalisation response) achieved a yield advantage of between 0.7–1.2 t/ha when sown on 20 April, with a declining yield response thereafter. In contrast, the yield responses of faster developing spring types, for example Scepter$^{\phi}$, peaked at later sowing dates. Despite the extreme frost conditions, some spring genotypes were able to maintain relatively stable grain yields (indicated by flatter slope), for example, Beckom⁽ᶲ⁾, which showed a similar response at the Wagga Wagga site.

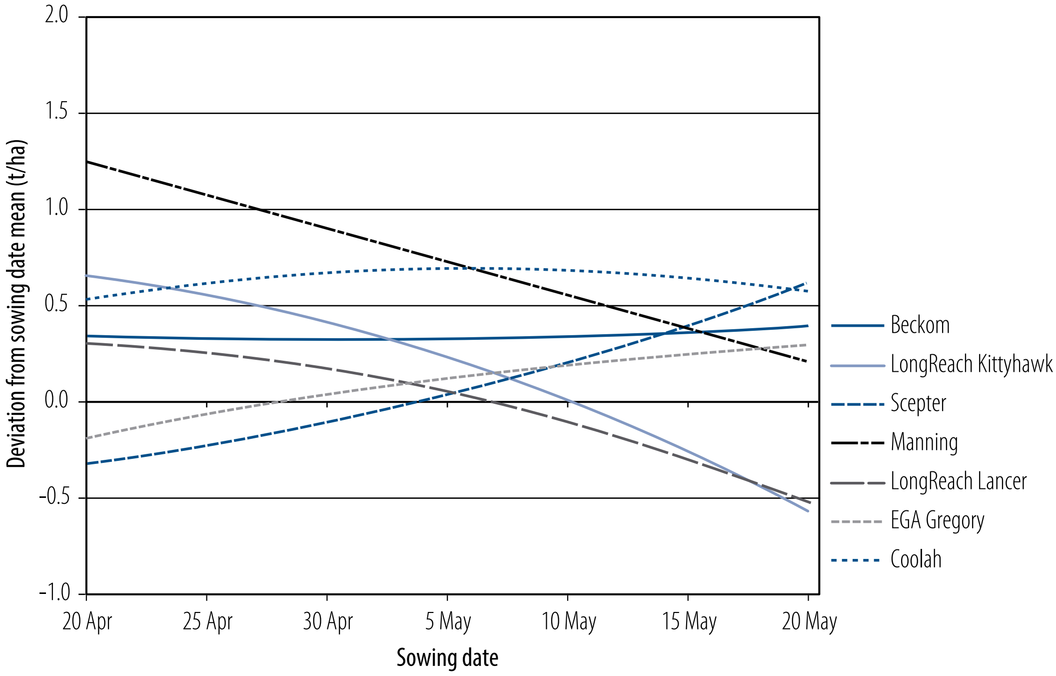

Figure 3. Genotype by sowing date response in 2017 for selected genotypes. Response is presented as deviation from sowing date mean across four sowing dates at Cudal. Sowing date mean: 20 April 3.03 t/ha; 5 May 3.20 t/ha; 18 May 3.26 t/ha.

Grain quality

Grain protein, test weight and screenings were significantly affected by genotype and sowing date. There was also a significant interaction between genotype and sowing date for grain quality (Table 3). All treatment combinations achieved greater than 11.5% grain protein, with frosted treatments (fast-developing genotypes sown early) accumulating higher protein concentrations (e.g. LongReach Dart⁽ᶲ⁾, Condo⁽ᶲ⁾, LongReach Mustang⁽ᶲ⁾ in SD1). All genotype and sowing date combinations also achieved a test weight of >76 kg/hL and <5% screenings, indicative of frost damage before grain filling (Table 3).

Table 3. Protein (%), screenings % (SCRN) and test weight (kg/hL) (TWT) of genotypes across three sowing dates at Cudal in 2017.

Genotype	SD1: 20 April			SD2: 5 May			SD3: 18 May		
	Protein (%)	TWT (kg/hL)	SCRN (%)	Protein (%)	TWT (kg/hL)	SCRN (%)	Protein (%)	TWT (kg/hL)	SCRN (%)
Beckom	14.3	83.5	0.3	13.0	83.4	0.3	12.8	84.2	0.3
Condo	16.6	83.9	0.3	14.3	84.7	0.4	13.9	85.1	0.4
Coolah	12.7	83.8	0.4	12.3	84.8	0.3	12.8	85.4	0.2
Corack	15.7	83.3	0.2	13.9	84.9	0.3	13.1	84.8	0.3
Cutlass	15.3	83.9	0.3	12.6	85.4	0.2	12.4	84.7	0.2
LongReach Dart	17.4	81.8	0.3	14.0	84.6	0.2	14.4	84.3	0.7
DS Pascal	12.2	83.2	0.3	12.4	83.4	0.5	13.0	84.0	1.1
EGA Eaglehawk	12.8	84.5	0.3	12.5	84.7	0.5	13.9	85.0	0.6
EGA Gregory	14.1	83.7	0.5	12.4	84.6	0.4	13.2	84.9	0.4
EGA Wedgetail	13.9	80.6	0.2	13.0	82.3	0.2	14.3	82.0	0.2
Janz	14.4	83.9	0.2	13.1	84.5	0.2	13.4	84.8	0.2
Kiora	13.6	84.1	0.2	13.3	85.1	0.2	13.7	85.8	0.2
LongReach Kittyhawk	12.9	85.5	0.3	13.1	85.7	0.2	13.5	85.7	0.2
LongReach Lancer	14.5	83.1	0.3	13.5	84.5	0.2	14.8	84.9	0.3
LongReach Mustang	15.2	84.7	0.3	12.8	86.2	0.4	12.7	86.4	0.3
LongReach Reliant	13.8	84.0	0.6	12.5	84.3	0.5	11.7	85.2	0.4
LongReach Trojan	14.4	84.8	0.2	13.0	85.1	0.1	13.1	86.5	0.1
Longsword	14.5	82.5	0.1	13.1	83.9	0.2	13.6	83.3	0.1
Mace	16.1	82.5	0.2	13.2	83.9	0.2	13.2	83.3	0.3
Manning	12.2	77.7	0.5	12.8	78.2	1.1	13.7	77.9	1.8
Mitch	13.1	82.3	0.7	11.9	82.6	0.8	12.9	83.7	1.3
RGT Accroc	12.4	82.8	0.7	12.5	82.8	0.6	12.6	76.5	0.5
Scepter	14.6	83.8	0.5	12.1	84.8	0.4	11.6	84.8	0.4
LongReach Spitfire	18.5	83.6	0.3	14.6	85.9	0.3	14.9	86.2	0.2
Sunlamb	13.9	83.5	0.7	13.8	83.8	1.5	14.5	79.2	1.8
Sunmax	14.3	82.7	0.4	13.0	83.7	0.3	13.9	84.3	0.4
Suntime	14.1	84.4	0.3	13.7	84.2	0.2	13.6	85.7	0.3
Suntop	13.6	84.1	1.7	12.5	84.8	1.8	12.9	84.9	2.8
Sunvale	14.3	84.4	0.2	13.6	85.0	0.1	13.2	85.7	0.2
l.s.d.									
genotype	0.6	0.5	0.2						
sowing date	0.2	0.2	0.1						
genotype × sowing date	1.1	0.9	0.3						

Summary

High grain yields were still achieved from various genotype × sowing date combinations for the 2017 season. The highest yields in SD1 were achieved by winter genotypes with strong vernalisation responses (Manning⚊ and RGT Accroc⚊), though yield of these genotypes declined with delayed sowing. Frost had a significant effect on phasic development and grain yield in 2017, and while fast-developing spring genotypes were not suited to early sowing, they were able to achieve comparable grain yields when sown at an optimal time. For example, Corack⚊ had a significant yield penalty for SD1 (1.72 t/ha), but achieved 5.09 t/ha for SD3. These results highlight the interaction between phasic development and yield formation, and the importance of matching genotype and sowing date to achieve flowering at an appropriate time as an effective management strategy for optimising grain yields.

Acknowledgements

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Early sowing options: sowing date influence on phenology and grain yield of long-season wheat genotypes – Wallendbeen 2017

Dr Felicity Harris, Hugh Kanaley, Greg McMahon, Cameron Copeland and Hayden Petty (NSW DPI, Wagga Wagga)

Key findings

- New winter genotypes had different phenology responses compared with current commercial genotypes.
- Frost significantly affected phenology and grain yield responses in 2017.
- The highest grain yields were achieved through various sowing date × variety combinations.
- Best management practice is matching varietal phenology with sowing date, however, pre-flowering phases had a significant influence on grain yield responses.

Introduction

Recent trends of 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 2017, field experiments were conducted at Wallendbeen, southern NSW and Wongarbon, central 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 had on the phenology, grain yield and quality of 12 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
Target plant density	140 plants/m^2
Soil pH_{Ca}	4.5 (0–10 cm)
Mineral nitrogen (N)	144 kg N/ha at sowing (1.8 m depth)
Fertiliser	80 kg/ha mono-ammonium phosphate (MAP) (sowing) Urea 108 kg/ha (spread 19 May) Urea 108 kg/ha (spread 17 July)
Weed control	Knockdown: glyphosate (450 g/L) 2 L/ha + Ally® 7 g/ha Pre-emergent: Sakura® 118 g/ha + Logran® 35 g/ha + Avadex® Xtra 1.6 L/ha In-crop: Precept® 500 mL/ha + Lontrel™ 750 SG 40 g/ha (11 July)
Disease management	Seed treatment: Hombre® Ultra 200 mL/100 kg Flutriafol-treated fertiliser (400 mL/ha) In-crop: Prosaro® 300 mL/ha (11 July)
In-crop rainfall	279 mm (April–October) (long-term average – 370 mm) 112 mm recorded between harvest dates

Harvest date	30 November 2017 11 December 2017 Cutlass⁽ᴾ⁾, Scepter⁽ᴾ⁾, LongReach Trojan⁽ᴾ⁾ (SD1 and SD2); Manning⁽ᴾ⁾ (SD1, SD2 and SD3) due to delayed maturity.

Treatments

Twelve wheat genotypes with varying responses to vernalisation and photoperiod were sown on three sowing dates: 28 March, 12 April and 1 May 2017 (Table 1).

Table 1. Expected phenology types of experimental genotypes at Wallendbeen, 2017.

Phenology type	Genotypes
Winter	RGT Accroc⁽ᴾ⁾ (slow), Manning⁽ᴾ⁾ (slow), ADV08.0008, ADV11.9419, EGA Wedgetail⁽ᴾ⁾, V09150-01, LongReach Kittyhawk⁽ᴾ⁾, Longsword⁽ᴾ⁾ (fast)
Spring	LPB14-0392 (slow), Cutlass⁽ᴾ⁾ (mid–slow), LongReach Trojan⁽ᴾ⁾ (mid), Scepter⁽ᴾ⁾ (fast)

Results

Phasic development

Generally, the genotype and sowing date combinations that flower early to mid to late October at Wallendbeen achieve the highest grain yields. Early stem frost damage directly influenced the flowering window at Wallendbeen in 2017, which resulted in significant tiller death, and late tiller regrowth in faster-developing spring genotypes on the first two sowing dates (e.g. Scepter⁽ᴾ⁾, LongReach Trojan⁽ᴾ⁾ and Cutlass⁽ᴾ⁾). This consequently influenced recorded flowering date and maturity uniformity within plots, which delayed harvest (Figure 1). In contrast, the winter types all had a prolonged vegetative phase, due to their vernalisation requirement; and flowering dates were relatively stable across sowing dates (Figure 1).

There was significant variation in genotype pre-flowering stages with respect to sowing time (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 recorded significant frost damage. For example, Scepter⁽ᴾ⁾ sown on 28 March 2017 at Wallendbeen, started stem elongation (GS30) on 16 May, 49 days after sowing. However, when sown on 1 May (within an appropriate sowing window for its given phenology type), Scepter⁽ᴾ⁾ reached GS30 on 25 July (85 days after sowing) and recorded no frost damage.

Among the winter types, there were differences in phasic duration, indicating varied phenology responses across the new winter cultivars (Figure 2). Newly released, fast winter type Longsword⁽ᴾ⁾ had a similar vegetative period to EGA Wedgetail⁽ᴾ⁾, though had hastened development thereafter, and did record some stem frost damage (and later maturity) on the first sowing date. In 2017, despite LongReach Kittyhawk⁽ᴾ⁾ flowering 1–3 days later than EGA Wedgetail⁽ᴾ⁾ across the sowing dates, we observed GS30 eight days earlier from the first sowing date (28 March), while it was 2–4 days slower in the later two sowing dates. There was also variation among the slower winter types, with RGT Accroc⁽ᴾ⁾ flowering 3–8 days earlier than Manning⁽ᴾ⁾, and despite having a similar grain-filling duration, reached physiological maturity before the rain that delayed its harvest (Figure 2).

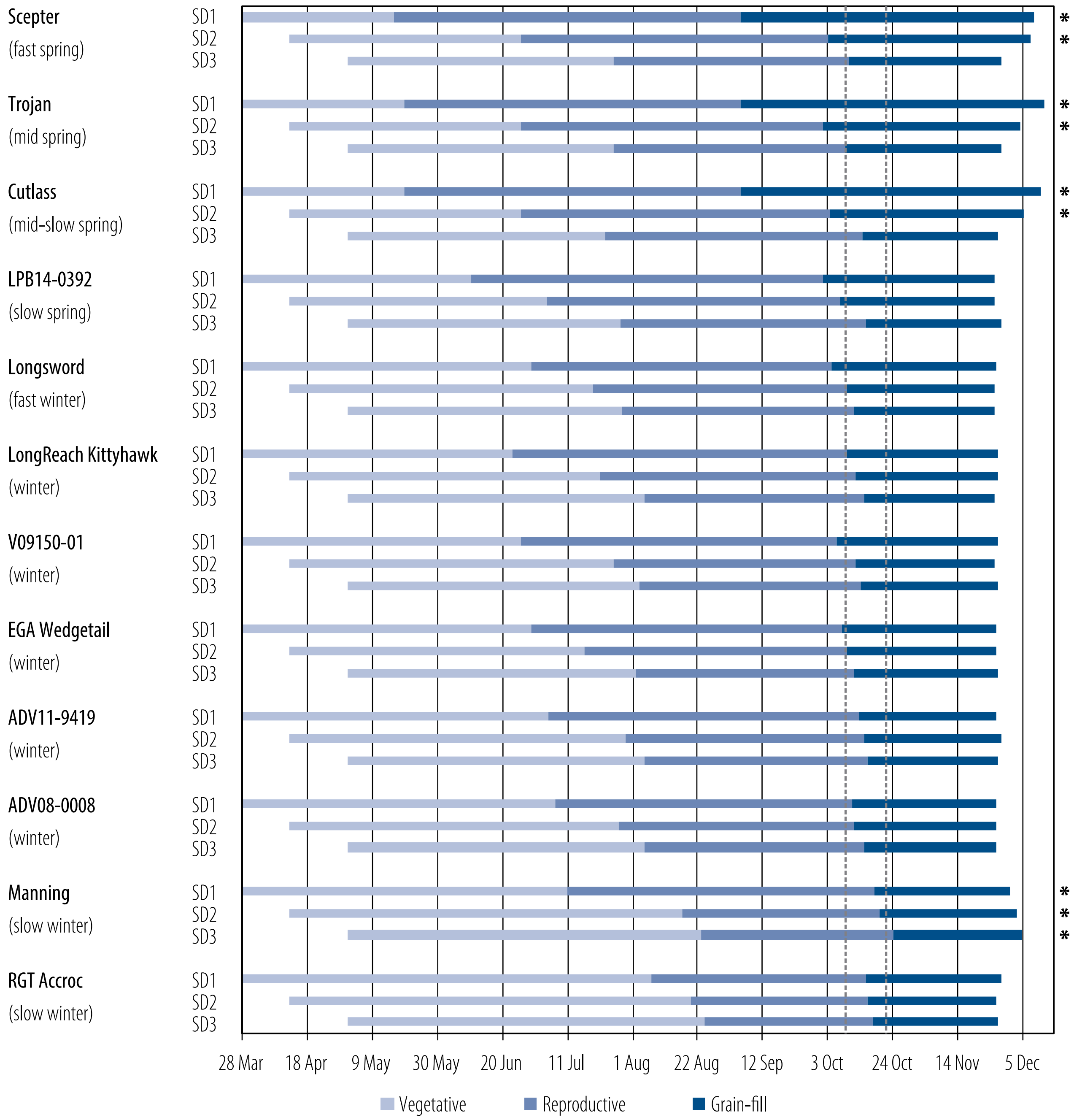

Figure 1. Sowing date influence on phasic development of 12 genotypes of wheat sown 28 March (SD1), 12 April (SD2) and 1 May (SD3) at Wallendbeen, 2017. Vegetative phase (sowing to GS30); reproductive phase (GS30 to flowering); grain-fill phase (flowering to maturity).

Note: Grey dotted lines indicate optimal flowering window; asterisk indicates treatments with delayed maturity which were harvested following rain.

Grain yield

In 2017, the winter genotypes achieved consistently high yields across sowing dates at the Wallendbeen site, with new winter genotypes indicating a possible yield advantage compared with benchmark variety EGA Wedgetail⁽ᵇ⁾ (Figure 2, Table 2). However, the accelerated development of spring genotypes, when sown early, highlighted the severe yield penalty associated with a lack of biomass accumulation and increased frost risk.

Table 2. Grain yield of genotypes across three sowing dates at Wallendbeen in 2017.

Genotype	Grain yield (t/ha)		
	SD1: 28 March	SD2: 12 April	SD3: 1 May
ADV08-0008	6.16	6.56	5.53
ADV11-9419	7.38	6.24	5.90
Cutlass	1.20	2.85	6.54
EGA Wedgetail	6.12	5.78	5.89
LongReach Kittyhawk	6.69	6.18	5.56
LPB14-0392	4.80	6.57	5.95
Manning	6.64	6.32	5.78
Longsword	2.87	4.67	5.82
RGT Accroc	7.86	6.36	6.37
Scepter	0.79	2.34	6.83
LongReach Trojan	0.45	3.96	6.09
V09150-01	4.92	6.03	5.80
Mean (Spring types)	1.81	3.93	6.35
Mean (Winter types)	6.08	6.02	5.83
l.s.d. (genotype × sowing date) 0.92 t/ha			

Grain quality

Genotype, sowing date and the interaction between sowing date and genotype significantly affected grain protein and test weight (Table 3). With the exception of Manning⁽ᶲ⁾, RGT Accroc⁽ᶲ⁾ and LongReach Kittyhawk⁽ᶲ⁾ (SD2), all commercial genotypes achieved greater than 11.5% grain protein. All genotypes harvested before rain (30 November) achieved a test weight of >76 kg/hL, with the exception of Longsword⁽ᶲ⁾ (SD1). Some genotype × sowing date treatments had delayed maturity and were harvested after significant rain on 11 December (grey shading, Table 3), they also had significantly lower test weights. There was only a main effect of genotype on screenings, with no significant effect of sowing date or interaction of sowing date by genotype (Table 3).

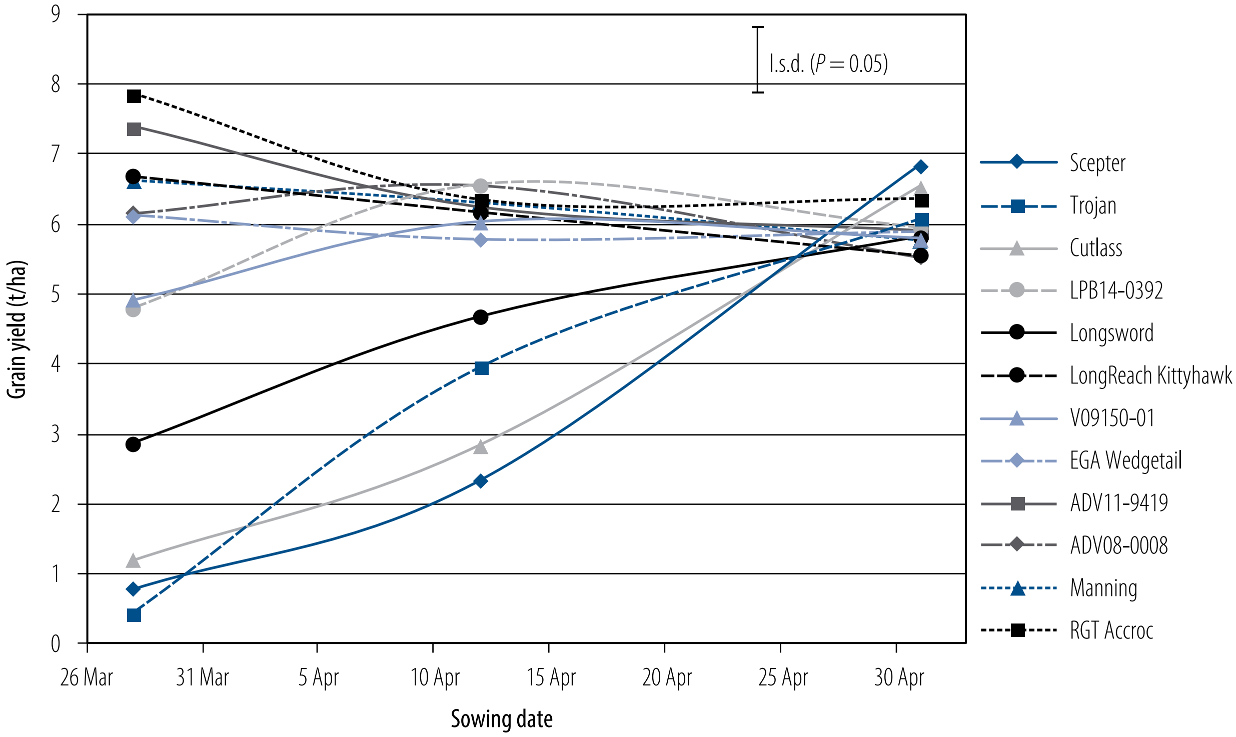

Figure 2. Grain yield responses across three sowing dates: 28 March, 12 April and 1 May at Wallendbeen, 2017.

Table 3. Protein (%), screenings % (SCRN) and test weight (kg/hL) (TWT) of genotypes across three sowing dates (SD) at Wallendbeen in 2017.

Genotype	SD1: 28 March			SD2: 12 April			SD3: 1 May		
	Protein (%)	TWT (kg/hL)	SCRN (%)	Protein (%)	TWT (kg/hL)	SCRN (%)	Protein (%)	TWT (kg/hL)	SCRN (%)
ADV08-0008	11.0	77.6	10.8	11.6	79.3	10.6	10.6	80.3	8.4
ADV11-9419	10.6	81.3	3.3	9.1	81.5	9.3	9.3	81.1	2.9
Cutlass	14.2	76.2	3.4	13.1	76.7	9.1	9.1	80.2	5.0
EGA Wedgetail	14.5	76.2	3.3	12.4	76.8	11.5	11.5	79.2	3.8
LongReach Kittyhawk	11.7	81.9	7.0	10.7	82.5	12.1	12.1	83.7	4.9
Longsword	17.0	75.0	1.1	15.6	77.9	13.5	13.5	79.7	2.2
LPB14-0392	15.5	78.8	3.3	11.5	78.3	12.1	12.1	81.6	4.1
Manning	9.2	77.2	4.0	8.7	77.4	9.7	9.7	78.1	3.1
RGT Accroc	11.2	78.6	5.8	10.7	79.7	10.2	10.2	79.1	6.5
Scepter	12.2	73.0	5.9	12.7	75.3	12.3	12.3	80.3	9.3
LongReach Trojan	13.3	71.1	3.1	13.2	76.6	11.7	11.7	80.6	6.1
V09150-01	13.3	74.7	4.0	13.2	77.2	12.0	12.0	79.8	4.7
l.s.d.									
genotype	0.8	0.9	2.8						
sowing date	0.4	0.5	ns						
genotype × sowing date	1.4	1.6	ns						

ns – not significant; shaded treatments were harvested following 112 mm rain due to delayed maturity.

Summary

High grain yields were achieved from various genotype × sowing date combinations, with winter genotypes generally stable across sowing dates from late March to early May. Frost had a significant effect on phasic development and grain yield in 2017, and while fast-developing spring genotypes were not suited to early sowing, they were able to achieve comparable grain yields when sown at an optimal time (e.g. Scepter⌽ SD3). These results highlight 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 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).

We sincerely thank Cameron and Sarah Hazlett, 'Braeside', Wallendbeen for hosting the experiment and acknowledge the technical support of Jessica Simpson, Mary Matthews, Dylan Male, Kathleen Bernie and Eliza Anwar.

The influence of sowing date and species phenology on yield dynamics in frost conditions – Wallacetown 2017

Hayden Petty, Danielle Malcolm, Rohan Brill, Warren Bartlett and Dr Felicity Harris (NSW DPI, Wagga Wagga)

Key findings

- Although time of heading and flowering are considered the most sensitive stages for frost damage in cereals, sensitivity to early frost damage occurs from the start of stem elongation and is referred to as 'stem frost'.
- Stem frost can be minimised by matching sowing date and cultivar phenology so that stem elongation starts after the period of greatest frost risk.
- Varieties that started stem elongation early (fast developing varieties sown early) were exposed to an increased number of frosts during the susceptible development stages, whilst winter types sown early had an extended vegetative period and were not exposed to the same frost risk, which reduced damage from stem frost.
- Crops can recover from stem frost where there is moisture available to support new tiller growth. However, the resulting effect on phasic development stage synchrony leads to delayed maturity and harvest issues.
- There was no observed difference in frost tolerance of specific cereal species observed in 2017.

Introduction

Oats and barley have traditionally been categorised as more tolerant to frost than wheat. However, these claims are based on the susceptibility of oats and barley to frost damage at flowering (Knights et al. 2017). Matching phenology with an optimum sowing window can allow crops to flower when frost, moisture and heat stress are low, which typically occurs in early October in southern NSW (Riffkin et al. 2011; Harris et al. 2017). As earlier reproductive stages are also sensitive to frost damage, such as stem elongation during periods of high frost incidence and severity, yields can suffer.

Site details

Location	Wallacetown, NSW
Soil type	Red chromosol
Previous crop	Canola
Sowing	Direct drilled with DBS tynes, 250 mm row spacings Target plant density: 150 plants/m^2
Soil pH_{Ca}	4.7 (0–10 cm)
Mineral N at sowing	190 kg N/ha (1.2 m depth)
Fertiliser applied	98 kg/ha mono-ammonium phosphate (MAP) (11% nitrogen (N), 22.7% phosphorus (P), 2% sulfur (S)) at sowing 90 L/ha urea-ammonium nitrate (UAN) (42.5 % nitrogen) (2 July)
Weed control	Pre-emergent: Dual Gold® at 350 mL/ha, Diuron® at 350 g/ha Post-emergent: Lontrel™ at 60 g/ha, Precept® at 1.5 L/ha

	Disease and pest management	
		Seed treatment: Hombre® Ultra at 2 mL/kg and Gaucho® at 1.2 mL/kg In-crop: Prosaro® at 300 mL/ha (19 June) Mascot® Duo at 240 mL/ha (2 November)
	In-crop rainfall	199 mm (April–October) (long-term average is 321 mm)
Treatments	**Varieties**	Wheat: Emu Rock⍭, Scepter⍭, Cutlass⍭, LongReach Trojan⍭, EGA Eaglehawk⍭, LongReach Kittyhawk⍭ Barley: La Trobe⍭, Commander⍭, Urambie⍭ Oats: Mitika⍭, Durack⍭, Bannister⍭
	Sowing date (SD)	SD1: 11 April 2017 SD2: 20 April 2017 SD3: 4 May 2017 SD4: 25 May 2017

Results

Fast developing varieties such as Emu Rock⍭ and La Trobe⍭ sown early (11 April) reached stem elongation in mid June, four weeks earlier than the winter wheat and barley varieties LongReach Kittyhawk⍭ and Urambie⍭. The number and severity of frosts during the 2017 season resulted in all varieties, regardless of maturity type, being exposed to frost from stem elongation through to flowering. However, the faster developing varieties were exposed to more frosts during the sensitive stem elongation phase and, as a result, suffered severe yield penalties.

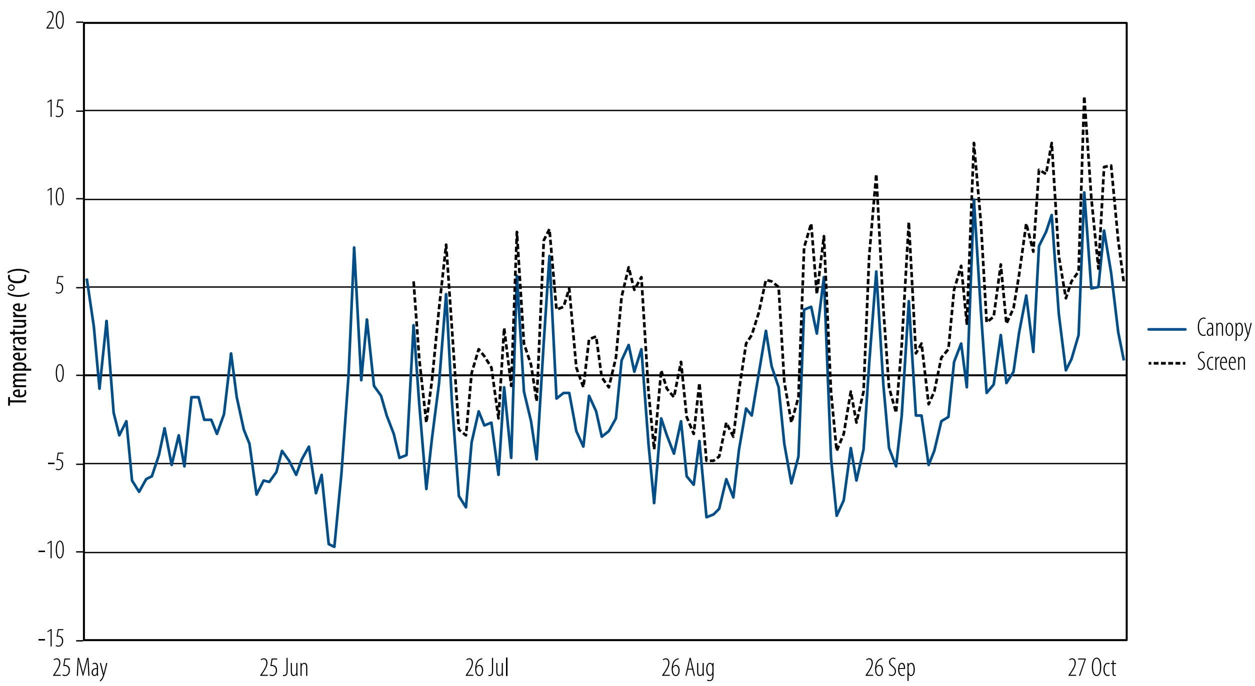

Figure 1. Minimum daily temperatures at the experiment site measured at the top of the crop canopy (solid line) using unshielded Tiny Tag data loggers (TGP-4017, manually moved up in 10 cm intervals through the season) and inside a radiation screen (dashed line) located on the paddock edge.

Slow developing winter wheat and barley varieties exhibited stable yields across all sowing dates. The vernalisation requirement in these varieties slowed the time to stem elongation (GS31). This allowed the winter varieties to avoid some of the stem frost damage.

Delaying the start of stem elongation through varietal selection and optimum sowing time for those varieties increased grain yields (Figure 2). Scepter⍭ was the highest performing wheat variety achieving 5.36 t/ha with a 25 May sowing date. Similarly, La Trobe⍭ performed the best from the later sowing, which emphasises the need to match sowing time with cultivar selection. Using winter type varieties stabilised yield across all sowing dates. LongReach Kittyhawk⊕ wheat and Urambie⊕ barley, with their relatively long vegetative period, only incurred minor stem frost damage and achieved yields between 4 t/ha and 5 t/ha (Table 2).

For earlier sowing dates, the yields achieved by the spring varieties such as Emu Rock⊕ and La Trobe⊕ were due mostly to regrowth after frost. Frost killed early-formed stems and tillers that had progressed rapidly to stem elongation. After the frost, tillers regrew and October rain supported grain filling. Varieties such as Scepter⊕ and Cutlass⊕ yielded well across all sowing dates, showing some flexibility in the 2017 season, undoubtedly attributed to the late rainfall that supported the grain fill in late formed regrowth.

The poor performance of the oats from the first two sowing dates, with only a slight yield improvement in the latter two sowing dates is due to limited phenological differences in the oat varieties used. All three varieties have fast to mid–fast development and hence should be sown mid to late May in frost-prone areas, to avoid frost exposure during sensitive development stages.

Despite the regrowth contributing a substantial amount of grain in early-sown spring cereal varieties, the regrowth resulted in sporadic and staggered flowering times, which could not be precisely measured. This led to delayed maturity in wheats as green regrowth continued through to late November and early December. The regrowth supported yields, however, harvest was delayed as immature spikes and stems had high moisture levels.

Table 2. Grain yield of the 12 varieties from the four sowing dates at Wallacetown, 2017.

Species	**Variety**	**Phenology***	**Yield (t/ha)**			
			SD1: 11 Apr	**SD2: 20 Apr**	**SD3: 4 May**	**SD4: 25 May**
Wheat	Emu Rock	VF	2.84	2.83	3.43	3.99
	Scepter	MF	4.01	4.31	4.36	5.36
	Cutlass	MS	4.12	3.76	4.67	4.90
	LongReach Trojan	M	3.74	3.83	4.60	4.43
	EGA Eaglehawk	MS	3.76	3.63	3.77	3.56
	LongReach Kittyhawk	W	4.26	3.96	4.38	4.07
	Mean		3.79	3.72	4.20	4.38
Barley	La Trobe	F	2.09	2.49	3.88	5.00
	Commander	M	3.33	3.66	4.55	5.04
	Urambie	W	4.24	4.90	5.16	5.12
	Mean		3.22	3.68	4.53	5.05
Oats	Bannister	M	2.80	2.71	3.50	3.27
	Durack	F	2.35	1.92	2.86	2.53
	Mitika	MF	2.03	2.15	2.79	2.92
	Mean		2.39	2.26	3.05	2.91
l.s.d. (P<0.05) Yield		genotype	0.41	0.47	0.43	0.35
		wheat	0.27	0.25	0.19	0.35
		barley	0.30	0.52	0.24	0.15
		oats	0.46	0.42	0.35	0.24

* VF – Very fast, F – Fast, MF – Mid–fast, M – Mid, MS – Mid–slow, S – Slow, W – Winter

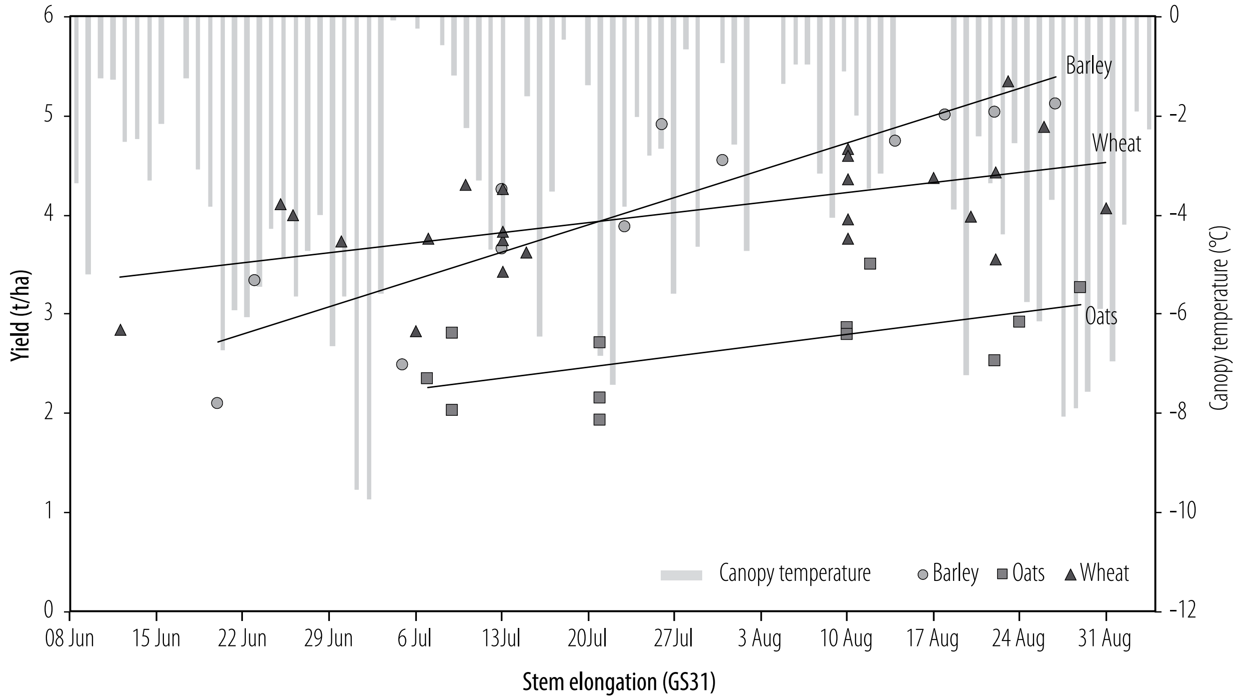

Figure 2. The relationship between the appearance of first node (GS31) and yield (t/ha) for the three cereal species used in the Wallacetown frost experiment. The incidence and severity of frosts measured at canopy height (shown in light grey bars) indicates the number of frosts when stem elongation occurred too quickly.

Summary

The 2017 season involved high frost incidence and severity, demonstrating the extent to which frost events can limit yield potential. Despite these seasonal conditions, the outcomes of the experiment emphasised that frost effects can be mitigated through matching phenology and sowing time, allowing the crop to reach sensitive stem elongation, heading and flowering stages post frost-risk period. Winter varieties performed well in this experiment having the most stable yields due to their longer vegetative phase. Faster developing wheats such as Scepter$^{\phi}$ and Cutlass$^{\phi}$ showed flexibility in the sowing dates in 2017 as the late rainfall allowed regrowth to mature after stem frost in the earlier sowings. This was the first year of an ongoing experiment, hence, further research in 2018 will improve our understanding of how frost interacts with different cereal species.

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Influence of sowing date on wheat phenology and grain yield – Wagga Wagga 2017

Dr Felicity Harris, Hugh Kanaley, Greg McMahon and Cameron Copeland (NSW DPI, Wagga Wagga)

Key findings

- Frost significantly influenced flowering date and grain yield in 2017.
- High grain yields can be achieved from a range of genotype × sowing date combinations.
- Whilst flowering time is important in maximising grain yield potential, timing pre-flowering phases was also found to significantly influence grain yield.

Introduction

There is a range of commercial cultivars suited for sowing across the northern grains region (NGR), which vary in phenology from slow-developing winter types to fast-developing spring types, providing growers with flexibility in their sowing window. Wheat's yield potential depends on matching a variety's phenology and sowing time to ensure flowering and grain formation occurs at an optimal time. In southern NSW, the optimal flowering window is bound by decreasing frost risk, and increasing water and heat stress.

In 2017, field experiments were conducted across eight NGR environments (located throughout central and southern QLD, northern, central and southern NSW) to determine phenology's influence on grain yield responses for a core set of wheat genotypes. This paper presents results from the Wagga Wagga site (southern NSW) and discusses the influence of sowing date 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
Target plant density	140 plants/m^2
Soil pH$_{Ca}$	4.5 (0–10 cm)
Mineral nitrogen (N)	145 kg N/ha at sowing (1.8 m depth)
Fertiliser	80 kg/ha mono-ammonium phosphate (MAP) (sowing) 42 90 L/ha urea ammonium nitrate (UAN) (2 July)
Weed control	Knockdown: glyphosate (450 g/L) 1.2 L/ha Pre-emergent: Sakura® 118 g/ha + Logran® 35 g/ha In-crop: Precept® 500 mL/ha + Lontrel™ 40 g/ha (12 July) LVE MCPA (570 g/L) 400 mL/ha + Paradigm™ 25 g/ha (9 August)
Disease management	Seed treatment: Hombre® Ultra 200 mL/100 kg Flutriafol-treated fertiliser (400 mL/ha) In-crop: Prosaro® 300 mL/ha (6 July, 9 August)
In-crop rainfall	222.8 mm (April–October) (long-term average – 355 mm)

Treatments Thirty-six wheat genotypes, varying in maturity were sown on four sowing dates: 10 April, 20 April, 5 May and 18 May 2017 (Table 1.)

Table 1. Expected phenology responses of the 2017 experimental genotypes.

Phenology type	Genotypes
Winter (W)	Longsword(PBR) (Fast), LongReach Kttyhawk(PBR), EGA Wedgetail(PBR), RGT Accroc(PBR) (Slow), Manning(PBR) (Slow)
Very slow (VS)	Sunlamb(PBR), EGA Eaglehawk(PBR), Sunmax(PBR)
Slow (S)	Cutlass(PBR), Kiora(PBR), Suntime(PBR)
Mid–slow (S–M)	Mitch(PBR), LongReach Lancer(PBR), Coolah(PBR), DS Faraday(PBR), DS Pascal(PBR), EGA Gregory(PBR), LongReach Trojan(PBR)
Mid (M)	Janz, Beckom(PBR), Sunvale(PBR), Suntop(PBR), DS Darwin(PBR), V09063-56,
Fast (F)	Scepter(PBR), Corack(PBR), LongReach Reliant(PBR), Mace(PBR), LongReach Mustang(PBR), LongReach Spitfire(PBR), RAC2388, V08025-18
Very fast (VF)	Condo(PBR), LongReach Dart(PBR), H45, Tenfour

Results

Phasic development

Optimum grain yield is achieved when genotypes are matched with sowing date to ensure flowering occurs at an appropriate time. Generally, flowering date is a strong predictor of yield, with genotype and sowing date combinations that flower in early to mid-October at Wagga Wagga capable of achieving the highest grain yields. In 2017, the flowering window spanned 4–19 October, with significant variation in grain yields for genotype × sowing date combinations that flowered on the same day (Figure 1). Early stem frost damage directly influenced the flowering window at Wagga Wagga in 2017, which resulted in significant tiller death and late tiller regrowth in faster-developing genotypes, consequently affecting maturity uniformity in the plots. Flowering dates are expressed as 50% of emerged spikes with visible anthers. Many of the recorded flowering dates reflect late tiller regrowth and do not account for early tiller losses. Faster developing genotypes had lower tiller survival (proportion of tillers that produced a spike) at early sowing dates, whilst the slower-developing genotypes, which remained vegetative for longer, were exposed to less frost and were able to maintain tillers and stabilise flowering time.

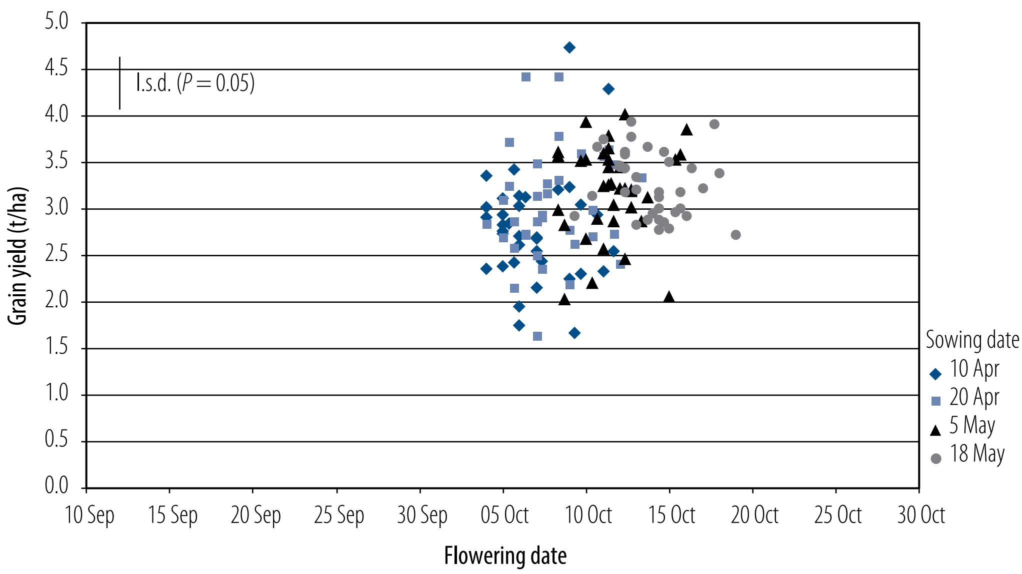

Figure 1. Relationship between flowering date and grain yield for 36 genotypes sown on 10 April, 20 April, 5 May and 18 May at Wagga Wagga, 2017.
Note: Flowering dates for Wagga Wagga were significantly affected by early stem frost damage.

Genotypes varied significantly in pre-flowering stage timing with respect to sowing time, which influenced the flowering grain yield responses shown in Figure 1. As phasic development is largely controlled by responses to vernalisation and photoperiod, these responses had a significant influence on pre-flowering phases timing and subsequently the genotypes' grain-filling phase in 2017 (Figure 2).

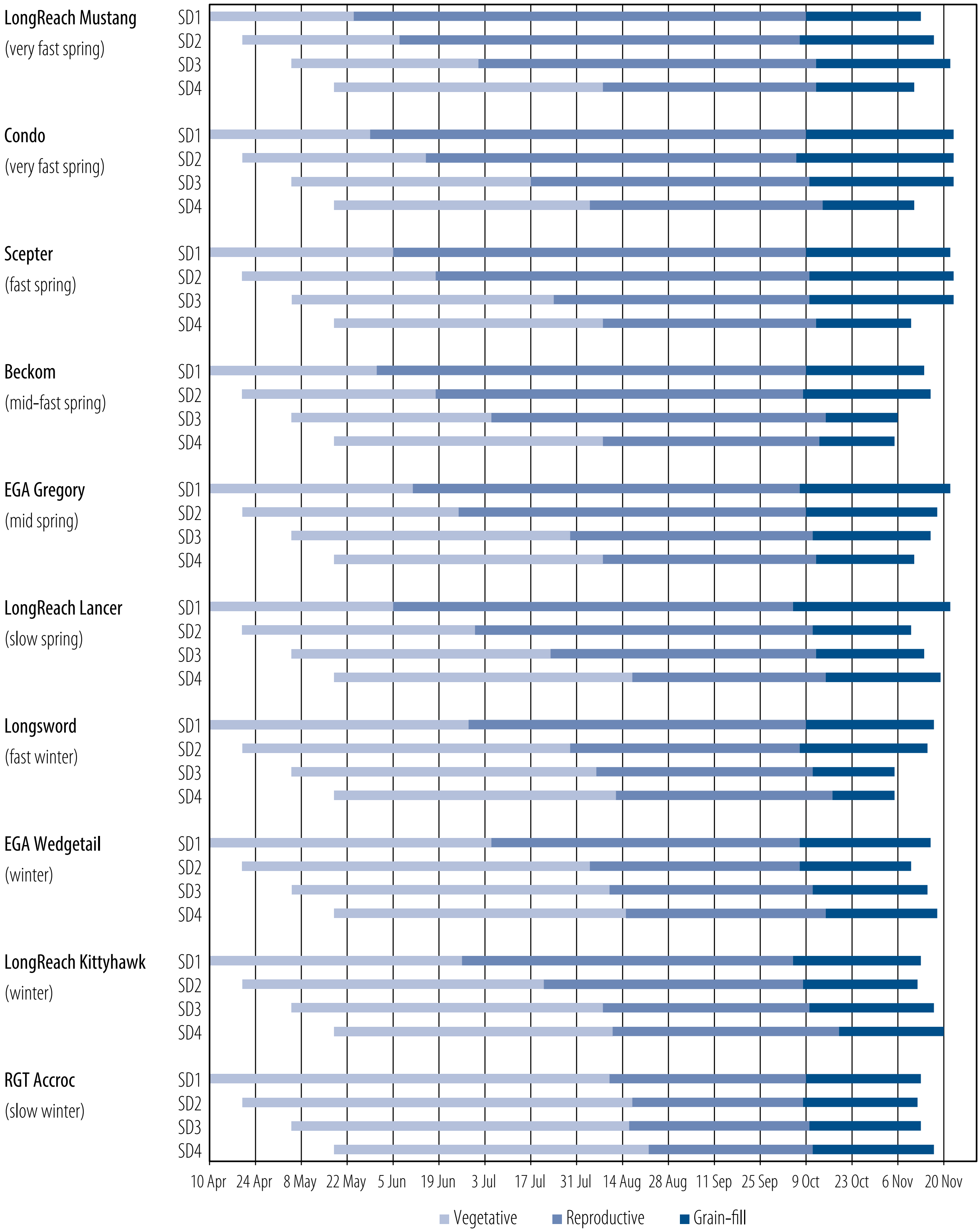

Figure 2. Influence of sowing date on phasic development of selected genotypes sown 10 April (SD1), 20 April (SD2), 5 May (SD3) and 18 May (SD4) at Wagga Wagga, 2017. Vegetative phase (sowing to GS30); reproductive phase (GS30 to flowering); grain-fill phase (flowering to maturity).

Faster-developing spring types (with minimal response to vernalisation), sown early (when temperatures are warmer and days longer), progressed quickly. For example, Condo⏀ sown on 10 April 2017 at Wagga Wagga, started stem elongation (GS30) on 29 May. However, winter type EGA Wedgetail⏀ sown on the same day (10 April), had a prolonged vegetative phase, due to its vernalisation requirement, reaching GS30 on 5 July (Figure 2).

Frost incidence significantly influenced phasic development, with Wagga Wagga recording 92 days below 0 °C (64 days below −2 °C) from late May to early September. The spring varieties' (e.g. LongReach Mustang⏀, Condo⏀) rapid development meant that when sown early, they were exposed to more severe frosts from early stem elongation to ear emergence. This resulted in significant tiller losses and late regrowth, which led to varied plant maturity within plots, and as such, delayed recorded flowering date and prolonged the grain-filling phase compared with later sowing dates (Figure 2). In contrast, the winter types had minimal stem frost damage, and had relatively uniform maturity across all sowing dates with the exception of the faster winter type Longsword⏀. Longsword⏀ had a prolonged vegetative phase (afforded by its vernalisation response), though progressed quickly thereafter, and some stem frost damage was recorded (and delayed maturity) in the earlier two sowing dates (Figure 2).

Grain yield

Winter and long-season genotypes achieved high yields from early sowing and were relatively stable across all sowing dates at the Wagga Wagga site (Table 2). This is likely due to the extended vegetative phase (afforded by vernalisation responses), which reduced exposure to frosts during early reproductive development and resulted in flowering at an optimal time. In contrast, faster developing genotypes were exposed to several frosts during stem elongation through to flowering when sown early, which significantly reduced yield.

There was variation in genotype yield responses across the four sowing dates (Figure 3). Generally, slow-developing genotypes had the highest yields when sown early (indicated by negative slope), for example, Manning⏀ (winter type, strong vernalisation response) and LongReach Kittyhawk⏀ (winter type). In contrast, many faster developing, spring genotypes had the greatest yields from later sowing times (indicated by positive slope), for example Scepter⏀. Despite the extreme frost conditions, some spring genotypes were able to maintain relatively stable grain yields across many sowing dates (indicated by flatter slope), for example EGA Gregory⏀ and Beckom⏀.

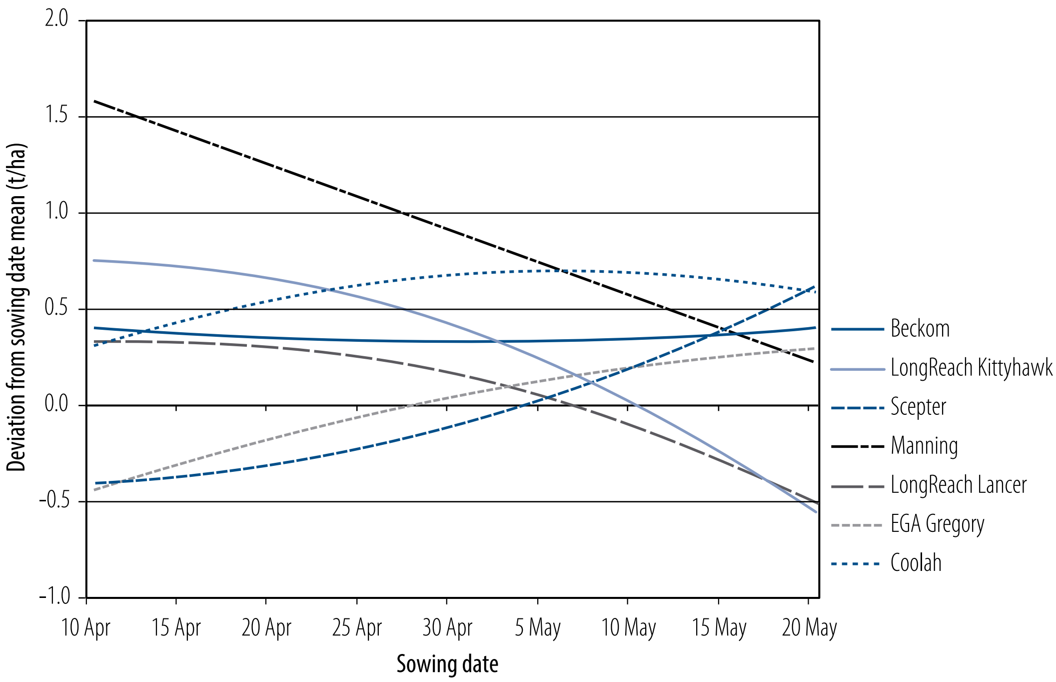

Figure 3. Genotype by sowing date response in 2017 for selected genotypes. Response is presented as deviation from sowing date mean across four sowing dates at Wagga Wagga. Sowing date mean: 10 April 2.79 t/ha; 20 April 3.03 t/ha; 5 May 3.20 t/ha; 18 May 3.26 t/ha.

Table 2. Grain yield of genotypes across four sowing dates (SD) at Wagga Wagga in 2017. Percentage of sowing date mean in parentheses.

Genotype	Grain yield (t/ha)							
	SD1: 10 April		SD2: 20 April		SD3: 5 May		SD4: 18 May	
Beckom	3.24	(116)	3.32	(110)	3.54	(111)	3.67	(113)
Condo	1.66	(60)	2.74	(90)	2.21	(69)	2.78	(85)
Coolah	3.04	(109)	3.61	(119)	4.02	(126)	3.79	(116)
Corack	1.95	(70)	2.16	(71)	2.06	(64)	3.35	(103)
Cutlass	3.12	(112)	3.11	(102)	3.54	(111)	3.50	(107)
Dart	2.16	(77)	2.36	(78)	2.47	(77)	2.96	(91)
DS Darwin	2.95	(106)	2.85	(94)	3.38	(106)	3.19	(98)
DS Faraday	2.74	(98)	3.34	(110)	3.60	(112)	3.67	(113)
DS Pascal	2.42	(87)	2.91	(96)	3.52	(110)	2.97	(91)
EGA Eaglehawk	2.92	(104)	3.15	(104)	3.46	(108)	2.89	(89)
EGA Gregory	2.44	(87)	2.63	(87)	3.60	(112)	3.44	(105)
EGA Wedgetail	2.70	(97)	3.28	(108)	3.28	(103)	3.00	(92)
H45	2.39	(86)	2.73	(90)	2.87	(90)	3.46	(106)
Janz	2.69	(96)	2.78	(92)	3.61	(113)	3.21	(98)
Kiora	2.77	(99)	3.73	(123)	3.27	(102)	3.01	(92)
LongReach Kittyhawk	3.42	(123)	3.8	(125)	3.54	(111)	2.72	(84)
LongReach Lancer	2.94	(105)	3.58	(118)	3.22	(101)	2.79	(86)
LongReach Mustang	2.61	(94)	2.87	(95)	3.02	(94)	3.38	(104)
LongReach Reliant	3.05	(109)	2.94	(97)	3.20	(100)	3.62	(111)
LongReach Trojan	2.71	(97)	2.72	(90)	3.86	(121)	3.46	(106)
Longsword	2.25	(81)	2.51	(83)	3.05	(95)	3.23	(99)
Mace	2.35	(84)	2.41	(80)	2.58	(81)	3.19	(98)
Manning	4.30	(154)	4.43	(146)	3.79	(119)	3.59	(110)
Mitch	2.83	(102)	3.25	(107)	3.58	(112)	2.86	(88)
RGT Accroc	4.74	(170)	4.43	(146)	3.95	(123)	3.75	(115)
Scepter	2.31	(83)	2.99	(99)	2.90	(91)	3.95	(121)
LongReach Spitfire	2.33	(83)	2.20	(72)	2.69	(84)	3.13	(96)
Sunlamb	3.22	(115)	3.17	(105)	2.88	(90)	2.88	(88)
Sunmax	3.14	(113)	3.48	(115)	3.46	(108)	3.01	(92)
Suntime	2.55	(91)	2.70	(89)	2.83	(88)	2.84	(87)
Suntop	3.36	(120)	3.50	(115)	3.66	(114)	3.18	(98)
Sunvale	2.85	(102)	3.65	(120)	3.23	(101)	2.93	(90)
Tenfour	1.75	(63)	1.64	(54)	2.03	(63)	3.44	(105)
Mean	2.79	(100)	3.03	(100)	3.2	(100)	3.26	(100)
l.s.d.								
sowing date	0.29							
genotype	0.08							
sowing date × genotype	0.58							

Agronomy—cereals

Summary

Genotypes vary in their phenology, which influences early development phases as well as flowering time. The extreme frost conditions in 2017 had a significant effect on flowering date and grain yield, as well as amplifying the effect of the timing and length of pre-flowering development phases on yield. Whilst matching variety and sowing time to achieve flowering at an appropriate time for each growing environment is the most effective management strategy to optimise grain yields, future research will also investigate the contribution of pre-flowering phases to yield development.

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).

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Effect of seeding density and nitrogen rate on yield and quality of milling oat varieties – Wagga Wagga 2016 and Marrar 2017

Hugh Kanaley, Dr Felicity Harris, Rohan Brill, Warren Bartlett, Greg McMahon and Jessica Simpson (NSW DPI, Wagga Wagga)

Key findings

- Yield responses to seeding density and nitrogen rate varied between the 2016 and 2017 seasons.
- Bannister⍉ achieved the highest grain yields and had consistent grain quality in both years compared with other varieties.
- In 2017 the new milling variety Kowari⍉ had a yield advantage over benchmark variety Mitika⍉, and had a more stable grain quality at higher seeding and nitrogen rates.

Introduction

Field experiments were conducted in 2016 (Wagga Wagga) and 2017 (Marrar) to evaluate the influence of seeding density and nitrogen (N) applied at sowing on plant establishment, phenology, grain yield and quality of four commercial milling oat varieties.

Site details

Season	2016	2017
Location	Wagga Wagga Agricultural Institute	'Pine Grove', Marrar
Soil type	Red chromosol	Red chromosol
Soil pH_{Ca}	5.1 (0–10 cm)	4.5 (0–10 cm); 4.9 (10–30 cm)
Mineral nitrogen at sowing	142 kg N/ha (180 cm depth)	172 kg N/ha (180 cm depth)
Previous crop	Canola – standing stubble	Canola – standing stubble
Fertiliser	100 kg/ha mono-ammonium phosphate (MAP) at sowing Nitrogen applied as per treatment at sowing	80 kg/ha mono-ammonium phosphate (MAP) at sowing
Sowing	Direct-drilled using six-row DBS cone seeder with GPS auto steer	
Row spacing	240 mm	250 mm
Sowing date	Sown 17 May, 2016	Sown 10 May, 2017
Target plant density	as per treatment	
Weed management	Knockdown: glyphosate (450 g/L) 1.2 L/ha Pre-emergent: Diuron 900 g/kg + Bouncer® 350 g/ha Post-emergent: Paradigm™ 25 g/ha, MCPA 570 g/L, Uptake™ 500 mL/ha	
Disease management	Seed treatment: Hombre® Ultra 200 mL/100kg Flutriafol-treated MAP 400 mL/ha Prosaro® 300 mL/ha (at GS30/37 to suppress disease) TILT®Xtra 500 mL/ha (at GS37 to suppress disease)	

	In-crop rainfall (April–October)	592 mm (long-term average 355 mm)	194 mm (long-term average 293 mm)
Treatments	**Varieties**	2016 – Bannister$^{\phi}$, Mitika$^{\phi}$, Durack$^{\phi}$ 2017 – Bannister$^{\phi}$, Mitika$^{\phi}$, Durack$^{\phi}$, Kowari$^{\phi}$	
	Seeding density	Plants were sown for a target density of 75, 150 and 300 plants/m^2	
	Nitrogen application	Nitrogen was applied as urea at sowing at 0, 30, and 90 kg N/ha	

Results

Plant density

Established plant density increased with seeding rates; however, none of the varieties achieved the target density of 300 plants/m^2. There was a lower plant establishment percentage recorded in 2016 than 2017 (Table 1).

Table 1. Established plant densities for all seeding density × variety treatment combinations at Wagga Wagga, 2016 and Marrar, 2017.

Variety	Target seeding density (plants/m^2)	Established plant density 2016 (plants/m^2)	Established plant density 2017 (plants/m^2)
Bannister	75	55	88
	150	100	140
	300	159	226
Durack	75	60	67
	150	100	111
	300	146	192
Mitika	75	63	76
	150	114	140
	300	176	215
Kowari	75		74
	150		130
	300		220
l.s.d ($P = <0.05$)			
genotype		8.0	9.3
seeding density		8.0	9.3

Phenology

Nitrogen treatment had no significant influence on phenology in either 2016 or 2017. There was a significant interaction between seeding density and time to ear emergence (GS55) recorded for Mitika$^{\phi}$ in both years and Kowari$^{\phi}$ in 2017, with ear emergence occurring faster with increasing plant density (Figure 1). There were no significant timing differences from sowing to ear emergence (GS55) in Bannister$^{\phi}$ and Durack$^{\phi}$ in both years (Figure 1). Overall, Durack$^{\phi}$ was faster to ear emergence, than Mitika$^{\phi}$ and Bannister$^{\phi}$ respectively, whilst the new milling variety Kowari$^{\phi}$ showed a similar maturity to Mitika$^{\phi}$.

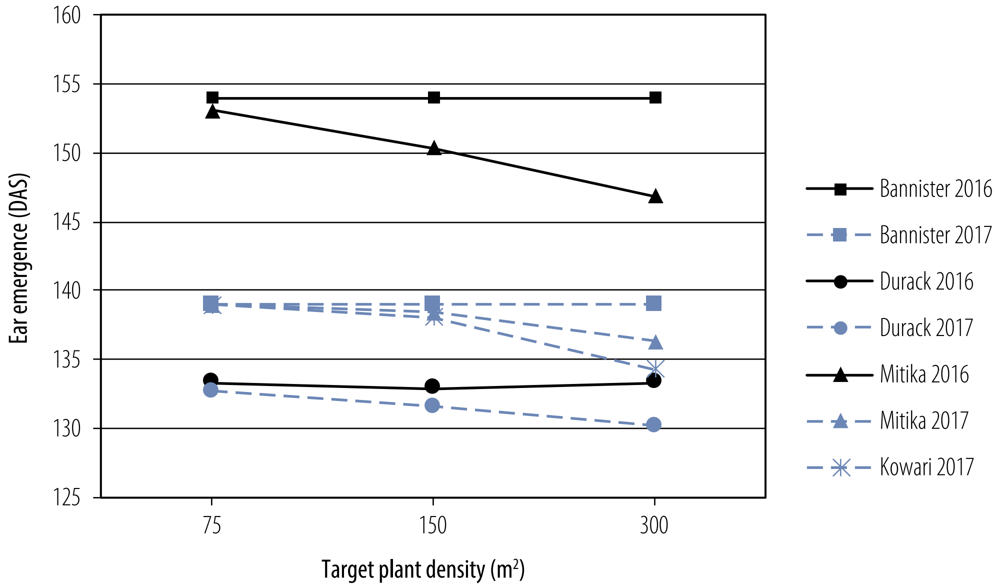

Figure 1. Relationship between timing of ear emergence date reported as days after sowing (DAS) and target plant density for four oat varieties at Wagga Wagga, 2016 and Marrar, 2017.

Grain yield

In 2016, there was no significant interaction between treatments on grain yield responses, with all varieties responding positively to higher seeding density and N rates. Conversely, in 2017, grain yields declined when the N rate and seeding density were increased. These responses are likely to have been driven by contrasting seasonal conditions: 2016 recorded above average rainfall (592 mm vs the long-term average [LTA] of 355 mm), and below average rainfall was recorded in 2017 (194 mm vs LTA 293 mm). Bannister$^{\phi}$ attained the highest grain yields in both years compared with other varieties, achieving 8.93 t/ha in 2016 and 6.46 t/ha in 2017 (Table 2).

Quality

All treatment combinations achieved screenings <8.0%, however, there was variability in recorded test weight, which influenced milling classification (Table 3). Bannister$^{\phi}$ had high test weights coupled with low screenings, achieving milling grade across all treatment combinations in both years. Durack$^{\phi}$ did not achieve milling grade in 2016, however, all treatment combinations, but not the target seeding density of 300 plants/m^2, did achieve milling grade in 2017. There was a contrasting effect of seeding density × nitrogen on Mitika$^{\phi}$ grain quality across 2016 and 2017. In 2016, high seeding density and N treatments had a positive effect on grain quality, whilst in 2017; grain quality was greatest at a low seeding density (Table 3). The new milling variety, Kowari$^{\phi}$, was only evaluated in 2017, and achieved milling grade across most N treatments at target seeding densities of 75 and 150 plants/m^2.

Table 2. Grain yield (t/ha) of all treatments: variety, N applied (0, 30 and 90 kg N/ha) and target seeding density (75, 150 and 300 plants/m^2) at Wagga Wagga, 2016 and Marrar, 2017.

Variety	Target seeding density (plants/m^2)	2016			2017		
		Nitrogen applied (kg N/ha)			Nitrogen applied (kg N/ha)		
		0	30	90	0	30	90
Bannister	75	5.23	5.21	7.42	6.46	5.85	5.59
	150	5.74	6.99	7.63	6.19	5.89	5.37
	300	7.58	7.34	8.93	5.92	5.53	5.42
Durack	75	4.56	4.30	4.95	4.60	4.72	4.35
	150	4.68	5.12	5.49	4.24	4.25	3.99
	300	4.67	5.77	5.81	3.56	3.69	3.95
Mitika	75	4.62	4.56	6.47	4.28	4.20	4.19
	150	5.73	6.16	6.36	3.38	3.65	3.67
	300	5.85	6.67	7.37	2.72	2.89	2.59
Kowari	75				4.66	4.70	4.80
	150				3.98	4.18	3.63
	300				3.49	3.53	3.44
l.s.d. ($P = 0.05$)							
genotype		0.39			0.15		
seeding density		0.39			0.13		
nitrogen		0.39			0.13		
genotype × seeding density		ns			0.27		
genotype × nitrogen		ns			0.27		

*ns indicates treatments were not significantly different.

Summary

Results varied across the two seasons. In 2016, all varieties had a positive grain yield response to higher seeding density and nitrogen rates, whilst in 2017 there was a negative effect on grain yield. Despite the high seeding rates, varieties were unable to achieve target plant densities of 300 plants/m^2, with 100–150 plants/m^2 more attainable.

Treatments had a minimal influence on varietal phenology, except Mitika$^{\phi}$, in 2016 and 2017, and Kowari$^{\phi}$ in 2017, which were faster to ear emergence at higher plant densities. Bannister$^{\phi}$ had higher grain yields and consistent grain quality across both years compared with other genotypes. New milling variety Kowari$^{\phi}$ showed a yield advantage over benchmark variety Mitika$^{\phi}$ across treatments in 2017, and had more stable grain quality at higher seeding and nitrogen rates.

Despite significant frosts in 2017, there was no observed effect on phenology and grain yield at the Marrar site.

Table 3. Screenings % (SCRN) and test weight (kg/hL) (TWT) for all treatments: variety, N applied (0, 30 and 90 kg N/ha) and target seeding density (75, 150 and 300 plants/m²) at Wagga Wagga, 2016 and Marrar, 2017.

Variety	Target seeding density (plants/m²)	2016						2017					
		Nitrogen applied (kg N/ha)						Nitrogen applied (kg N/ha)					
		0		30		90		0		30		90	
		SCRN	TWT	SCRN	TWT	SCRN	TWT	SCRN	TWT	SCRN	TWT	SCRN	TWT
Bannister	75	7.3	55.3	5.4	52.4	4.9	53.3	2.3	61.0	3.1	60.5	4.2	58.1
	150	5.1	63.1	4.8	58.8	4.6	54.9	3.0	60.9	3.7	58.8	4.1	58.7
	300	4.7	62.8	4.1	64.4	4.0	58.3	2.9	59.4	3.7	57.8	4.1	58.8
Durack	75	5.0	50.3	4.9	47.0	4.6	46.2	3.2	55.7	3.6	58.5	4.7	53.6
	150	4.6	48.9	4.0	49.5	3.0	48.5	3.8	53.1	3.0	58.3	4.4	52.4
	300	3.8	49.7	2.9	49.9	2.6	49.1	4.9	49.1	5.5	47.6	4.8	50.3
Mitika	75	2.9	48.5	2.4	51.8	2.2	48.6	2.1	56.3	2.9	54.8	3.2	53.6
	150	2.0	51.3	1.5	51.1	1.5	51.7	4.2	49.3	4.2	50.8	3.4	50.2
	300	1.9	48.6	1.6	53.1	1.2	53.7	7.0	44.7	6.6	44.9	6.6	45.2
Kowari	75							2.1	54.6	1.8	55.6	1.9	57.2
	150							2.7	52.6	2.1	52.3	2.9	50.4
	300							3.6	48.7	3.3	48.6	3.7	48.2
l.s.d. ($P = 0.05$)		SCRN	TWT					SCRN	TWT				
genotype		0.4	1.5					0.4	1.4				
seeding density		0.4	1.5					0.3	1.3				
nitrogen		0.4	1.5					0.3	n.s.				
genotype × seeding density		n.s.	2.7					0.7	2.5				
genotype × nitrogen		n.s.	2.7					0.7	n.s.				
seeding density × nitrogen		n.s.	2.7					0.6	n.s.				
genotype × seeding density × nitrogen		n.s.	n.s.					n.s.	n.s.				

*Shading indicates treatments that achieved milling quality (specifications according to Crokers Grain at time of publication: SCRN<8%. TWT >52 kg/hL); ns indicates treatments were not significantly different.

Acknowledgements

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Influence of sowing date on phenology and grain yield of fifteen barley varieties and nine wheat varieties – Matong 2017

Danielle Malcolm, Dr Felicity Harris, Hugh Kanaley, Warren Bartlett, Greg McMahon and Jessica Simpson (NSW DPI Wagga Wagga)

Key findings

- The highest grain yields in 2017 were obtained from the first sowing date.
- In 2017, frost and rainfall had a significant influence on grain yield responses to sowing date.
- Seasonal conditions altered expected phenology responses of genotypes in 2017.

Introduction

This experiment was conducted to investigate the sowing date effect on phenology and grain yield of 15 commercially relevant barley varieties compared with nine wheat varieties.

Site details

Location	'Yarrawonga', Matong NSW
Soil type	Brown chromosol
Previous crop	Canola
Sowing	Direct drilled with DBS tynes spaced at 250 mm using a GPS auto-steer system
Target plant density	150 plants/m^2
Fertiliser	80 kg/ha mono-ammonium phosphate (MAP) (sowing) 40 kg/ha urea (surface spread) 24 April
Weed control	Knockdown: Paraquat 250® 2.0 L/ha Pre-emergent: Boxer Gold® 2.5 L/ha Post emergent: LVE MCPA 600® 600 mL/ha + Archer® 150 mL/ha (2 August)
Disease management	Seed treatment: Hombre Ultra® 200 mL/100kg Flutrialfol-treated fertiliser 400 mL/ha In-crop: Prosaro® 300 mL/ha (12 July)
In-crop rainfall	134.7 mm (April–October) (long-term average is 319 mm)

Treatments

Fifteen barley and nine wheat varieties were sown on three sowing dates: 24 April, 9 May and 30 May (Table 1).

Table 1. Barley and wheat varieties included in the experiment at Matong, 2017.

Species	Variety
Barley	AGTB0015, Biere, Commander⟨PBR⟩, Compass⟨PBR⟩, Fathom⟨PBR⟩, Bottler, La Trobe⟨PBR⟩, Navigator⟨PBR⟩, Oxford, RGT Planet⟨PBR⟩, Rosalind⟨PBR⟩, Spartacus CL⟨PBR⟩, Urambie⟨PBR⟩, Westminster⟨PBR⟩, WI4592
Wheat	Beckom⟨PBR⟩, Condo⟨PBR⟩, Cutlass⟨PBR⟩, EGA Eaglehawk⟨PBR⟩, Emu Rock⟨PBR⟩, LongReach Kittyhawk⟨PBR⟩, LongReach Lancer⟨PBR⟩, Scepter⟨PBR⟩, LongReach Trojan⟨PBR⟩

Total rainfall for the growing season (April to October) was 134.7 mm, well below the long-term average of 319 mm (Figure 1).The site received 42 mm of rain in January with no rain recorded in February or March. In April, 19 mm of rain was recorded, just before the first sowing date (24 April). However, the next significant rain was not until 18 May (8 mm), which meant conditions were drier for the second and third sowing dates (9 May and 30 May). The site recorded below average rainfall throughout the growing season, with no rain recorded from 19 August to 8 October, which coincided with the critical late-reproductive and early grain filling period of many genotypes.

In addition, the site had severe frost conditions throughout the growing season, recording 74 days below 0 °C, with 54 of these being below −2 °C (measured at crop height with an unshielded Tiny Tag) from 31 May until 21 September.

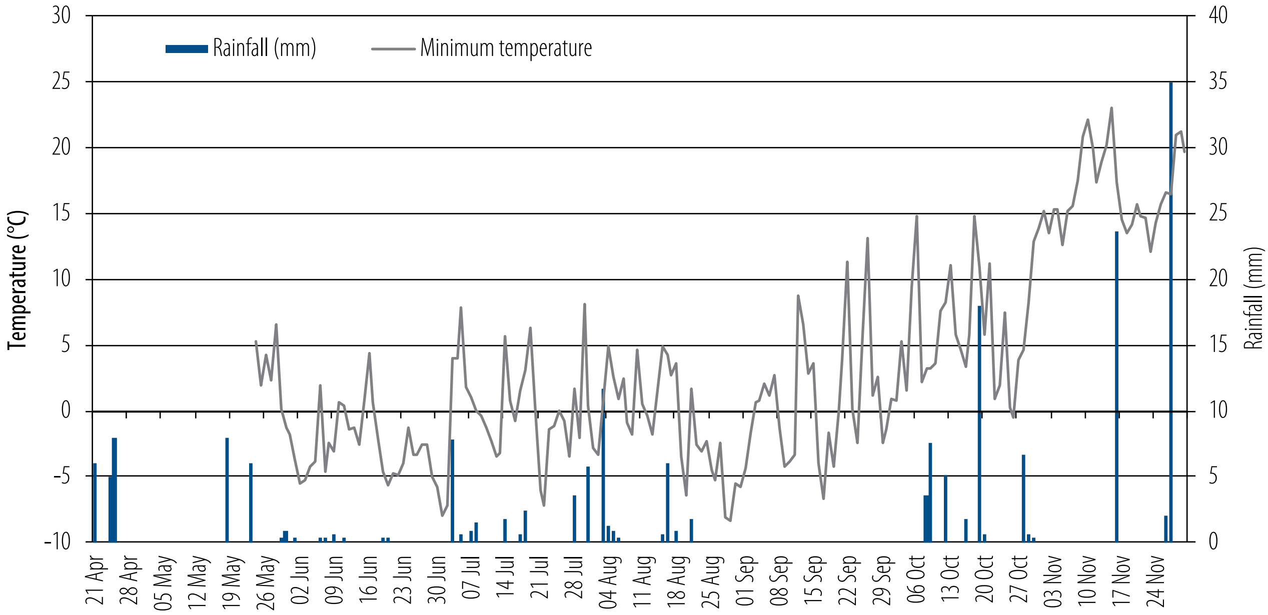

Figure 1. Minimum temperatures (recorded from unshielded Tiny Tag at crop height) and rainfall from 21 May to 30 November at the Matong site, 2017.

Results

Phenology

Optimum grain yield is achieved when genotypes are matched with sowing date to ensure flowering occurs at an appropriate time. Previous results have indicated that the genotype and sowing date combinations which flower mid–late September at Matong have the highest grain yields (Harris et al. 2017). However, in 2017, the early stem frost damage and moisture stress influenced the plant flowering window. Significant tiller death and late tiller regrowth was reported across all sowing dates and genotypes, which consequently altered phenology and uniformity of maturity in plots. In 2017, other experiments reported a positive relationship between delayed stem elongation onset and grain yield due to reduced exposure to the number and severity of frosts (e.g. Harris et al. 2018; Petty et al. 2018). However, the severe freezing temperatures and dry conditions at the Matong site nullified any association between phenology and grain yield responses to sowing date for either barley or wheat genotypes in 2017 (Table 2, Figure 2).

Grain yield

The highest grain yields were obtained from the first sowing date (24 April), (Table 2); Rosalind$^{(\phi)}$ the highest yielding barley variety (2.19 t/ha) and Cutlass$^{(\phi)}$ the highest yielding wheat variety (1.95 t/ha). This is a contrast to 2014–16 results where the highest reported yields were achieved from a mid May sowing for many barley varieties (Harris et al. 2017).

Despite the adverse climatic conditions during the growing season, some varieties achieved similar yields from the 2017 harvest, maintaining their relative yield ranking across sowing dates, for example Rosalind$^{(\phi)}$ for barley and Scepter$^{(\phi)}$ and Cutlass$^{(\phi)}$ wheat. (Table 2).

Table 2. Grain yield, yield ranking (1–15 for barley, 1–9 for wheats) and stem elongation date (GS31) of barley and wheat varieties sown on three sowing dates at Matong, 2017.

Variety	Sowing date								
	24 Apr			9 May			30 May		
	Grain yield (t/ha)	Yield ranking	GS31 date	Grain yield (t/ha)	Yield Ranking	GS31 date	Grain yield (t/ha)	Yield ranking	GS31 date
Barley									
AGTB0015	1.31	11	2 Jul	1.16	8	28 Jul	0.97	12	16 Aug
Biere	1.29	12	10 Jul	1.04	10	30 Jul	1.00	10	16 Aug
Bottler	1.58	7	28 Jun	0.81	12	26 Jul	0.99	11	16 Aug
Commander	1.24	14	17 Jul	0.73	15	8 Aug	1.59	1	20 Aug
Compass	1.74	5	8 Jul	1.61	1	1 Aug	1.12	7	16 Aug
Fathom	1.96	4	30 Jun	1.24	5	1 Aug	1.47	3	16 Aug
La Trobe	1.57	8	25 Jun	1.20	7	24 Jul	1.58	2	16 Aug
Navigator	1.26	13	22 Jul	0.79	13	16 Aug	0.87	14	24 Aug
Oxford	1.59	6	22 Jul	1.54	2	8 Aug	1.07	9	24 Aug
RGT Planet	1.17	15	10 Jul	0.84	11	30 Jul	0.77	15	18 Aug
Rosalind	2.19	1	20 Jun	1.45	3	17 Jul	1.18	5	16 Aug
Spartacus CL	2.00	2	28 Jun	1.26	4	24 Jul	1.18	5	16 Aug
Urambie	1.96	3	30 Jul	0.75	14	18 Aug	0.97	12	23 Aug
Westminster	1.45	9	17 Jul	1.06	9	6 Aug	1.19	4	24 Aug
WI4592	1.35	10	12 Jul	1.24	5	1 Aug	1.10	8	20 Aug
Wheat									
Beckom	1.32	5	12 Jul	1.01	8	5 Aug	1.20	2	21 Aug
Condo	0.84	9	28 Jun	1.16	3	30 Jul	0.89	8	16 Aug
Cutlass	1.95	1	28 Jun	1.28	2	1 Aug	1.19	3	21 Aug
EGA Eaglehawk	1.14	7	17 Jul	1.11	4	13 Aug	1.14	4	23 Aug
Emu Rock	0.91	8	22 Jun	1.04	6	20 Jul	0.94	7	16 Aug
LongReach Kittyhawk	1.18	6	11 Aug	0.88	9	18 Aug	1.12	5	24 Aug
LongReach Lancer	1.61	3	10 Jul	1.06	5	13 Aug	0.83	9	24 Aug
Scepter	1.81	2	3 Jul	1.46	1	1 Aug	1.57	1	19 Aug
LongReach Trojan	1.58	4	3 Jul	1.03	7	5 Aug	0.98	6	16 Aug
Mean Barley	1.58			1.11			1.14		
Mean Wheat	1.37			1.11			1.10		
l.s.d. variety × sowing date ($P<0.05$) barley = 0.55									
l.s.d. variety × sowing date ($P<0.05$) wheat = 0.61									

Grey shading indicates highest yielding wheat and barley varieties.

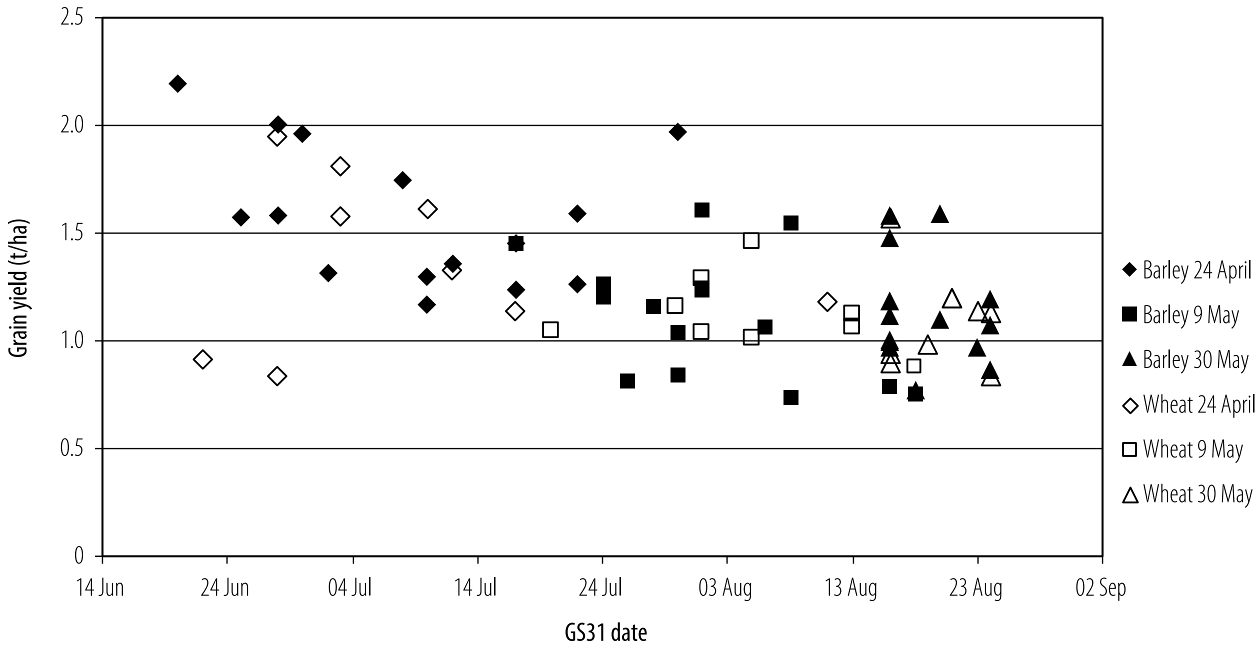

Figure 2. Stem elongation date (GS31) and grain yield of barley (solid marker) and wheat (open marker) varieties for three sowing dates at Matong, 2017.

Summary

The extreme frosts and below average rainfall throughout the growing season in 2017 significantly influenced the phenology and grain yield of genotypes in response to sowing date. The yield responses to sowing date for genotypes are different from those recorded in the 2014–16 experiments at Matong.

Matching genotype and sowing time to achieve flowering at an appropriate time is the most effective strategy for optimising grain yield responses; the results reported for 2017 highlights the importance of making decisions based on results from a number of seasons.

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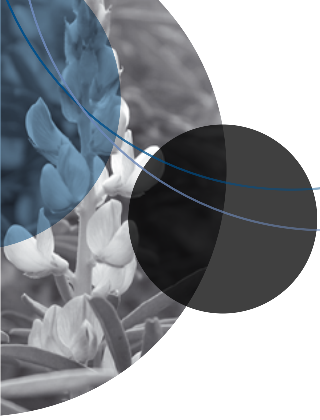

Agronomy – canola

Optimising growth and avoiding stress to canola through sowing date, variety choice and nitrogen management

Rohan Brill, Danielle Malcolm and Warren Bartlett (NSW DPI, Wagga Wagga); Don McCaffery (NSW DPI, Orange); Dr John Kirkegaard and Dr Julianne Lilley (CSIRO, Canberra)

Key findings

- Highest yields were obtained when flowering started in early to mid-August. Treatments that flowered in July were affected by frost and treatments that flowered in September were affected by heat and drought.
- The strongest yield response to nitrogen was on treatments that flowered in early to mid-August.
- Hybrids tended to recover better from frost damage than open-pollinated (OP) triazine tolerant (TT) varieties, but flowering date and nitrogen management were more important to maximise yield potential than variety type.
- The highest oil concentration was obtained from varieties that flowered in early to mid-August.

Introduction

In the 'Optimised canola profitability project, data from 2014 to 2016 showed strong correlations between total biomass (at crop maturity) and grain yield. The purpose of experiments conducted in 2017 was to determine the optimum combination of sowing date, nitrogen management and variety for growth, grain yield and oil concentration. Eight canola varieties with diverse phenology, herbicide tolerance and breeding type were sown on two sowing dates with two rates of nitrogen applied across all treatments.

Site details

Location	Ganmain, 60 km north-west of Wagga Wagga
Soil type	Brown chromosol
Previous crop	Wheat
Fallow rainfall	180 mm (November 2016–March 2017)
In-crop rainfall	190 mm (April 2017–October 2017), (long-term average = 300 mm)
Soil pH_{Ca}	5.6 (0–10 cm, 13 April)
Soil nitrogen	123 kg/ha (0–120 cm, 13 April)
Soil phosphorus	65 mg/kg (Colwell, 0–10 cm)
Starter fertiliser	100 kg/ha MAP (mono-ammonium phosphate) (11% nitrogen [N], 22.7% phosphorus [P], 2% sulfur [S]), treated with 2.8 L/tonne flutriafol (500 g/L)

Treatments	Varieties	Nuseed® Diamond	Fast spring, conventional herbicide hybrid
		ATR Stingray⟨PBR⟩	Fast spring, TT, OP
		Pioneer® 44Y90 CL	Mid–fast spring, Clearfield® hybrid
		ATR Bonito⟨PBR⟩	Mid–fast spring, TT, OP
		Hyola® 600RR	Mid spring, Roundup Ready® hybrid
		Pioneer® 45Y25 RR	Mid spring, Roundup Ready® hybrid
		ATR Wahoo⟨PBR⟩	Slow spring, TT, OP
		Archer	Slow spring, Clearfield® hybrid
	Sowing date (SD)	SD1: 8 April	
		SD2: 26 April	
	Nitrogen rates	70 kg N/ha	Spread pre-sowing and incorporated by sowing (IBS).
		170 kg N/ha	70 kg N/ha applied at sowing (as above) plus 100 kg N/ha broadcast 4 July.

Results

Seasonal conditions

Frosts at Ganmain in 2017 were frequent and severe, including 1 July (–5.5°C), 2 July (–4.1°C), 22 July (–3.5°C), 20 August (–3.4°C), 26 August (–3.1°C), 28 August (–4.4°C), 29 August (–5.7°C), 30 August (–3.5°C) and 17 September (–4.6°C). Rainfall was also well below average and a heat stress day of 36.3°C occurred on 23 September.

Phenology and frost damage

A frost scoring system was developed where the number of viable seeds was counted in 20 pods from the main stem, in each plot. There was a strong relationship between flowering date and the number of viable seeds per pod (Figure 1). Early sown Nuseed® Diamond and ATR Stingray⟨PBR⟩ flowered in early July and both averaged less than six seeds per pod on the main stem. From the same sowing date, flowering in Archer and ATR Wahoo⟨PBR⟩ was delayed until early–mid August and both had more than 10 viable seeds per pod. This scoring gave an insight into the level of frost damage in each variety, but did not completely relate to grain yield, as there were differences in the ability to compensate from frost damage through forming new pods.

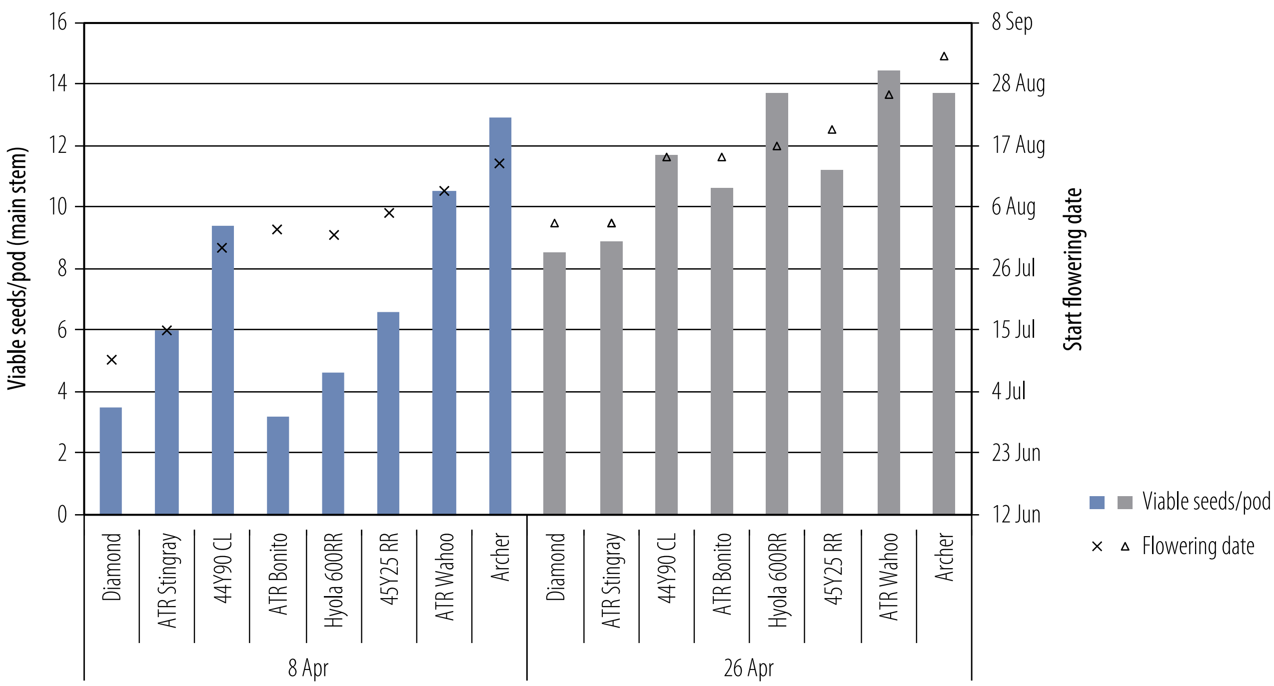

Figure 1. Viable seeds per pod (columns) and flowering date (× and Δ) of eight canola varieties sown on two sowing dates (averaged across N rates) at Ganmain, 2017 (viable seeds/pod l.s.d. $P<0.05 = 2.1$).

Grain yield

Highest yield occurred when varieties were sown in the window that achieved the optimum flowering date (early August) and where they were well fertilised with N. The fast varieties' yields (Nuseed® Diamond and ATR Stingray⁽ᐧ⁾) were severely penalised by frost from the early sowing and subsequent early flowering (see flowering dates in Figure 1). The yields of slower varieties (e.g. Archer and ATR Wahoo⁽ᐧ⁾) were reduced from later sowing, as flowering occurred later (late August to early September) than optimal and pod development was limited by rising spring temperatures (Figure 2).

Importantly, the yield response to N increased for varieties sown in their correct window. For example, there was a strong response to N in Archer, Pioneer® 45Y25 (RR) and ATR Wahoo⁽ᐧ⁾ sown early (flowering in early August), but minimal response when sown later (flowering in later August). Conversely there was a strong response to N in Nuseed® Diamond when sown later (flowering in early August), but not when it was sown early (flowering in early July). Both Pioneer® 44Y90 CL and Hyola 600RR responded well to N at both sowing dates (Figure 2).

Sowing hybrid varieties was beneficial; however, varietal choice was less important than ensuring optimum sowing date, phenology and nitrogen management. For example, sowing the OP TT variety ATR Wahoo⁽ᐧ⁾ (2.8 t/ha) early with a high rate of N yielded 0.7 t/ha more than the experiment mean yield of 2.1 t/ha, whereas there were several treatments where hybrids with sub-optimal management (low N or incorrect sowing date) yielded less than the experiment mean.

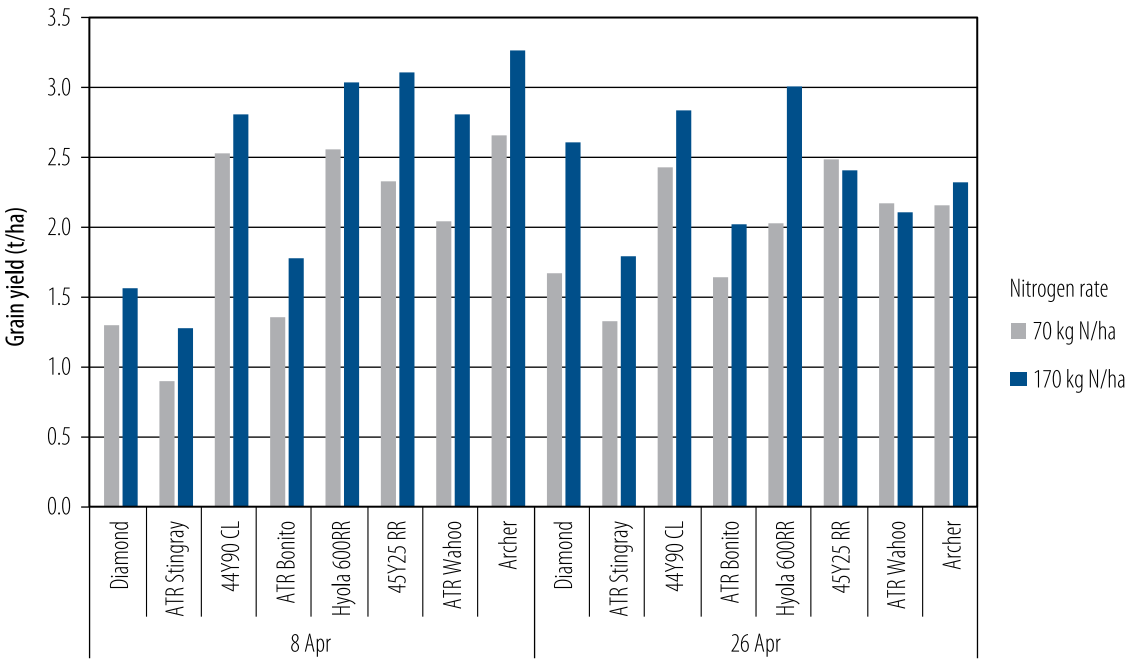

Figure 2. Grain yield of eight canola varieties sown on two sowing dates and fertilised at two nitrogen (N) rates at Ganmain, 2017 (l.s.d. $P<0.05 = 0.38$ t/ha).

Oil concentration

Flowering date had a strong effect on oil concentration. Early sown Nuseed® Diamond and ATR Stingray⁽ᐧ⁾, which flowered in early–mid July, had an oil concentration around 37% (Table 1), whereas treatments that flowered in mid-August (see Figure 1) had oil concentrations above 42%. Oil was reduced by 1% (across all treatments) where the N rate increased from 70 kg/ha to 170 kg/ha (data not shown).

Table 1. Oil concentration (%) of eight canola varieties sown on two sowing dates (averaged across two N rates) at Ganmain, 2017. The varieties are ranked from fastest to slowest development.

Variety	Sowing date	
	8 Apr	26 Apr
Nuseed Diamond	36.5	39.2
ATR Stingray	37.0	40.2
ATR Bonito	39.9	43.0
Pioneer 44Y90 (CL)	41.0	43.0
Hyola 600RR	42.2	45.7
Pioneer 45Y25 (RR)	42.1	44.4
ATR Wahoo	42.8	44.4
Archer	43.3	42.5
l.s.d. (P<0.05)	1.0	

Relationship between biomass and grain yield

Similar to previous seasons, growing a large quantity of biomass (above 10 t/ha) was necessary to achieve a high grain yield (above 2.5 t/ha). However, in contrast to previous seasons, growing a large quantity of biomass did not guarantee a high grain yield as frost reduced the grain number of early-flowering treatments (Figure 3). For example early sown Nuseed® Diamond had 11.4 t/ha of biomass at maturity and only yielded 1.4 t/ha, whereas Pioneer® 45Y25 (RR) grew a similar amount of biomass, flowered later (with less frost damage) and yielded 2.6 t/ha.

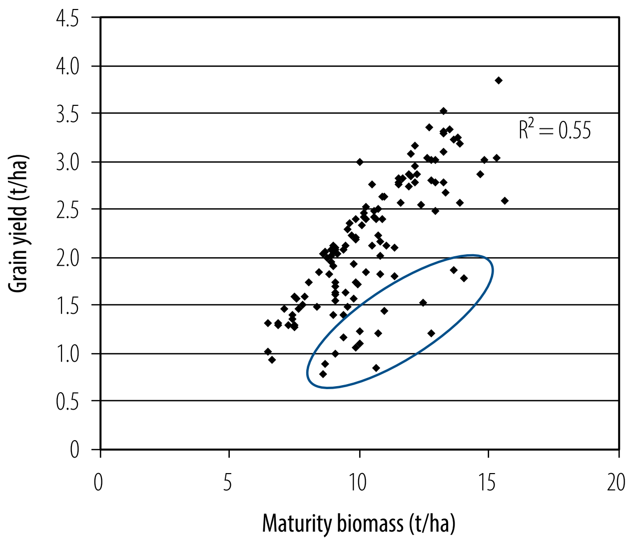

Figure 3. Relationship between maturity biomass and grain yield of canola at Ganmain in 2017. The oval marks treatments that were severely frost-affected so had a low conversion of biomass into grain yield.

Conclusion

Although rainfall was low and frost incidence and severity was high in 2017, canola was still a productive option for growers. The yield response from correctly matching sowing date with phenology was the main message from 2017, reaffirming a consistent result from canola research conducted in recent years. Growers are advised to aim to have crops flowering close to the optimum start of flowering date for the environment in which they are grown; these dates are summarised in the E-Book *10 tips for early sown canola* (Lilley et al. 2017). Secondly, benefits are obtained by managing the crop with optimum nitrogen fertility. Finally, with those factors in place, hybrid varieties can take grain yield to the next level, but varietal choice is not a 'silver bullet' in isolation.

This experiment will be continued across several sites in 2018 with some minor adjustments made to the varieties sown. More detailed economic analysis will be conducted after the experiments are completed.

Reference

Lilley J, Kirkegaard J, Brill R and Ware A 2017, 'Ten tips to early-sown canola': www.grdc.com.au/10TipsEarlySownCanola, accessed 31 March 2017.

Acknowledgements

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

Thanks to technical assistance from Sharni Hands, John Bromfield, Dylan Male, Tom Quinn and Sophie Prentice. Thanks to experiment cooperators Dennis and Dianne Brill.

Effect of heat stress on canola yield: A novel method of imposing heat stress in the field environment

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

Key findings

- A preliminary experiment in 2017 showed that extra heat can be applied to canola plots successfully using specially designed heat chambers.
- Heat stress of four days, applied seven days after flowering started, significantly reduced the grain yield of the flowers opening during that period.
- Four days of heat stress significantly reduced harvest index and thousand seed weight at the plot level, however, grain yield and biomass yield was not affected due to recovery during cooler nights.
- Further research is needed to extend the duration and intensity of heat stress to show differences, and for rigorous validation across different varieties.

Introduction

Past research indicates that canola is particularly susceptible to temperatures above 28 °C during flowering. The frequency of extreme climatic events is predicted to increase, which would pose a serious risk to winter season crops. There is limited research on canola heat stress; most research has been undertaken in controlled temperature growth chambers where flowers are exposed to a constant high temperature at the same growth stage. However, in the field environment all the plants are not exposed to the same heat intensity – canola's indeterminate growth habit means that flowers can miss a heat stress event. Secondly, heat stress research has focused on using different sowing dates, which are then generally confounded by differences in the insidious effects of temperature, water stress; and vapour pressure deficits. Therefore, there is the need to develop a reliable method of imposing heat stress in the field environment. The aim of this experiment was to test a novel method of imposing heat stress in the field and determine the effect of heat stress on canola grain yield and its interaction with water availability.

Site details

The experiment was conducted at Wagga Wagga Agricultural Institute located at 35.01379°S latitude and 147.1940°E longitude. Soil at the experiment site was a red–brown chromosol with pH_{Ca} 5.3 and soil nitrogen 75 kg/ha at the time of sowing. The experiment was sown on 4 May 2017 with the variety Nuseed® Diamond. To establish the different water regimes, four irrigations (40, 20, 20 and 40 mm) were applied to wet plots using drip lines from August to October. All crop husbandry operations were carried out as per best management practices for canola.

Heat chambers

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

Heat treatment

A randomised complete block design with two heat treatments (control vs heat stress 31 °C), seven timings of heat stress (start of flowering until end of flowering), two water regimes (wet vs dry) and three replications was used. When 50% of the plot reached first flowering with one open flower, heat treatments (31 °C) were applied for four days. Each chamber enclosed six rows of plot for a length of 2.5 m. The chambers were placed on the plots at 11.30 am and the heaters were switched on at 12.00 pm. The chambers were then heated to 31 °C – the time taken to achieve this temperature depended on the ambient conditions. The temperature inside the chambers oscillated between 28 °C and 34 °C with an average of 31 °C. The heaters were turned off at 3.30 pm and the chambers removed from the plots at 4.00 pm.

Measurements

Before applying heat stress, the most recent fully opened flower on the main, secondary and tertiary branches on 10 random plants were tagged using coloured duct tape (Figure 2). After removing the heat stress, the process was repeated to mark the periods of heat stress. The same 10 sample plants were tagged (using different coloured tape) for each heat stress application in control plots. This tagged band was used to assess the grain yield from the flowers opening during that heat stress period. Seed yield, biomass, seed size (thousand seed weight) and harvest index (HI) were assessed from a 1.5 m^2 sample from each plot. The experiment was hand-harvested on 9 November 2017.

Figure 1. Heat chambers in a canola plot at Wagga Wagga Agricultural Institute in 2017.

Figure 2. Tagged plants in control plots at Wagga Wagga Agricultural Institute in 2017.

Results

Grain yield from heat stress periods

The yield from the tagged band (flowers opened during heat stress period) from heat stressed plants was less than the control plants for each timing of heat stress application (Table 1), but usually only at the *P*<0.01 level (with the exception of the treatment applied 14 days after start of flowering [DAF]).

Table 1. Grain yield (g) of tagged band (flowers opening during heat stress period averaged across 10 plant samples) for four heat stress timings (7, 14, 21 and 28 days after flowering [DAF]) under heat stress and control, averaged across wet and dry plots.

	Timing of heat stress (days after flowering [DAF])			
	7 DAF	**14 DAF**	**21 DAF**	**28 DAF**
Heat stress	0.063	0.867	0.744	1.192
Control	0.187	1.164	1.025	1.793
S.E.D.	0.08	0.32	0.28	0.56
P (0.05)	0.037	0.108	0.094	0.084

Plot grain yield and yield components

Heat stress did not affect grain yield or biomass at the plot level, however, heat stress did affect HI and grain size. Harvest index significantly decreased when stress was applied at 7 DAF and 28 DAF; however, grain size increased at the same heat stress applications (Figure 3). There was an overall increase in both grain yield and biomass yield of 19% with irrigation, but there was no interaction between heat stress timing and irrigation.

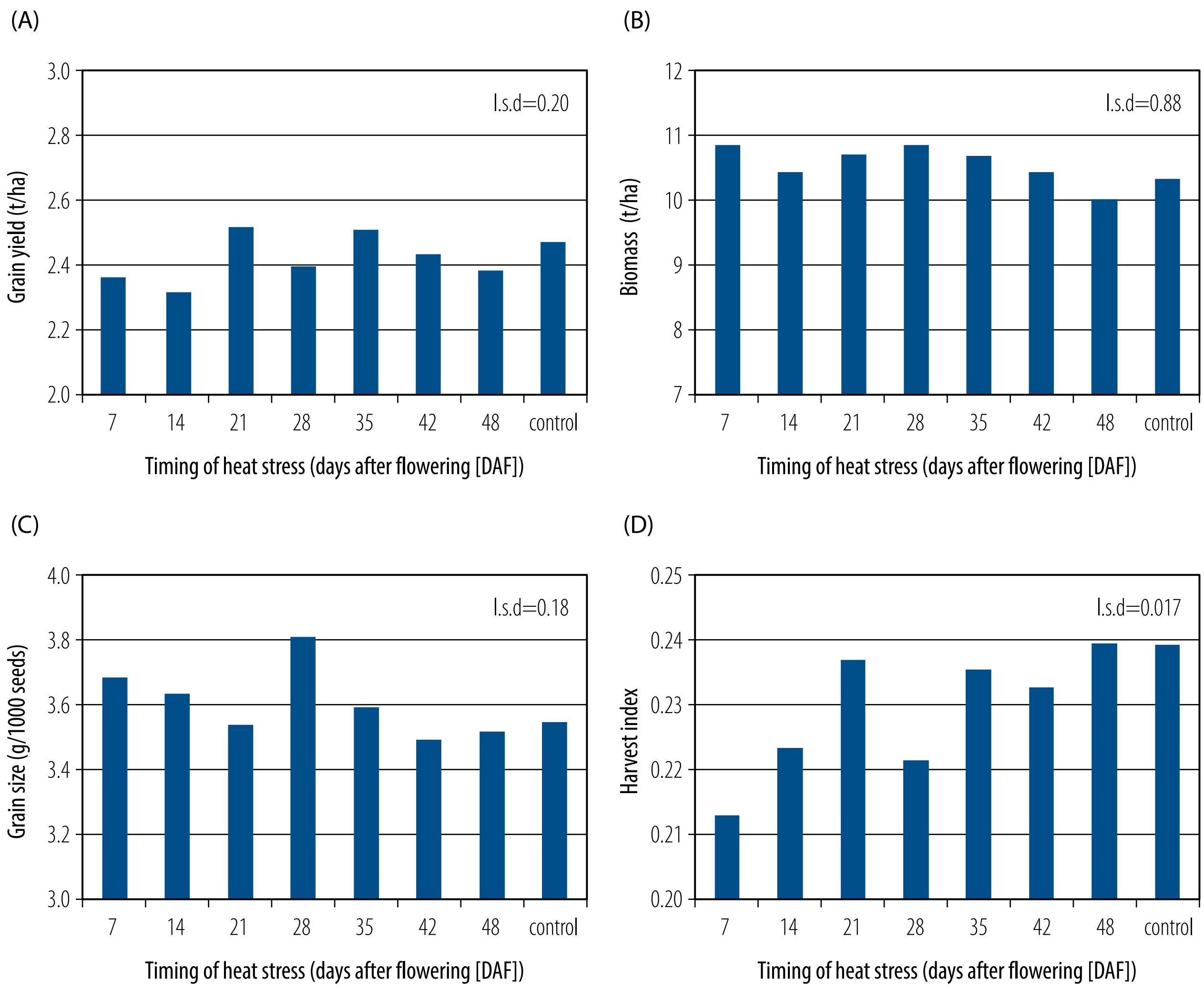

Figure 3. Effect of timing of heat stress (days after flowering [DAF]) on (A) grain yield, (B) biomass, (C) grain size and (D) harvest index (HI).

Conclusions

This preliminary experiment to develop a methodology to impose heat stress in the field environment was successful in establishing heat chambers and imposing heat stress of 31 °C for four days with minimal confounding effects. Preliminary statistical analysis shows heat stress imposed seven days after the start of flowering significantly reduced grain yield obtained from the flowers opening during that period. However it appears there was some recovery from cooler nights, therefore there is need to improve the methodology by increasing the duration and severity of heat stress in future experiments.

This is the first report on heat stress effect in canola at the plot level in the field environment. Developing a novel method of heat tolerance research will set a clear path for heat stress physiology research that will benefit canola growers, particularly in northern and western growing regions.

Acknowledgements

This research was a joint investment by NSW DPI and GRDC Grains Agronomy and Pathology Partnership (GAPP) program.

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

Fertiliser management at sowing for improved canola establishment

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

Key findings

- Phosphorus (P) fertiliser (as triple super) reduced the establishment of canola when it was applied with the seed in furrow. Placing the P fertiliser 2.5 cm below the seed did not affect establishment.
- Nitrogen (N) fertiliser (as urea) reduced establishment of canola when it was banded 2.5 cm under the seed. Broadcasting N followed by incorporation by sowing (IBS) also reduced establishment, but only at very high N rates (200 kg N/ha).

Introduction

There are efficiencies to be gained by applying both N and P fertiliser as part of the sowing operation; however, with canola seed costs of up to $80/ha it is important to ensure that these fertilisers do not reduce crop establishment. Experiments were set up to examine the effects of N and P rates and placement on canola establishment using a small plot seeder with Ausplow DBS parallelogram tine units (Figure 1). For the N experiment, we compared (with seed delivered through the seed tube) delivering the N through the fertiliser tube (giving 2.5 cm of vertical separation between seed and urea) and broadcasting urea ahead of sowing (IBS – incorporated by sowing). For the P experiment, we compared (with seed delivered through the seed tube) delivering fertiliser through the fertiliser tube (giving 2.5 cm of vertical separation between seed and triple super), with delivering P fertiliser in the seed tube with the seed.

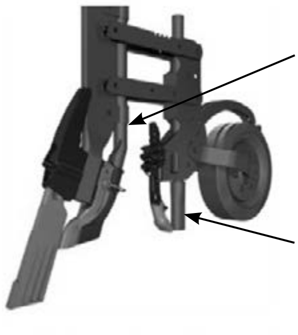

Figure 1. Drawing of DBS tine unit highlighting the fertiliser tube on a rigid tine at the front and the seed tube on a ground-following press wheel at the rear.

Site details

Location	Wagga Wagga Agricultural Institute
Sowing date	11 May 2017
Soil type	Brown kandosol
Previous crop	Wheat
Rainfall	Fallow rainfall (November 2016–March 2017) 158 mm In-crop rainfall (April 2017–October 2017) 196 mm
Soil characteristics	pH_{Ca} (0–10 cm, 13 April) 5.1 Nitrogen (0–120 cm, 13 April) 184 kg/ha Phosphorus (Colwell, 0–10 cm) 63 mg/kg

Treatments		
	Experiment 1: Phosphorus (factorial combinations of rate and placement)	
	Phosphorus rate	0, 10, 20 and 40 kg/ha triple super (20.7% phosphorus)
	Phosphorus placement	Seed = with seed Banded = 2.5 cm below seed
	Experiment 2: Nitrogen (factorial combinations of rate and placement)	
	Nitrogen rate	0, 25, 50, 100 and 200 kg/ha urea (46% nitrogen)
	Nitrogen placement	Banded = 2.5 cm below seed Incorporated by sowing (IBS) = broadcast in front of seeder

Results

Experiment 1: Phosphorus

There was a reduction in canola establishment of up to 51% (from 53.1 to 26.1 plants/m^2) as P fertiliser rate was increased to 40 kg/ha, but only where the P fertiliser was placed with the seed (Table 1). The P fertiliser rate had no effect on canola establishment where the fertiliser was banded 2.5 cm below the seed.

Table 1. Effects of phosphorus rate and placement (with seed compared with banded 2.5 cm below seed) on canola establishment (cv. Nuseed® Diamond) at Wagga Wagga, 2017.

P rate (kg/ha)	Establishment (plants/m^2)	
	Seed	Banded
0	53.1	51.4
10	45.4	51.2
20	31.1	49.9
40	26.1	49.8
l.s.d. (P<0.05)	10.1	

Experiment 2: Nitrogen

Applying N both banded 2.5 cm under the seed and IBS reduced canola establishment, but the effect was greatest where N was banded. Banded N reduced canola establishment (compared with nil N) at all rates from 25 kg/ha (54 kg/ha urea), with a 95% reduction in establishment at the very high N rate of 200 kg/ha (434 kg/ha urea). Nitrogen applied IBS only reduced establishment at the 200 kg/ha N rate (Table 2).

Table 2. Effects of nitrogen rate and placement (banded 2.5 cm below seed compared with IBS) on canola establishment (cv. Nuseed® Diamond) at Wagga Wagga, 2017.

N rate (kg/ha)	Establishment (plants/m^2)	
	Banded	IBS
0	52.4	47.6
25	39.5	47.0
50	30.5	44.6
100	13.6	42.0
200	2.6	34.2
l.s.d. (P<0.05)	10.3	

Conclusion

Phosphorus fertiliser (as triple super) reduced canola establishment when placed with the seed in this experiment. Brill and Jenkins (2014) reported similar reductions in establishment where mono-ammonium phosphate (MAP), di-ammonium phosphate (DAP) and single super were placed with canola seed in an experiment conducted in the Central West of NSW in 2013. It is recommended to separate canola seed from P fertiliser to improve canola establishment. Further research will determine the distance required for P safety, and interactions with soil moisture and seeding equipment. Where the canola seed cannot be separated from P fertiliser, it is recommended to minimise the rate of P applied and potentially increase P rates on less sensitive crops in the rotation (e.g. cereals).

The traditional practice of banding nitrogen under canola seed also reduced establishment at rates above 25 kg N/ha (54 kg/ha urea). Applying N at sowing to canola can be a useful management tactic, however, it is safer to broadcast the N in front of seeding (at rates up to 100 kg N/ha). Growers could also consider mid-row banding N to give some lateral separation between the seed and N fertiliser.

Reference

Brill, R & Jenkins, L 2014, 'Effect of starter fertiliser choice and phosphorus rate on establishment and grain yield of canola – Trangie and Nyngan 2013', in L Serafin, S Simpfendorfer, M Sissons, A Verell & G McMullen (eds) *Northern grains region trial results – Autumn 2014*, NSW Department of Primary Industries, Orange, pp. 173–175.

Acknowledgements

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

Thanks to technical assistance from Sharni Hands, John Bromfield, Dylan Male, Tom Quinn and Sophie Prentice.

High yielding canola agronomy – optimum sowing date and variety type for the South West Slopes region of NSW

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

Key findings

- There is wide phenological diversity in Australian canola varieties. From a 28 March sowing date the fastest variety, Nuseed® Diamond, started flowering on 22 June and the slowest variety, Hyola® 970CL (winter type), started flowering on 28 September, a difference of 98 days from sowing to start of flowering.
- The highest yield of 4.7 t/ha came from sowing fast (e.g. Nuseed® Diamond) and mid (e.g. Pioneer® 45Y25 (RR)) spring phenology types in mid-April to early May. Sowing the fast variety early (Nuseed® Diamond) resulted in significant frost damage, reducing yield and quality, as it started flowering in June.
- The winter varieties and the slow spring varieties had stable yield across sowing dates, but generally yielded closer to 4 t/ha.
- Open-pollinated (OP), triazine tolerant (TT) varieties yielded within 5% of hybrid non-TT varieties (with similar phenology).

Agronomy–canola

Introduction

There has been recent interest in sowing slow spring and winter canola varieties in late March to early April. Crop models generally show higher yield potential from sowing long season varieties early, but there are secondary benefits from early sowing such as avoiding some establishment pests in no-till systems and capitalising on seedbed moisture from summer rain. There has, however, been little research comparing early sowing (late March to early April) long season canola varieties with later sowing (mid–late April) faster canola varieties in high yielding environments. Research started in 2017 through the project 'High yielding canola for southern NSW', which includes a site at Wallendbeen in the South West Slopes. Results from the first year are reported in this paper.

Site details

Location	Wallendbeen (530 m ASL), 15 km north-east of Cootamundra
Soil type	Red ferrosol
Previous crop	Wheat
Rainfall	Fallow rainfall (November 2016–March 2017) 228 mm In-crop rainfall (April 2017–October 2017) 279 mm (long-term average = 450 mm)
Soil characterisitcs	pH_{Ca} (0–10 cm, 13 April) 5.4 Soil nitrogen (0–120 cm, 13 April) 187 kg/ha Soil phosphorus (Colwell, 0–10 cm) 37 mg/kg
Nitrogen	Urea (46% nitrogen (N)) @ 190 kg/ha and ammonium sulfate (20% N, 24% sulfur (S)) @ 150 kg/ha, applied 27 March (broadcast and incorporated by a plot seeder). Urea @ 100 kg/ha, applied 4 July (broadcast).
Starter fertiliser	MAP (mono-ammonium phosphate) (11% N, 22.7% phosphorus (P), 2% S) @ 100 kg/ha, treated with 2.8 L/tonne flutriafol (500 g/L)

Treatments	Varieties	Nuseed® Diamond	Fast spring, conventional herbicide hybrid
		Pioneer® 44Y90 (CL)	Mid–fast spring, Clearfield® (CL) hybrid
		ATR Bonito⁽ᵈ⁾	Mid–fast spring, TT, OP
		Pioneer® 45Y25 (RR)	Mid spring, Roundup Ready® (RR) hybrid
		ATR Wahoo⁽ᵈ⁾	Slow spring, TT, OP
		Victory® V7001CL	Slow spring, CL hybrid
		SF Edimax CL	Winter, CL hybrid
		Hyola® 970CL	Winter, CL hybrid
	Sowing date (SD)	SD1: 28 March	
		SD2: 13 April	
		SD3: 1 May	

Results

Phenology

Nuseed® Diamond was the fastest variety to flower from all three sowing dates and flowered close to the optimum start of flowering date (OSF) from the latest sowing date, 1 May (Figure 1). Pioneer® 44Y90 (CL), ATR Bonito⁽ᵈ⁾ and Pioneer® 45Y25 (RR) all flowered close to the OSF date from the 13 April sowing, while the slow spring varieties ATR Wahoo⁽ᵈ⁾ and Victory® V7001CL flowered close to the OSF date from the 28 March sowing date. The winter varieties Hyola® 970CL and SF Edimax CL flowered at least a month after the OSF date from all three sowing dates.

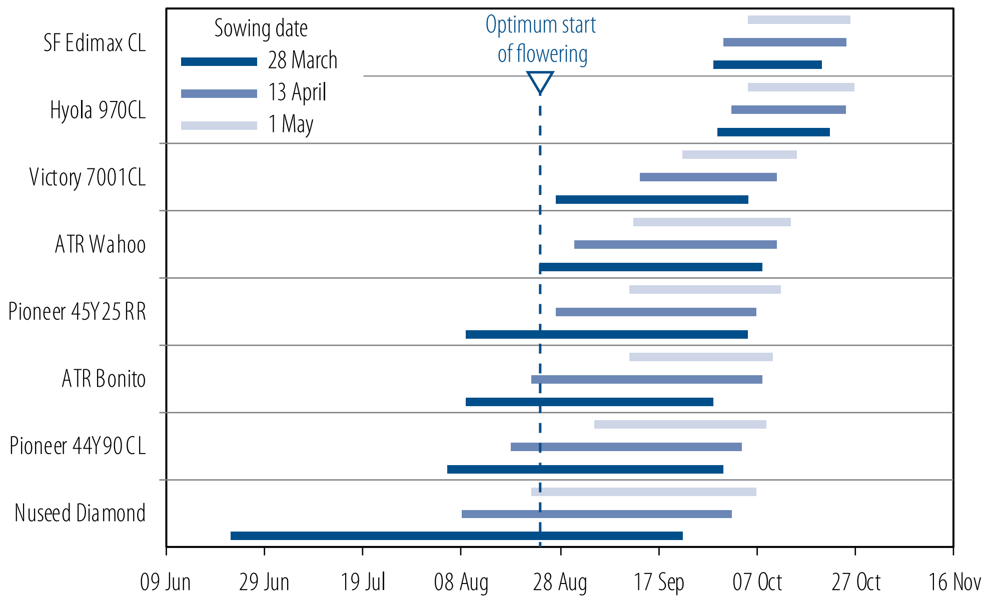

Figure 1. The effect of sowing date (three) on the flowering period of eight canola varieties at Wallendbeen in 2017.
Note: The date at the start of each line is the start of flowering (50% of plants with one open flower). The date at the end of each line is the end of flowering (95% of plants with no flowers). The vertical dashed line shows the Agricultural Production Systems Simulator (APSIM)-prediction for optimum start of flowering date for nearby Young (available at www.grdc.com.au/10TipsEarlySownCanola).

Grain yield

Phenology largely influenced the grain yields of the spring varieties. The fast and mid spring varieties Nuseed® Diamond, Pioneer® 44Y90 (CL), ATR Bonito⁽ᵈ⁾ and Pioneer® 45Y25 (RR) all had a lower yield from early sowing than later sowing as their yield was limited by frost and potentially lack of radiation as a result of early flowering (Table 1). Nuseed® Diamond was the most affected by early sowing and yielded 1.1 t/ha less from the 28 March sowing than the 13 April sowing date. The yield from the slow spring varieties ATR Wahoo⁽ᵈ⁾ and Victory® V7001CL was consistent across sowing dates, but yielded less than the faster spring varieties.

The OP TT varieties ATR Wahoo$^{\Phi}$ and ATR Bonito$^{\Phi}$ both grew approximately 15–20% less biomass than the hybrid varieties with similar phenology (Victory® 7001CL and Pioneer® 44Y90 (CL) respectively), but yielded within 5% of the hybrids as they had a higher harvest index (higher conversion of biomass to grain).

The winter varieties Hyola® 970CL and SF Edimax CL, although not as high yielding as the fast and mid spring varieties, yielded well considering their very late flowering. In seasons where growers miss early sowing opportunities for winter varieties for grain and grazing, this experiment shows that profitable yields can be achieved as a grain-only crop when sown into April. High yielding canola environments such as Wallendbeen generally have a wide optimum flowering window as spring is relatively cool with reliable rainfall.

Table 1. Grain yield (t/ha) of eight canola varieties sown on three dates at Wallendbeen in 2017.

Variety	Sowing date		
	28 March	13 April	1 May
Nuseed Diamond	3.7	4.7	4.8
Pioneer 44Y90 CL	4.1	4.3	4.4
ATR Bonito	4.1	4.4	3.9
Pioneer 45Y25 RR	4.2	4.7	4.7
ATR Wahoo	3.9	4.0	4.0
Victory V7001CL	3.8	4.0	3.6
SF Edimax CL	4.0	4.0	3.6
Hyola 970CL	4.1	4.1	3.8
l.s.d. ($P<0.05$)		0.3	

Oil concentration

There were only minor differences between the oil concentration across the treatments (varieties and sowing dates) with an average of 47.5%. The main exception was the early sown Nuseed® Diamond which was frosted and had an oil concentration of 43.3%.

Conclusion

In 2017 at the Wallendbeen experiment site, the highest grain yield came from sowing fast and mid spring canola varieties in mid-April to early May. Sowing slow spring and winter varieties early resulted in lower grain yield. This experiment will be repeated in 2018 with four extra varieties; Phoenix CL (winter), Archer (slow spring), Pioneer® 45Y91 (CL) (mid spring) and an experimental slow spring variety. There will also be experiments examining responses to the rate and timing of nitrogen in a winter and a mid spring variety.

Reference

Lilley J, Kirkegaard J, Brill R & Ware A 2017, 'Ten tips to early-sown canola': www.grdc.com.au/10TipsEarlySownCanola, downloaded 20 June 2018.

Acknowledgements

This experiment is part of the project 'High yielding canola', BLG107, 2017–20, a joint investment by NSW DPI and GRDC as part of the Grains Agronomy and Pathology Partnership project, DAN00213.

Thanks to technical assistance from Sharni Hands, John Bromfield, Dylan Male, Tom Quinn and Sophie Prentice.

The effect of sowing date, nitrogen rate and irrigation on flowering and grain yield of four canola varieties – Condobolin 2017

Ian Menz, Daryl Reardon and Craig Ryan (NSW DPI, Condobolin)

Key findings

- Variety phenology and sowing date need to match to avoid plants flowering and podding during periods of severe frost. The highest yield in 2017 came from the 6 April sowing of the long season varieties Archer and ATR Wahoo⁽ᴰ⁾ that flowered in early August.
- ATR Stingray⁽ᴰ⁾ and Nuseed® Diamond flowered earlier than the optimum start of flowering (OSF) date (28 July) from both the 6 April and 20 April sowing dates with significant frost damage incurred at both sowing dates.
- Canola varieties have the ability to recover from severe frost damage where soil water is not limited.

Introduction

The experiment was designed to determine the optimum sowing date, phenology and nitrogen management to optimise grain yield within the Central West region of NSW. These combinations were tested across two contrasting scenarios: irrigation versus dryland.

This experiment was part of a series of experiments sown from southern Queensland to the Eyre Peninsula in South Australia, to determine variety response to sowing dates across varying climatic zones.

Site details

Location	Condobolin Agricultural Research and Advisory Station (Condobolin ARAS)
Soil type	Red–brown earth, pH_{Ca} 6.5 (0–10 cm)
Previous crops	Pasture 2012, barley 2013, field pea 2014, barley 2015, wheat 2016
Fertiliser	70 kg/ha mono-ammonium phosphate (MAP) + Jubilee (flutriafol 500 g/L) at 400 mL/ha (fungicide on fertiliser)
Soil available nitrogen (N)	77 kg/ha (0–120 cm) soil test conducted in March 2017
Fallow rainfall	313 mm (November 2016–March 2017)
Growing season rainfall	99 mm (1 April–30 September)
Harvest date	Harvested by hand as varieties reached maturity

Treatments

Canola varieties	Nuseed® Diamond – fast spring, hybrid conventional herbicide ATR Stingray⁽ᴰ⁾ – fast spring, open-pollinated triazine tolerant (TT) Archer – slow spring, Clearfield® hybrid ATR Wahoo⁽ᴰ⁾ – slow spring, open-pollinated TT
Sowing date (SD)	SD1: 6 April SD2: 20 April
Irrigation	Irrigated (total amount applied and timing is shown in Table 1). Dryland
Nitrogen rate	Decile 5: 50 kg N/ha (pre-sowing) Decile 9: 150 kg N/ha (50 kg N/ha pre-sowing, 100 kg N/ha at 6/8 leaf stage)

Seasonal conditions

The growing season rainfall at the experiment site was below average at 98.7 mm. The long-term average (LTA) growing season rainfall is 192.1 mm. There was 126.2 mm of rain in March and 20.8 mm in April. There was below average rainfall during spring with 20.9 mm and 6.2 mm for August and September respectively (Table 2).

There were a total of 48 days between June and September that the temperature was at or below 0 °C: 15 (June), 14 (July), 12 (August) and seven (September). There was a number of major frosts during the growing season; –6.6 °C (1 July), –5.0 °C (2 July), –4.0 °C (12 July), –5.1 °C (22 July), –4.1 °C (29 July), –4.5 °C (20 August), –5.3 °C (29 August) and –3.9 °C (1 September).

Irrigation application

Table 1. Irrigation applied to experiment across the irrigated treatment at Condobolin, 2017 (*irrigation applied to complete experiment, both irrigated and dryland treatments).

Date	8 Mar	9 Mar	28 Mar	13 Apr	20 Jun	15 Aug	1 Sep	5 Sep	21 Sep
Irrigation (mm)	25 *	30	30	15 *	30	15	15	15	15

Table 2. Monthly rainfall 2017 and long-term average (LTA) at Condobolin ARAS.

Condobolin ARAS rainfall (mm)														
Dec 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Growing season
56.7	31.2	4.6	126.2	20.8	27.0	4.8	19.0	20.9	6.2	52.7	75.0	59.9	448.3	98.7
LTA	39.9	41.1	34.3	29.8	34.4	34.0	32.3	32.5	29.1	41.3	39.3	39.7	427.7	192.1

Results

The fast spring varieties Nuseed® Diamond and ATR Stingray⟨PBR⟩ started flowering in late June/early July from the early sowing date (6 April) (Figure 1). The slow spring varieties Archer and ATR Wahoo⟨PBR⟩ flowered a month later in early August. When sown late (20 April), Nuseed® Diamond and ATR Stingray⟨PBR⟩ flowered two weeks earlier than Archer and ATR Wahoo⟨PBR⟩ did from the 6 April sowing.

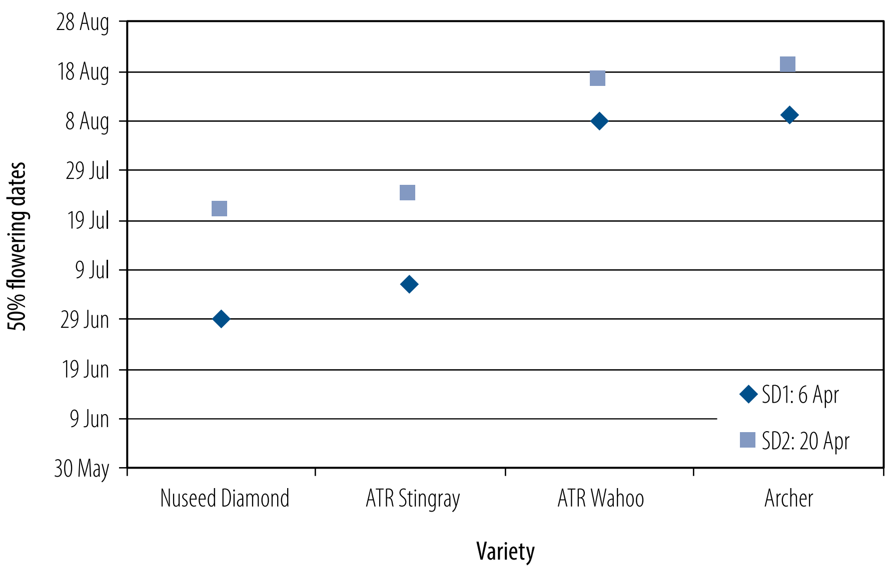

Figure 1. Start of flowering (50% of plants with one open flower) of four canola varieties sown on two sowing dates (SD) at Condobolin in 2017.

During flowering/podding there were a number of major frosts which contributed to the low yield and water use efficiency of all treatments (Figure 2).

The slow spring varieties, ATR Wahoo$^{\Phi}$ and Archer had yields of 0.9 t/ha and 1.1 t/ha, respectively from the early sown dryland treatment. The later flowering of these varieties (compared with Nuseed® Diamond and ATR Stingray$^{\Phi}$) reduced the amount of frost damage incurred during the podding period. Early sown Nuseed® Diamond and ATR Stingray$^{\Phi}$ that flowered in late June both yielded less than 0.4 t/ha. Delaying sowing to 20 April of Nuseed® Diamond and ATR Stingray$^{\Phi}$ only delayed flowering to mid-July and these treatments were still severely frosted and were low yielding.

Irrigation increased grain yield of all treatments by 0.6 t/ha, helping canola recover from frost damage by setting new pods. There was no effect of nitrogen rate on grain yield.

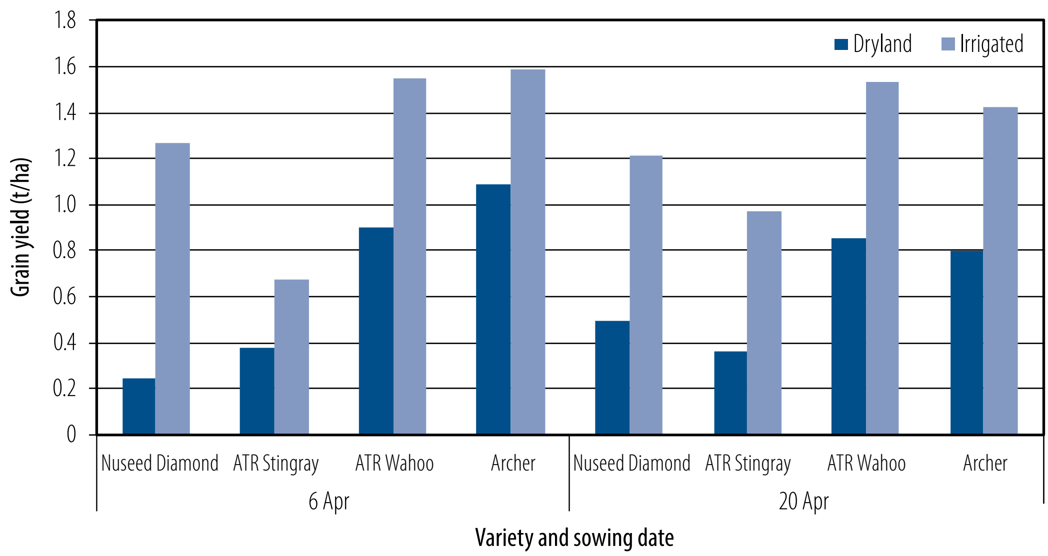

Figure 2. Grain yield of four canola varieties sown on two dates, with irrigation and without irrigation (dryland), at Condobolin in 2017 (l.s.d. $P<0.05 = 0.26$ t/ha).

Summary

This experiment highlighted the importance of matching varietal phenology and sowing date to achieve the correct flowering date to avoid stress and optimise yield. Sowing a fast developing variety early results in that variety flowering/podding during a period of high frost risk. However, this experiment did show that with increased plant available water, canola can recover from severe frost.

Stated in Ten Tips to Early-Sown Canola the simulated OSF date for Condobolin is 25 July (Lilley et al. 2017). In 2017, treatments that flowered before late July were severely frosted.

It is recommended that growers ensure a weed-free fallow to maximise water available to canola to aid in frost recovery. Rotation planning can also make a large difference; choose a crop sequence (such as pulses) that leaves some deeper sub-soil moisture for the canola crop. This experiment has shown that if additional water is available and the crop suffers frost damage it has the ability to recover.

Reference

Lilley, J, Kirkegaard, J, Brill, R & Ware, A 2017, 'Ten tips to early-sown canola': www.grdc.com.au/10TipsEarlySownCanola, downloaded 14 Feb 2018.

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 ARAS for assistance throughout this experiment.

Nutrition & soils

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

Dr Guangdi Li, Richard Hayes, Dr Ehsan Tavakkoli, Helen Burns, Richard Lowrie, Adam Lowrie, Graeme Poile, Albert Oates and Andrew Price (NSW DPI, Wagga Wagga); Dr Jason Condon, Dr Sergio Moroni and Dr Alek Zander (Charles Sturt University, Wagga Wagga)

Key findings

- Deep placement of organic amendments (e.g. lucerne pellets) did not increase soil pH as high as measured in laboratory/glasshouse experiments, but it did reduce exchangeable aluminium (Al) significantly at 10–20 cm and 20–30 cm, indicating that the organic amendment would relieve Al toxicity by combining Al^{3+} to form insoluble compounds, hence reducing toxicity to plant growth.
- There was a large crop yield response to deep organic amendments in year 1 due to extra nutrients supplied from the lucerne pellets, but no crop response was detected in year 2, partly due to lack of soil moisture during the crop growing season. To date, soil treatments have had little effect on soil water.
- Soil chemical, physical and biological properties will continue to be monitored to understand the soil–plant interactions, the factors driving the differences in crop response to the various treatments, and the residual value of the amendments over the long-term.

Introduction

A long-term field experiment was set up in 2016 to run for at least two four-year crop rotation cycles, or one eight-year soil amendment cycle. The objectives were to:

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

Site details

Location	Dirnaseer, west of Cootamundra, NSW
Soil type	Red chromosol (Isbell 1996)
Previous crop	Oats
Crop rotation	Phase 1 EGA Gregory⟨PBR⟩ wheat Phase 2 Hyola® 559TT canola Phase 3 La Trobe⟨PBR⟩ barley Phase 4 Morgan⟨PBR⟩ field pea (2016) PBA Samira⟨PBR⟩ faba bean (2017)
Liming history	No lime for the past 10 years
Fallow rainfall	2016 (265 mm) (Nov–March) 2017 (302 mm) (Nov–March) Long-term average (261 mm Nov–March)

In-crop rainfall	2016 (676 mm) (April–Oct) 2017 (269 mm) (April–Oct) Long-term average (347 mm April–Oct)
Starter fertiliser	75 kg/ha di-ammonium phosphate (DAP) – 14% nitrogen (N), 15% phosphorus (P), 1% sulfur (S) for all crops
Top-dressing fertiliser	50–100 kg N/ha as urea for wheat, canola and barley, depending on the season
Ripping machine	3-D Ripper (5 tynes), designed and fabricated by NSW DPI
Ripping width and depth	50 cm between rip lines; to 30 cm depth

Crop rotation and treatments

There were four crops in rotation arranged in a fully phased design. The crops sequence is wheat (*Triticum aestivum*), canola (*Brassica napus*), barley (*Hordeum vulgare*), pulse, either faba bean (*Vicia faba*) or field peas (*Pisum sativum*) depending on the season. Each crop appears once in any given year so that:

1. responses of different crops to different soil amendments can be assessed
2. 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	No amendment	No amendment, representing the 'do nothing' approach.
2	Surface liming	Lime was applied at 4.0 t/ha, incorporated into 0–10 cm depth, to achieve an average pH_{Ca} of 5.5 over 8 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 into 0–10 cm depth after plots were ripped, to achieve an average pH_{Ca} of 5.0 over 8 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 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.

Results

Soil chemical properties

There was no difference in soil pH at any depth in year 1 before treatments were imposed in 2016. In autumn 2017, one year after treatments were applied, surface liming increased pH to 5.9 at 0–10 cm. The deep liming treatment with and without OA significantly increased soil pH at 10–20 cm and 20–30 cm (Figure 1), showing the efficacy of the 3-D Ripper (Figure 2) to deliver soil ameliorants to depth (Li & Burns 2016).

However, the deep OA treatment did not increase pH as high as measured in laboratory/glasshouse experiments (data not shown). There are two possible explanations for this. First, the organic amendment was normally fully mixed with soil when it was incubated in the laboratory or put in soil columns in the glasshouse compared to that in the field where it was placed in a concentrated row in the rip line. Lack of homogenisation of the soil with OA makes it difficult to demonstrate what is more easily observed in a controlled environment with adequate water supply, usually maintained at field capacity. Secondly, all controlled environment experiments were conducted for 1–3 months, which would capture the initial soil pH increase due to decomposition of organic materials as demonstrated by Butterly et al (2010b). However, the subsequent nitrification processing would reduce soil pH (Butterly et al. 2010a). Nitrate leaching, if it occurs, will exacerbate the acidifying process. As a result, the net effect would keep soil pH unchanged in the longer term.

A number of soil column experiments demonstrated that the soluble component from organic material moves faster down the soil profile with alkali if combined with lime, compared with lime alone (Meda et al. 2002; Diehl et al. 2008). However, there is no evidence to show the lime being moved under lime plus OA in field conditions at this time. Monitoring soil pH will continue for the next few years to observe whether evidence of this emerges at the field site.

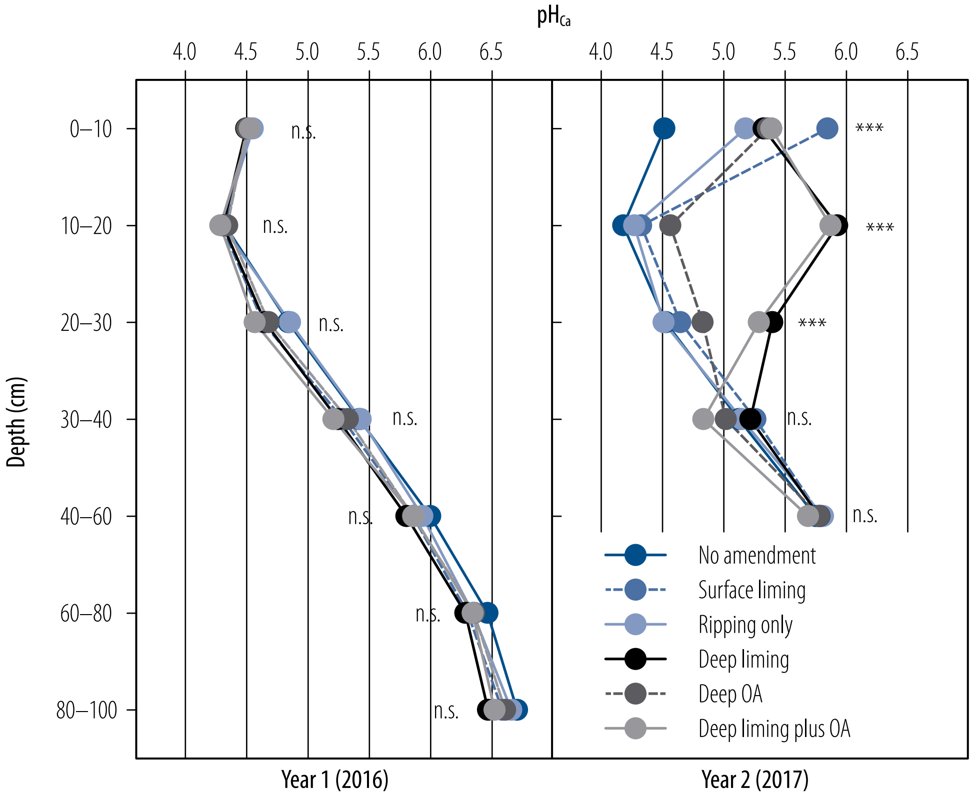

Figure 1. Soil pH_{Ca} under different soil amendment treatments in autumn in years 1–2 at the Cootamundra site; n.s., not significant.

Figure 2. 3-D Ripper, designed and fabricated by the NSW Department of Primary Industries.

Although OA did not increase soil pH, it did reduce exchangeable Al% significantly at 10–20 cm and 20–30 cm (Figure 3) compared with the no amendment treatment, indicating that the soluble organic molecules from OA could combine active Al^{3+} to form insoluble hydroxy-Al compounds (Haynes & Mokolobate 2001), which would reduce Al toxicity to plant growth.

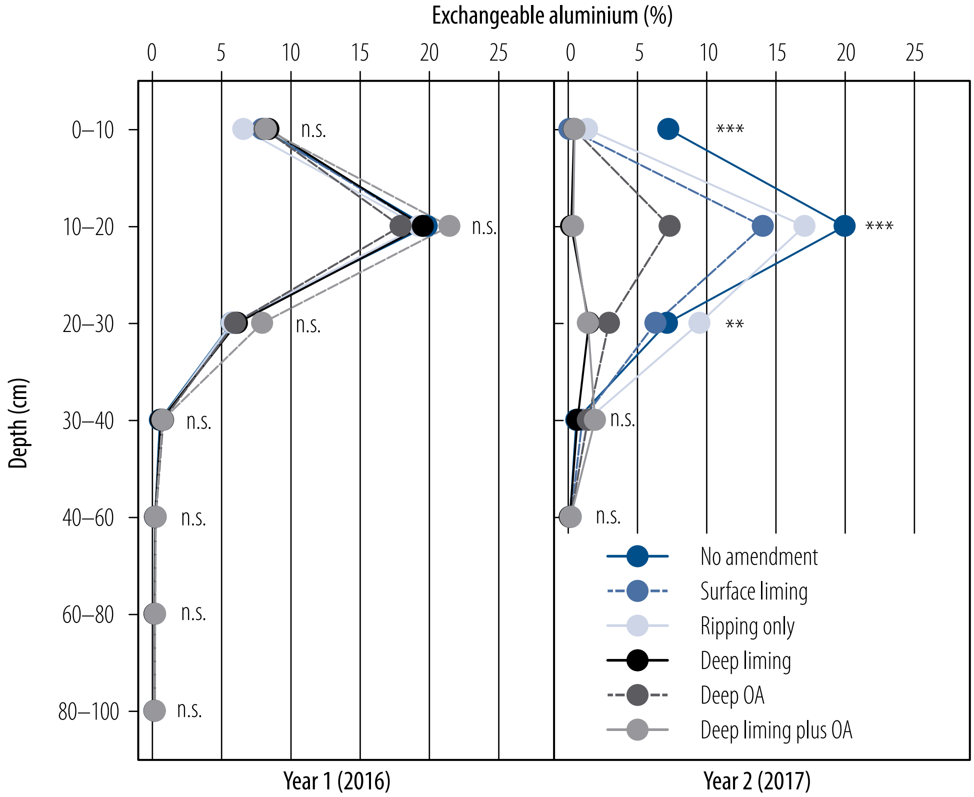

Figure 3. Soil exchangeable Al% under different soil amendment treatments in autumn in years 1–2 at the Cootamundra site; n.s., not significant.

There was significantly more soil mineral nitrogen (N) under the deep OA treatments with and without lime in spring 2016 (six months after treatments were implemented, $P<0.01$) and in autumn 2017 (12 months after treatments were implemented, $P<0.001$) (Figure 4), most likely due to the high N content (3.15%) of the lucerne pellets. On average, there was more than double the mineral N available on the deep OA and deep lime plus OA treatments compared with the remaining treatments.

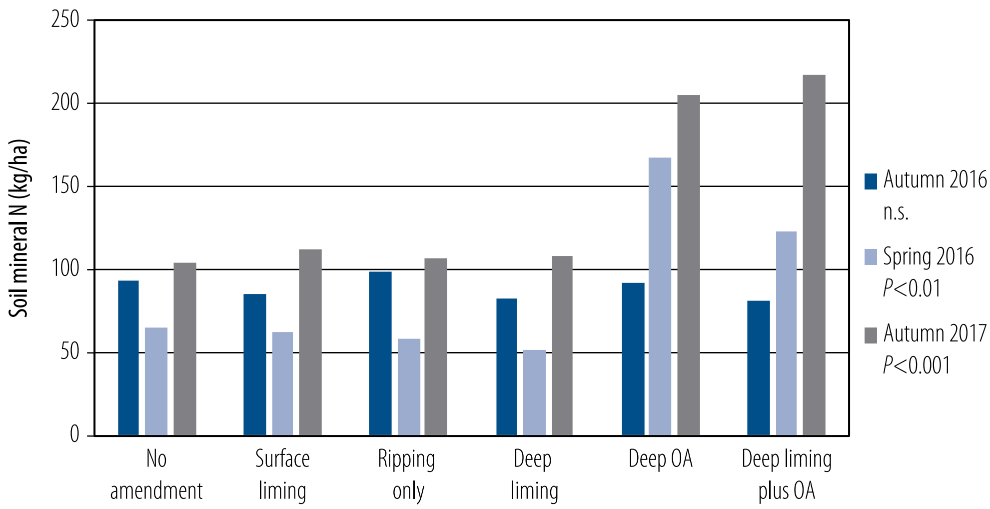

Figure 4. Soil mineral N (kg/ha) in 0–60 cm soil profile under different soil amendment treatments in autumn and spring in year 1, and autumn in year 2 at the Cootamundra site; n.s., not significant.

Rooting depth and root density

Rooting depth and root density was measured at crop anthesis at the end of October 2017 using the core-break method. Two soil cores were taken on each plot, one on the ripping line and the other between ripping lines. Data are presented on the average of two cores for each plot as no significant difference was found between two locations.

Canola was the deepest rooting crop, down to 140 cm and faba bean had the shallowest rooting depth (90–100 cm), whereas wheat and barley were intermediate. There was no significant difference in average maximum rooting depth between treatments (Figure 5).

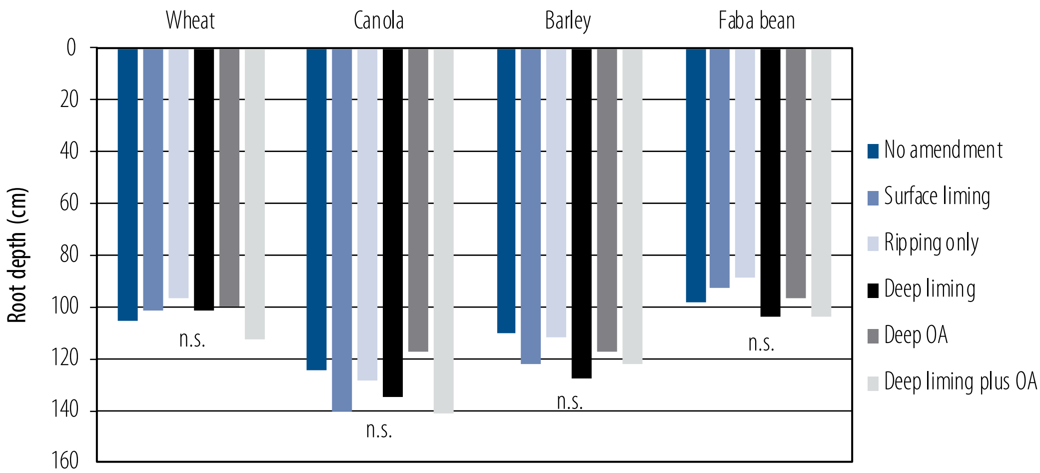

Figure 5. Maximum rooting depth (cm) under different soil amendment treatments at crop anthesis in year 2 at the Cootamundra site; n.s., not significant.

Soil total water

Neutron probe access tubes were inserted in autumn each year immediately after crops were sown then monitored for 12 months before new crops were sown in autumn the following year. One access tube was inserted 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 neutron probe reading was calibrated twice a year at the wettest and driest periods and the soil volumetric moisture content and soil total water in the profile were calculated.

The amount of soil water, in general, followed the rainfall pattern. In year 1, the soil profile was nearly full under all crops at the end of October due to the significant rainfall events. The site receiving 667 mm rainfall from May to October in that year. Late in the growing season, soil water decreased sharply for all crops due to high evapo-transpiration rates during the grain fill period. There was more soil water under the field pea crop at the end of November due to its earlier maturity and shallower rooting depth (Figure 6). The autumn and winter of year 2 were very dry and soil water remained at a constant level until the end of August before crop growth took off and water demands increased. During spring, soil water decreased to the lowest level due to vigorous crop growth and limited rainfall during that period among all treatments. The early summer rainfall re-filled the soil profile to different levels depending on soil moisture status in spring for different crops and treatments (Figure 6).

For wheat and canola in year 1, crops on treatments with deep soil amendments had lower soil water at the end of November 2016, particularly for the deep liming plus OA treatment (figures 6a and b) due to vigorous crop growth (Figure 8). In year 2, the deep liming treatment had the lowest soil water on the canola crop following the wheat crop (Figure 6a), whereas the deep liming plus OA treatment had lowest soil water on the barley crop following canola for the whole season (Figure 6b).

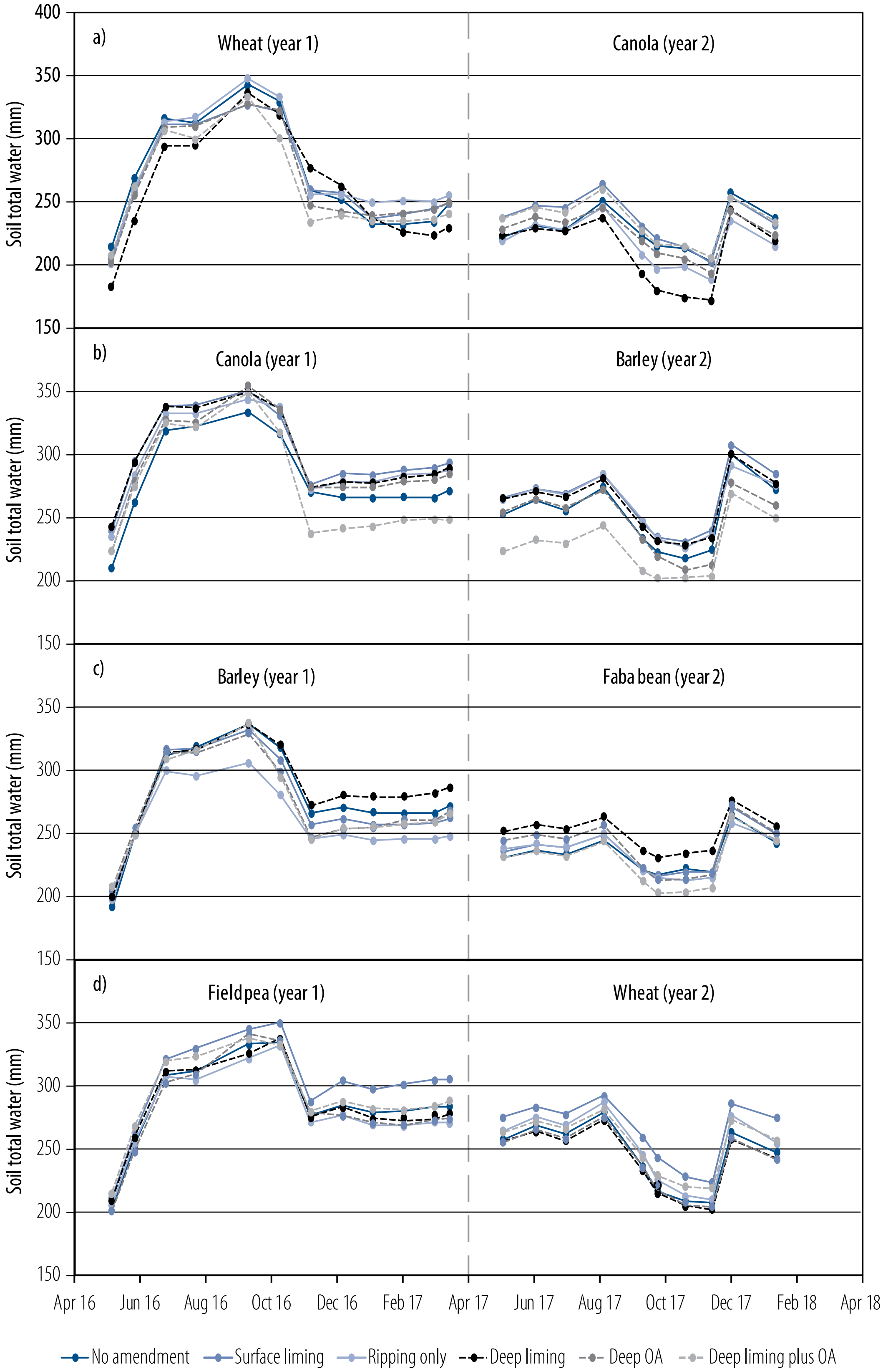

Figure 6. Soil water (mm) in the profile under different soil amendment treatments over two growing seasons (2016 and 2017) at the Cootamundra site.

For the barley crop in year 1, the ripping only treatment had the lowest soil water among all treatments during the early growing season, possibly due to more evaporation (Figure 6c). Later in the growing season during November, soil water on deep liming plus OA decreased sharply, reflecting the vigorous crop growth. Soil water on the deep liming treatment, however, was much higher than other treatments. In year 2, it was a very poor faba bean crop. Soil water on different treatments remained similar through the season with the highest soil water on the deep liming treatment and the lowest on the deep liming plus OA treatment.

For the field pea crop in year 1, there was not much difference in soil water during the growing season (Figure 6d); soil water was higher on this crop than other crops in year 1. The surface lime treatment had the highest soil water among all treatments after the crop was harvested. In year 2, vigorous wheat crops used more soil water and brought soil water down to a level similar to the other crops in the rotations (Figure 6d). Overall, soil amendment had little apparent effect on soil water values.

Agronomic performance

There was no significant difference in seedling density for all crops except for the barley crop where two treatments with deep OA had a higher seedling density in year 1 (Figure 7). There was no treatment difference in seedling density for any crops in year 2 due to the extremely dry conditions during crop establishment. The site only received 3.2 mm in June.

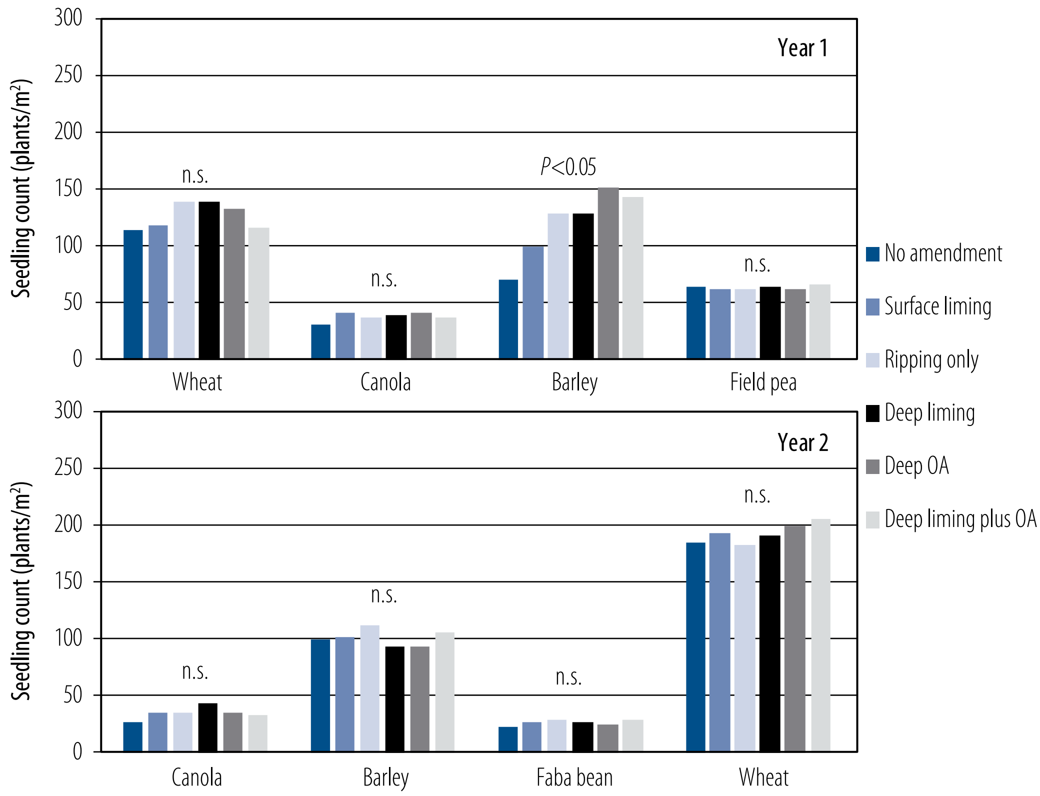

Figure 7. Seedling density (plants/m^2) at crop establishment in response to different soil amendments in years 1–2 at the Cootamundra site; n.s., not significant.

At anthesis, significant crop biomass responses were observed on wheat, barley and canola crops (Figure 8). The large crop biomass responses in year 1 under treatments with organic amendments applied were largely due to extra nutrients supplied by lucerne pellets (Figure 4). The dramatic crop biomass responses observed at anthesis on canola and barley crops did not translate into grain yield under treatments with lucerne pellets (Figure 9) due to severe lodging. In 2017, no significant difference was found for anthesis dry matter and grain yield between treatments for all crops (Figure 8). However, both deep OA and deep lime plus OA treatments tended to have a lower grain yield despite significantly higher mineral N at sowing (Figure 4). Lack of rainfall early in the growing season in 2017 (3.2 mm in September) and severe frost damage in late winter almost wiped out the canola and faba bean crops and severely suppressed the barley and wheat crops. The later growing season rainfall (53 mm and 70 mm in October and November, respectively) certainly boosted cereal crop grain yield (Figure 9).

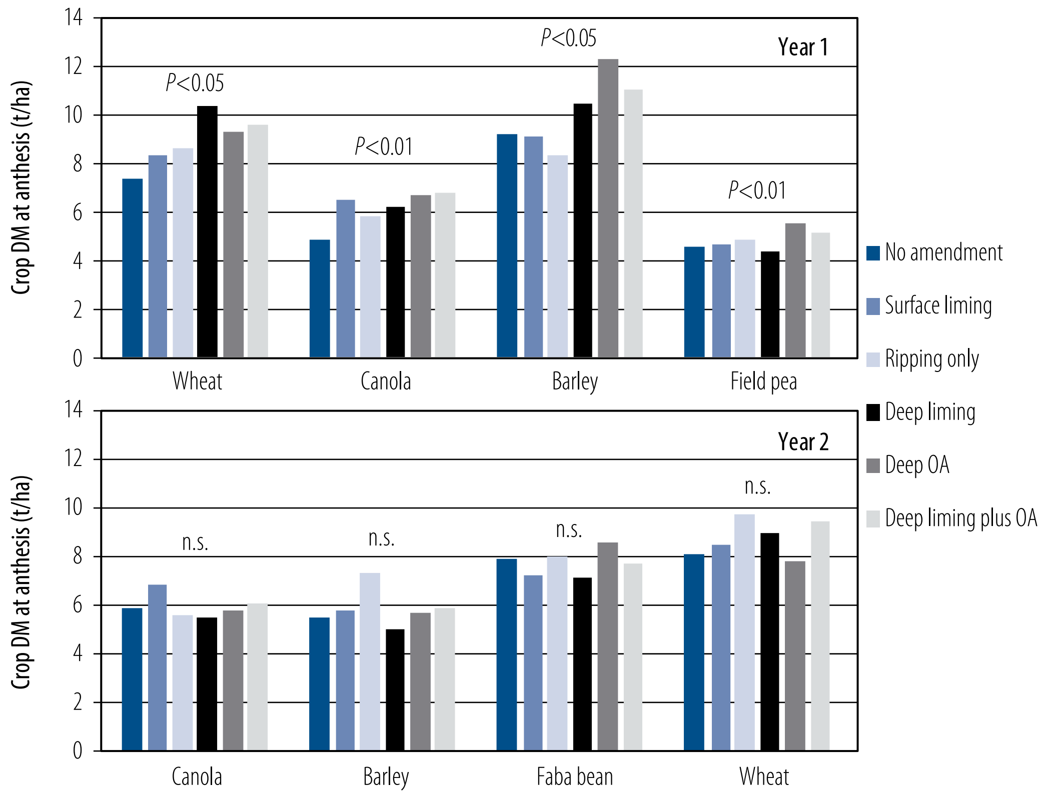

Figure 8. Crop dry matter (DM) at anthesis (t/ha) in response to different soil amendments in years 1–2 at the Cootamundra site; n.s., not significant.

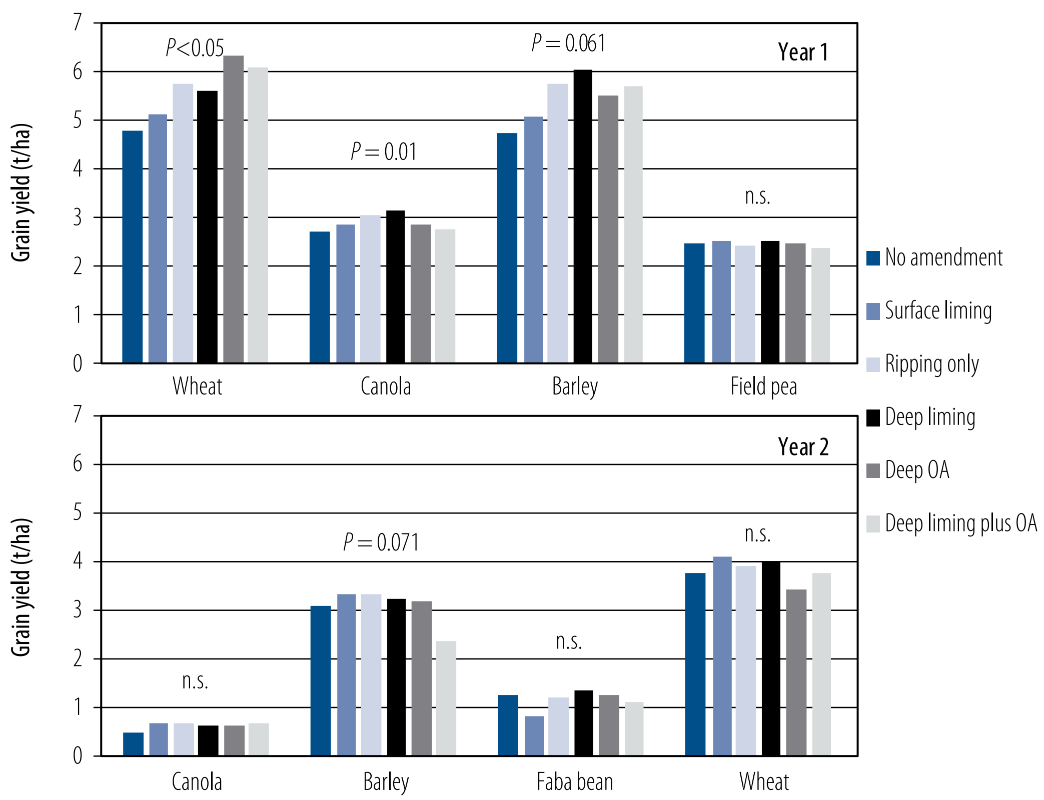

Figure 9. Grain yield (t/ha) in response to different soil amendments in years 1–2 at the Cootamundra site; n.s., not significant.

Conclusion

Deep placement of organic amendments (lucerne pellets) did not increase soil pH as much as that measured in laboratory experiments, but it did reduce exchangeable Al% significantly at 10–20 cm and 20–30 cm depth, indicating that the organic amendment would relieve Al toxicity by combining Al^{3+} to form insoluble compounds, hence reducing toxicity to plant growth.

There were large crop yield responses to deep organic amendment in year 1 due to extra nutrients supplied from the organic amendment, but no crop response was detected in year 2, partly due to a lack of soil moisture during the crop growing season. To date, soil treatments have had little effect on soil water.

Soil chemical, physical and biological properties will continue to be monitored to understand the soil–plant interactions, the factors driving the differences in crop response to the various treatments, and the residual value of the amendments over the long-term.

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Acknowledgements

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Our thanks extend to the property manager, Tony Flanery, and land owner, Ian Friend, Dirnaseer, west of Cootamundra, NSW for their ongoing cooperation since 2016.

Amelioration of subsoil acidity using inorganic amendments

Dr Guangdi Li, Richard Hayes, Dr Ehsan Tavakkoli and Helen Burns (NSW DPI, Wagga Wagga); Dr Jason Condon and Dr Sergio Moroni (Charles Sturt University, Wagga Wagga)

Key findings

- Deep ripping had an adverse effect on crop establishment and crop yield in the establishment year.
- Both lime and magnesium silicate (a blended product of 70% Doonba dunite and 30% F70 lime) were capable of increasing soil pH and decreasing exchangeable aluminium (Al) at the 20–30 cm depth where the soil amendment was applied.
- Deep placement of gypsum had no effect on soil acidity and did not improve grain yield.

Introduction

A three year deep ripping experiment was conducted on a highly acidic soil to test how effective a range of inorganic soil amendments were to ameliorate subsoil acidity and improve crop growth and yield. A novel product, MgSi (a blend of 70% Doonba dunite and 30% F70 superfine lime), was tested in the field for the first time.

Site details

Location	'Billa', Holbrook NSW	
Soil type	Yellow chromosol (Isbell 1996)	
Previous crops	Millet (2010); canola (2011); wheat (2012); lupins (2013); wheat (2014)	
Crop sequence	2015 2016 2017	Hyola® 970CL canola EGA Wedgetail⟨ᶲ⟩ wheat EGA Wedgetail⟨ᶲ⟩ wheat
Liming history	2011 2015	2 t/ha 2 t/ha
Fallow rainfall (Nov–March)		2015 (263 mm) 2016 (250 mm) 2017 (253 mm)
In-crop rainfall (April–Oct)		2015 (409 mm) 2016 (712 mm) 2017 (337 mm)
Fertiliser at sowing	60 kg/ha mono-ammonium phosphate (MAP) – 11% nitrogen (N), 22.7% phosphorus (P), 2% sulfur (S) annually	
Top-dressing fertiliser (urea)		2015 (130 kg N/ha) 2016 (60 kg N/ha) 2017 (50 kg N/ha)
Ripping machine	A single tyne ripper to 30 cm depth	
Ripping width	50 cm for the deep liming treatment 80 cm for all remaining treatments	

Treatments

There were nine treatments (Table 1) with four treatment contrasts:

- Surface vs. deep application
- Lime vs. MgSi (blend with 30% of lime) vs. gypsum
- Surface application of urea vs calcium nitrate [$Ca(NO_3)_2$] under deep ripping
- Deep liming with ripping width of 50 cm vs. 80 cm.

Table 1. Soil amendment and treatment description at 'Billa', Holbrook, NSW.

ID	Treatment	Treatment description	Additional details
1	No amendment	Farmer's practice (surface limed at @ 2 t/ha)	
2	Surface liming	Surface liming @ additional 1.4 t/ha	Lime rate was calculated based on an incubation study, targeting average pH_{Ca} of 5.5 over four years.
3	Deep liming	Deep ripping + lime @ 1.4 t/ha (30 cm deep, 80 cm apart)	
4	Surface MgSi	Surface application with MgSi @ 1.4 t/ha	MgSi was a blend of 70% Doonba dunite (crushed to <250 µm) and 30% lime (F70). The neutralised value of the MgSi was estimated to be equivalent to F70 lime.
5	Deep MgSi	Deep ripping + MgSi @ 1.4 t/ha	
6	Deep ripping + urea	Deep ripping only (urea top-dressed 50–100 kg N/ha)	
7	Deep ripping + calcium nitrate	Deep ripping only (calcium nitrate top dressed at equivalent N rate as urea)	Calcium nitrate [$Ca(NO_3)_2\ 4H_2O$, 11.9% N], top-dressed at equivalent rate as urea.
8	Deep gypsum	Deep ripping + gypsum @ 3.0 t/ha	Gypsum (20.6% Ca and 15.3% S), applied at equivalent Ca concentration as lime.
9	Deep liming at 50 cm	Deep ripping + lime @ 1.4 t/ha (30 cm deep, 50 cm apart)	Deep ripped at 50 cm apart in contrast with 80 cm for the rest of the ripping

Results

Soil chemical properties

The initial soil samples were taken before treatments were implemented using large tubes (44 mm diameter) to a depth of 100 cm, two cores per plot composited every 10 cm in 0–40 cm and every 20 cm in 60–100 cm. The soil samples in year 3 were taken using a multi-corer to a depth of 60 cm, two locations per plot, composited with corresponding depths to the initial sampling. The multi-corer consists of six small tubes (25 mm diameter) in a row across 25 cm (Figure 1). At each sampling location, the multi-corer was positioned across a ripping line to ensure that at least one tube would strike soil amendment if applicable.

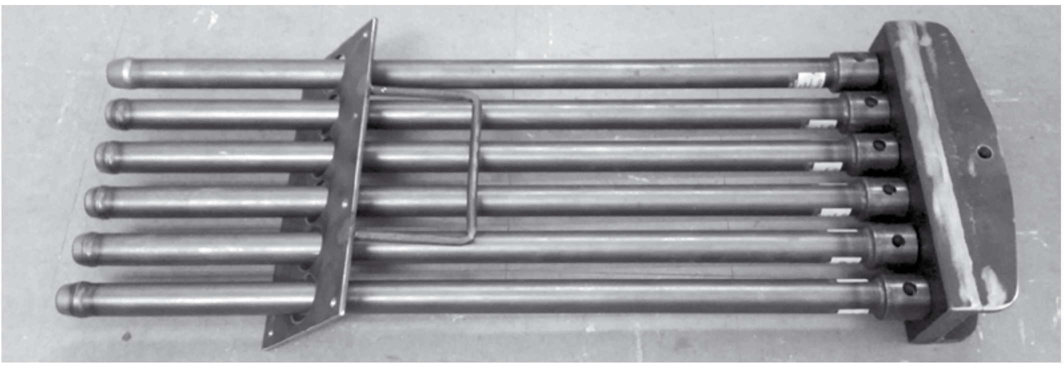

Figure 1. A new multi-core sampler.

Both deep liming and deep MgSi treatments increased soil pH significantly at the 20–30 cm depth (P<0.001) where soil amendments were applied compared with the no amendment treatment three years after treatments were implemented (Figure 2). However, there was no significant difference in soil pH between deep liming and deep MgSi treatments at either 10–20 cm or 20–30 cm. In the current study, the MgSi was blended with 30% of F70 lime to improve MgSi

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efficiency, and the neutralising value of the MgSi blend was assumed to be equivalent to F70 lime. There was no difference in soil pH between different ripping widths of 50 cm and 80 cm. As expected, deep placement of gypsum had no effect on soil acidity.

There was a significant difference in exchangeable Al% between treatments at 10–20 cm ($P<0.01$) and 20–30 cm ($P<0.05$) (Figure 3). The exchangeable Al% tended to be lower in the deep MgSi treatment than that in the deep liming treatment, but no significant difference was found between deep liming and deep MgSi treatments. Further research is required to explore whether MgSi is more efficient in decreasing Al toxicity than lime, as claimed by Castro and Crusciol (2013).

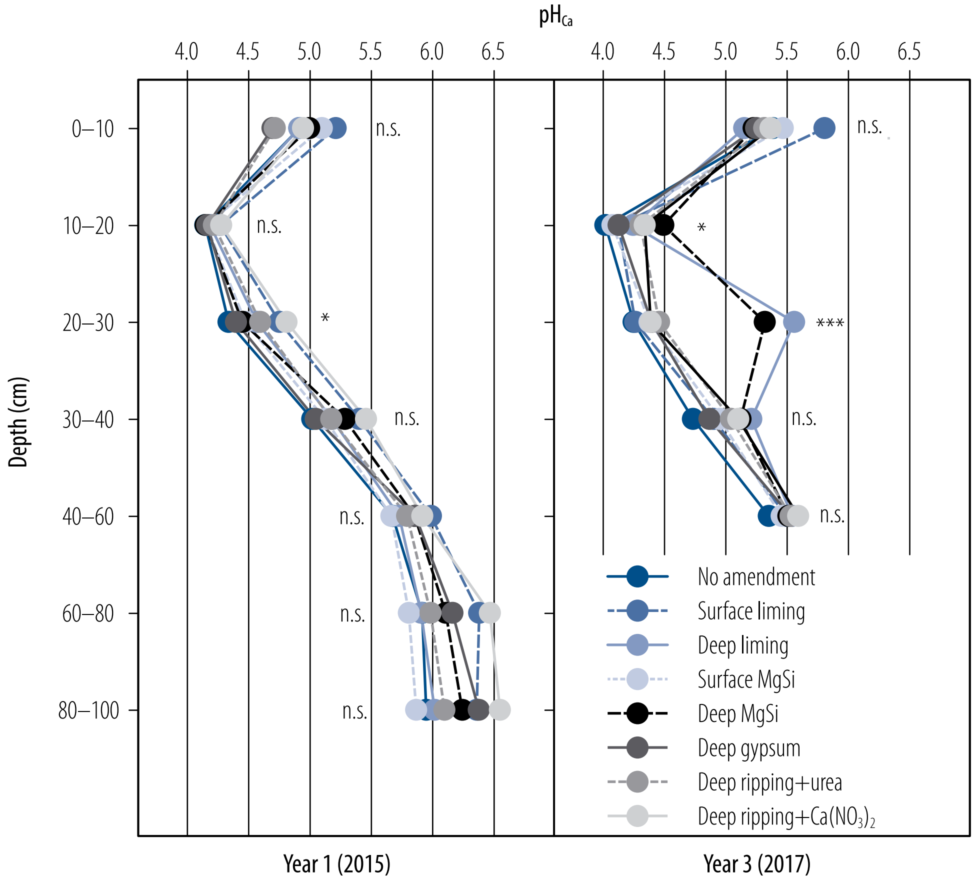

Figure 2. Soil pH_{Ca} under different soil amendment treatments in autumn in years one and three at the Holbrook site. n.s., not significant.

Agronomic performance

There was a significant difference in seedling density for the canola crop in year 1 only ($P<0.001$), but not for wheat crops in years 2 and 3 (Figure 4). In year 1, all ripped treatments had lower seedling densities, probably due to the uneven seedbed, or increased evaporation due to the ripping operation (Poile et al. 2012). There was a similar trend for seedling density in year 2, but not in year 3.

At anthesis, all deep ripping treatments tended to have higher dry matter (DM) production for the canola crop in year 1 at $P = 0.06$, but there were no differences in anthesis DM of treatments for wheat crops in years 2 and 3 (data not shown). At harvest, surface liming and surface MgSi, including the no amendment treatment, had a significantly higher yield than the deep liming, deep MgSi or deep gypsum treatments ($P<0.05$) (Figure 5). No difference was found in wheat grain yield in year 2, most likely due to plentiful in-crop rainfall in 2016, but the $Ca(NO_3)_2$ treatment in year 3 had a significantly higher yield than the remaining treatments (Figure 5), presumably due to less nitrogen volatilisation losses that would occur with urea application.

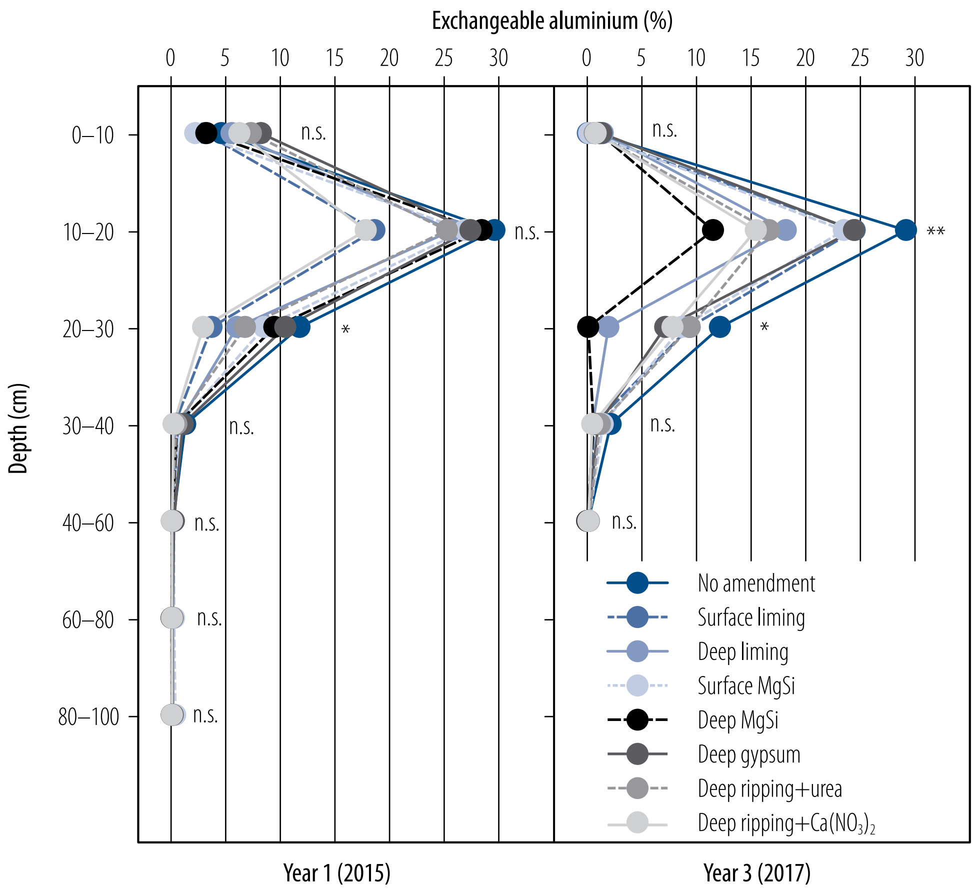

Figure 3. Soil exchangeable Al% under different soil amendment treatments in autumn in years one and three at the Holbrook site. n.s., not significant.

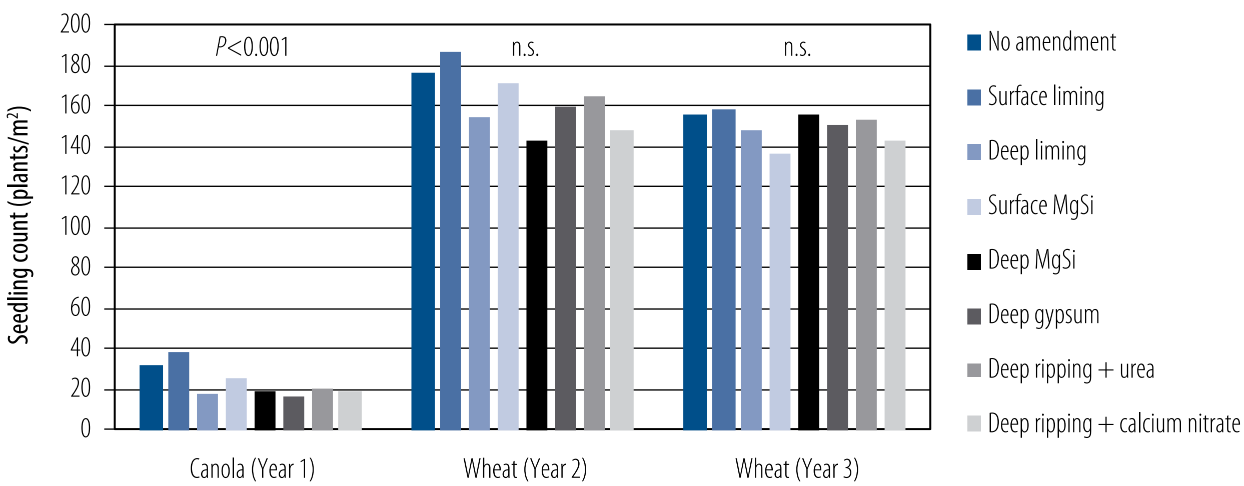

Figure 4. Seedling density (plants/m^2) at crop establishment in response to different soil amendments in years 1–3 at the Holbrook site. n.s., not significant.

Nutrition & soil

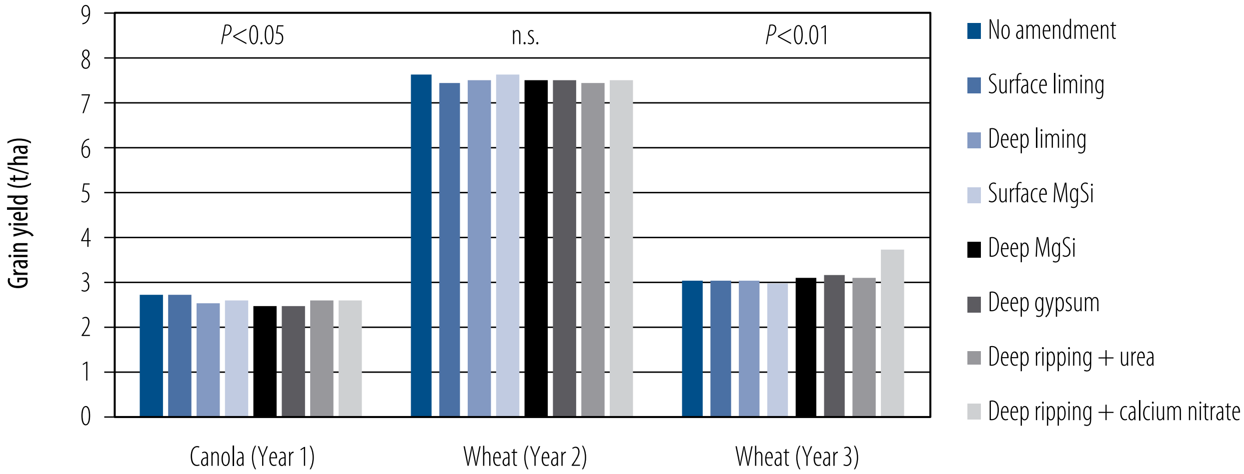

Figure 5. Grain yield (t/ha) in response to different soil amendments in years 1–3 at the Holbrook site. n.s., not significant.

Conclusion

The deep ripping operation had an adverse effect on canola establishment and crop yield in the first year, but no yield penalty was observed in the wheat crops in years 2 and 3. Deep placement of lime and MgSi increased soil pH and decreased exchangeable Al% significantly at 20–30 cm compared with the no amendment treatment. Deep placement of gypsum had no effect on soil acidity and did not improve grain yield at the current site.

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Acknowledgements

The project 'Innovative approaches to managing subsoil acidity in the southern grain region', DAN00206, 2015–20, is a joint investment by NSW DPI and GRDC. MgSi product was sourced from PW English & Associates P/L at Armidale NSW.

Richard Lowrie, Adam Lowrie, Graeme Poile, Albert Oates, Binbin Xu, Andrew Price and Yan Jia (NSW DPI, Wagga Wagga), Alek Zander, Matt Dunn and Kerry Schirmer (Charles Sturt University) provided quality technical support.

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

Screening faba bean for tolerance to low pH

Dr Mark Norton, Peter Tyndall, Andrew Price and Richard Lowrie (NSW DPI, Wagga Wagga)

Key findings

- The critical pH_{Ca} threshold is in the range of 5.2 to 5.4, below which faba bean growth is reduced.
- Variability for tolerance to low pH is present within the species with cultivar (cv) PBA Zahra⦶ more tolerant at low pH than cultivars (cvv) PBA Samira⦶, Farah⦶ or PBA Nasma⦶.
- The sensitivity of uninoculated faba bean plants to low pH suggests it may not be sufficient to overcome the poor performance of faba bean on acid soils simply by developing more acid-tolerant rhizobium. Further research is warranted to address this question.

Introduction

Faba bean (*Vicia fabae* L.) is a popular pulse crop in the high rainfall zone (HRZ) of south-eastern Australia because of all the pulse species adapted to temperate climates, it has good waterlogging tolerance and high grain yield potential. Waterlogging is a commonly encountered abiotic constraint to growth in the HRZ and it is important that adapted crop species exhibit some tolerance. In addition, the HRZ has a long growing season and crops need to be flexible enough to use these conditions to maximise yield for growers. Acid soils, however, are widespread across this zone and faba bean appears to have little tolerance to this constraint (Matthews & Marcellos 2003).

Soil acidity presents several problems for crops, including toxicities caused by low pH (H^+), aluminium (Al) and manganese (Mn). Research in developing faba bean rhizobia with enhanced tolerance to acid soils is currently underway. Information about the level of tolerance of this species to low pH is scant, with no indication of whether within-species variability exists. This preliminary screening had two objectives:

1. ascertain the presence of any pH threshold below which the tolerance of the species declined
2. study the response of several faba bean cvv to a range of pH to determine whether there were any genetic differences in tolerance to low pH.

Materials and methods

Screening conditions and germplasm

A solution culture experiment was conducted in a temperature controlled growth chamber for 14 days. The temperature was set at 23 °C and light was artificially provided above the plants at an average photosynthetic photon flux density of 340 ± 70 µmol/m^2 per second on a 14/10 hour day/night cycle. The concentration of nutrients in the basal nutrient solution in micro moles (µM) was: 500 calcium (Ca); 2000 nitrogen (N) (300 NH_4, 1700 NO_3); 500 potassium (K); 201 sulphate (SO_4); 200 magnesium (Mg); 50 phosphate (PO_4); 23 boron (B); 10 iron (Fe); 9 Mn; 0.8 zinc (Zn); 0.3 copper (Cu); and 0.1 molybdenum (Mo).

The test solutions' pH were set at 4.5, 4.8, 5.1, 5.4 and 5.7 over the course of the experiment and adjusted daily using 1 M hydrochloric acid (HCl) or 1 M sodium hydroxide (NaOH). Deionised water was added to the containers when necessary to account for evaporation and transpiration losses.

The four cvv of faba bean evaluated were PBA Samira⦶, PBA Zahra⦶, Farah⦶ and Nasma⦶. Seeds were not inoculated with any rhizobium and were germinated on filter paper in dishes containing deionised water. Each seedling was transferred to its individual cell set in a plastic tray, which was suspended on the surface of the tub containing the nutrient solution held at the relevant test pH. All seedlings were transferred on the same date and occurred when radicles were long enough to reach the solution. Each tub contained 21 L, which was under continual aeration and agitation. All seedlings were harvested after 14 days of growth in the nutrient solution.

The experiment was a split plot design with pH levels as the main plots and genotypes as subplots with two replicates. Within each tub (main plot), 10 adjacent seedlings of each genotype were grown in individual cells within a tray, representing the subplot in this experiment design. At harvest, seedlings were removed from their cells and individual shoot lengths measured before all plants were separated into roots and shoots. Individual roots and shoots from each subplot were bulked, dried at 70 °C for 48 hours and weighed.

Results and discussion

Cultivar PBA Zahra$^{\Phi}$ had greater shoot weight (Figure 1a) than the three other test cvv at pH 4.8 and although not significant, it was tending to have greater weight at pH 4.5. PBA Zahra$^{\Phi}$ also had greater shoot length (Figure 1c) than the three other cvv at pH 4.5 and 4.8. PBA Zahra$^{\Phi}$ was also tending to have greater root weight (Figure 1b) than the other cultivars at the lower pH levels 4.5 and 4.8 although not significant. It appears that there is genetic variability for tolerance to low pH within faba bean and that the attempt to develop an acid tolerant cultivar could be achievable.

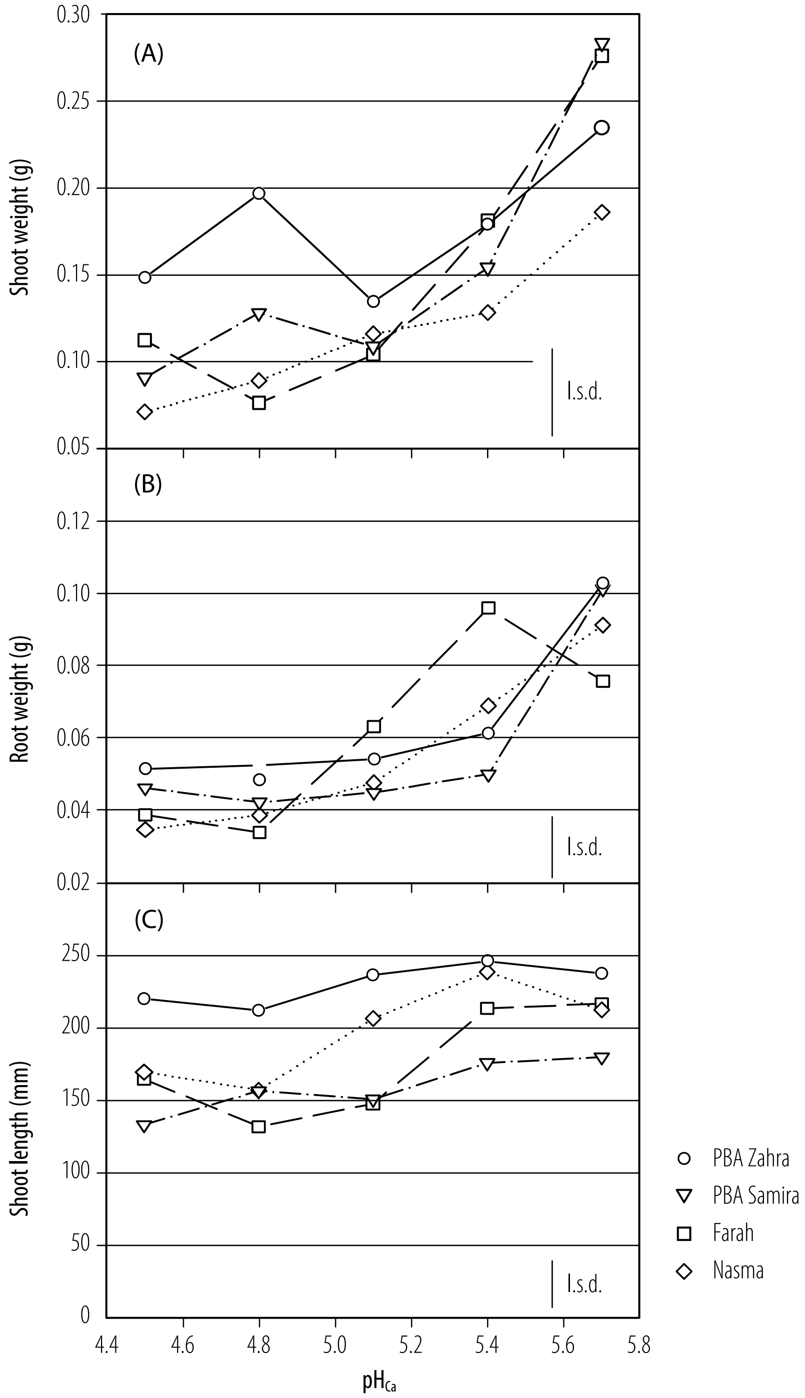

Figure 1. The effects of pH on (A) shoot weight, (B) root weight and (C) shoot length of the faba bean cultivars PBA Zahra$^{\Phi}$, PBA Samira$^{\Phi}$, Farah$^{\Phi}$ and Nasma$^{\Phi}$.

These results also confirm the general observation made by Matthews and Marcellos (2003) that faba bean performs poorly once soil pH_{Ca} levels fall below 5.2, which makes it one of the more acid-sensitive crops grown by farmers in southern Australia.

Conclusions and future research requirements

- Faba bean itself is sensitive to low pH and there appears to be scope to improve low pH tolerance within the species. Therefore, it may not be sufficient to overcome the poor performance of faba bean on acid soils simply by developing more acid tolerant rhizobium. Further research is required to explore this question.
- Further research needs to address the effects of Al and Mn toxicity on faba bean as these are associated constraints on many acidic soils.
- Appropriate lime management to ameliorate soil acidity must not be neglected as acidification processes are on-going in agricultural production systems. Genetic improvement either of the plant or the rhizobia is not a 'magic bullet' and can only ever partially address constraints to produce acid-sensitive pulses on acidic soils.

Reference

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Acknowledgements

This experiment was part of the GRDC project 'N fixing break crops and pastures on high rainfall zone acid soils', DAN00191, July 2014–June 2018. We are grateful to Helen Burns for her advice and encouragement and wish to acknowledge our collaborators, CSIRO Agriculture and Food, Mackillop Farm Management Group, Holbrook Landcare Network and Roberts Ltd.

Crop protection

Assessing the effects of natural enemies on insect pests in canola

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

Key findings

- Natural enemies (predators and parasitoids) found within the crop were diverse, but had variable distribution.
- The abundance of natural enemies increased with time, which was probably related to an increase in pest pressure as well as temperature.
- Growers might be able to use more targeted sprays to control pests.
- Seed treatments appeared to have no long-term effects on natural enemy abundance.

Background

Grain crops are home to a diversity of invertebrate pest species, but each year only a few species will reach high enough densities to cause significant damage and yield loss. The diversity of beneficial species, such as predators, parasitic wasps and flies, in certain contexts can suppress pest population growth thus stopping pest outbreaks. We are currently limited in our ability to predict when and where pest outbreaks will occur. This is partly due to a lack of fundamental ecological knowledge around where pest and beneficial species are found and the factors that facilitate pest outbreaks. This means that growers depend upon reactive chemical control with limited scope for alternatives such as cultural or biological control options.

The aims of these experiments were to determine:

- the potential effect of natural enemies on insect pests
- any long-term effects from insecticide seed treatments on natural enemies
- any differences in natural enemies and pest distribution.

Methodology

Site

All experiments and sampling were conducted in a 1 ha plot in the north-western corner of a canola (var. ATR Stingray(b)) paddock, sown on 4 May 2017, located at the Wagga Wagga Agricultural Institute. The experiment area was divided into two plots: half sown with fungicide-treated seed (Jockey®) and the rest, as well as the remainder of the paddock, sown with insecticide- (Gaucho®) and fungicide-treated seed. Apart from the seed treatment, no other insecticides were used on the canola crop.

Cage experiments

To assess the effect of natural enemies on pests, two types of cage experiments were conducted. In all experiments the target organism used was the green peach aphid (GPA).

In July, paired open and closed clip cages (Figure 1) were placed on canola plants either close to the edge (N = 5) or towards the centre (N = 10) of the untreated and treated plots. Each clip cage contained 20 GPA on a canola leaf and was left for 48 hours. Results were analysed as the percentage of live aphids in the open cage compared with those in the closed cage (control). A camera was set up at one of the open clip cages, recording photos at one minute intervals.

Figure 1. Paired open and closed clip cages with green peach aphid on a canola plant, July 2017.

In September, six replicates of five exclusion cages were erected around single canola plants distributed within the central section of the treated seed plot (Figure 2). The extra cage was to ensure there was a full set of four cages with good aphid colonies, but unfortunately this meant there were not enough cages to do comparison experiments within the untreated seed plot. Any invertebrates found on or near the plant were removed during the set up. The canola was at the flowering/podding stage, but was relatively sparse due to the dry conditions. Each plant was first inoculated with 50 GPA on the top leaves and left enclosed for one week to ensure the aphids had colonised the plants. At day 0 of the experiment, aphid numbers were counted and excess aphids removed to ensure a start of approximately 50 GPA. Buds, flowers and lower leaves were removed to allow for an easier and more accurate aphid count, and the following treatments were applied:

- For reared predators (CR), five green lacewing larvae at the 2nd instar stage were added and the cage closed.
- For local predators (CP), the surrounding area was sampled using a sweep net to identify local predatory species. Although predators appeared scarce, adult brown lacewing were the most common. Therefore, two of these, plus two commercially-reared spotted ladybeetles (*Harmonia octomaculata*) were added and the cage closed.
- For the open control (OC), the net on the cage was removed to determine the effect of natural local predators and the environment.
- For the closed control (CC), the cage was left closed to determine aphid growth without predation.

Live aphids were counted and recorded, along with any predators or aphid mummies, on days 0, 2, 4, 7 and 15, starting on 26 September 2017. As this was part of a project to look at the regional diversity of natural enemies across southern Australia, these cage experiments were also conducted in WA, SA and Victoria. Consequently, all protocols had to be the same in each state.

Figure 2. Set of exclusion cages in a canola paddock, after applying 50 green peach aphids in September 2017.

Paddock sampling

To determine the abundance and diversity of natural enemies and pests, the paddock was sampled during July, September and October using pitfall traps. Nine traps (45 mm diameter, 120 mL volume, containing 50 mL propylene glycol) were placed towards the centre of each of the untreated and treated seed plots and five were placed along the edges. These were left open for one week before collection.

Analysis

Data were 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

Seed treatment

No significant differences were found between treated and untreated seed plots. This was true for the clip cage experiment as well as abundance and diversity within all three pitfall trap samples including June, which occurred only seven weeks after sowing. Consequently, data from these two plots were pooled for further analyses.

Cage experiments

Within the clip cages, the total numbers of aphids found were significantly less in the open cages compared with the closed cages ($P = 0.001$, F = 11.74, DF = 1). While it cannot be confirmed that all the aphids had been eaten, a photo of a predatory mite on an open cage provides some evidence that there might have been some predation. While the percentage of live aphids found within the open clip cages was greater in those located at the centre of the paddock (20.5±7.5%) than those at the edge (13.3±6.9%), the difference was not significant ($P = 0.55$, F = 0.36, DF = 1).

In the exclusion cage experiment, the mean number of aphids displayed a similar pattern in most of the cages, though there was a large degree of variation among the cages. This resulted in no significant effect from the treatments (*P* = 0.15, F = 1.83, DF = 3; Figure 3). However, there was a significant effect of time (*P*<0.001, F = 11.14, DF = 4). Aphid numbers were suppressed for the seven days in all treatments apart from OC, but on day 15 numbers had significantly increased (*P*<0.05; Tukey). For the OC cages, numbers generally steadily increased over the entire 15 days. It was noticeable during the experiment that the timing coincided with a large influx of cabbage aphids in the paddock. Several parasitised aphid mummies were found in the OC, but as these can take 2–4 weeks to develop, the controlling influence of parasitoid wasps could not be measured. This could be investigated in later experiments.

Of the other state experiments, only WA had significant suppression in both OC and CR cages, while results in Victoria and SA were very similar to NSW. This probably indicates that stressed plants, due to lack of moisture and warmer temperatures in south-eastern Australia, were major factors for this lack of significant results.

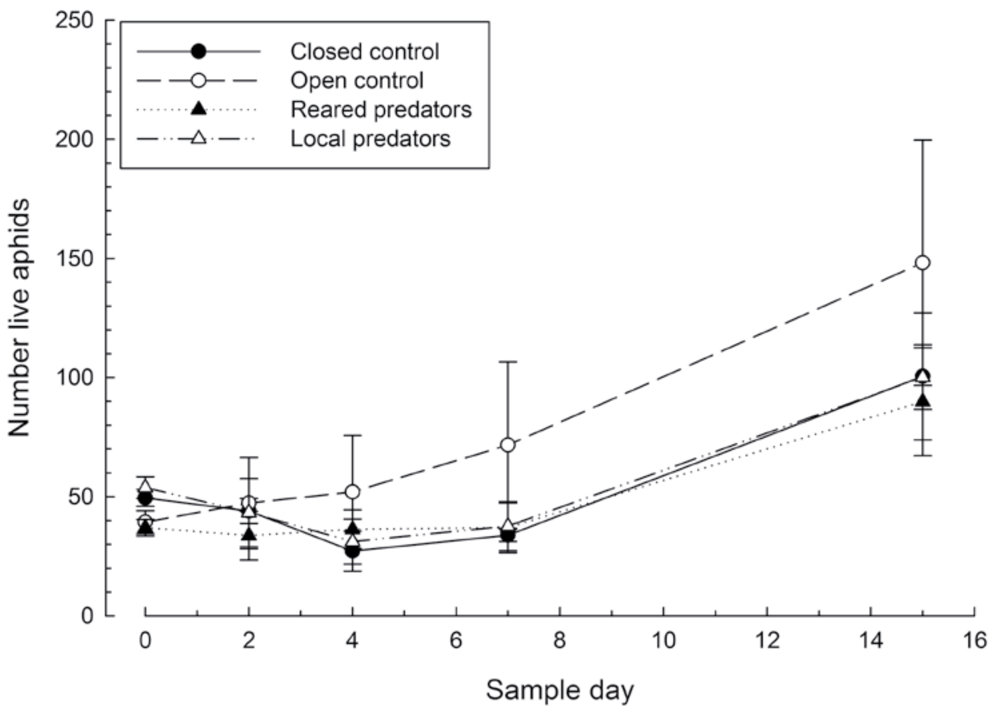
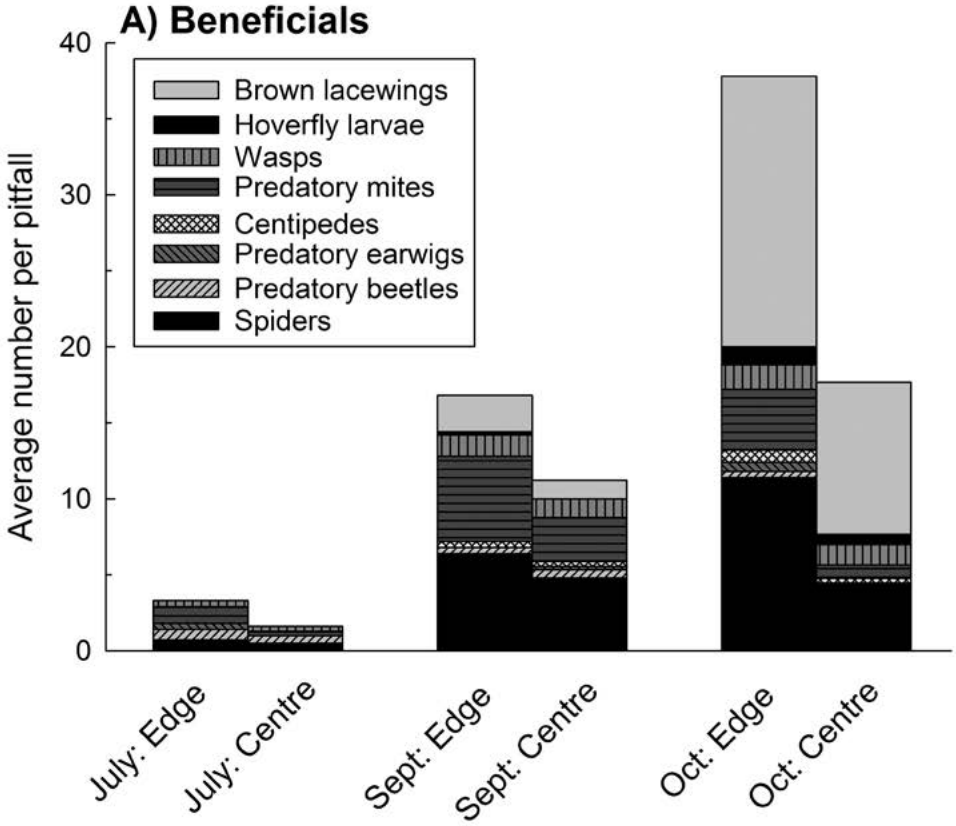


Figure 3. Changes in the mean (±SE) number of live aphids on canola plants over time during a large exclusion cage experiment.

Paddock sampling

As would be expected with rising temperatures, the abundance of both natural enemies and pests significantly increased with time (natural enemies: *P*<0.001, F = 40.99, DF = 2; pests: *P*<0.001, F = 47.96, DF = 2; Figure 4). Pests comprised between 33.60–90.88% of the invertebrates sampled during the different periods, while natural enemies ranged from 1.68–28.00%. The composition of invertebrates also changed. For pests, lucerne flea was predominant in July, while aphids were the primary pest in September and October. This resulted in a corresponding change in natural enemies. In July low numbers of ground-dwelling invertebrates such as spiders, predatory mites and beetles, plus a few wasps were found. By September, the numbers of spiders and mites, which probably contributed to suppressing the lucerne flea population, had increased, while brown lacewings and hoverfly larvae, whose diet is primarily aphids, were also present. In October, brown lacewings comprised approximately half of the natural enemies trapped.



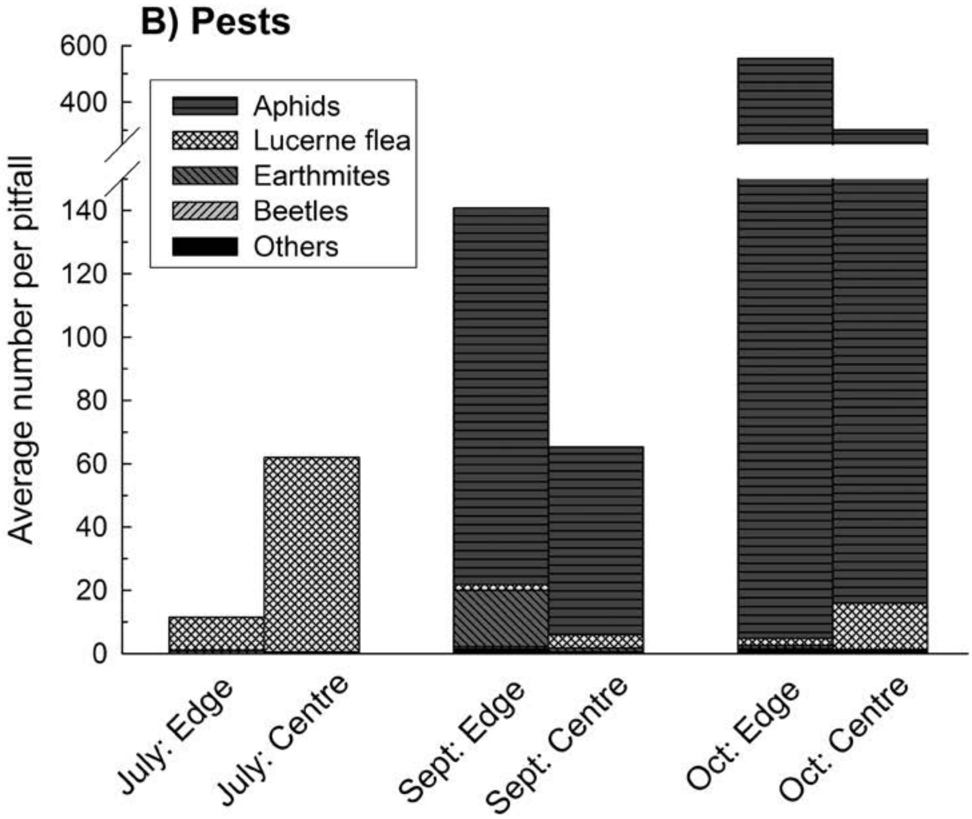


Figure 4. Comparison of diversity and abundances of natural enemies and pest invertebrates captured in pitfalls located either at the edge or centre of a canola paddock throughout 2017.

Distribution in the paddock was also influenced by location (Figure 4). Significantly more natural enemies were found along the edge, compared with the centre of the paddock in both July (P = 0.002, F = 12.38, DF = 1) and October (P = 0.011, F = 9.17, DF = 1). While a similar pattern was also found in September, this was not significant (P = 0.059, F = 4.34, DF = 1). Pests also had significantly higher abundance along the edge during September (P<0.001, F = 30.51, DF = 1) and October (P = 0.044, F = 5.04, DF = 1), corresponding with aphid flights arriving in the paddock from other fields. In July, however, pests were primarily found in the centre of the paddock (P<0.001, F = 16.76, DF = 1), probably due to lucerne flea hatchings from the previous season.

Summary

The abundance and composition of natural enemies responded to the abundance and composition of pests present, and both cage experiments indicated signs of predation and parasitism. However, these natural enemies appeared unable to control large infestations, as seen with the large influx of aphids late in the season. Unfortunately, as yield was not measured in this experiment, it is not known whether these aphids caused any economic damage in this moisture-stressed crop.

The effect of location preference for pests can influence pest-management decisions. For flying dispersal species such as aphids, a border spray might be sufficient to control them. Combined with a selective rather than a broad spectrum spray, this could increase the numbers of natural enemies present in the field throughout the season and possibly the next one as well.

Seed treatments appear to have no lasting effects on natural enemies and can be seen as a 'softer' option in pest control during crop establishment. However, continued prophylactic use can lead to other issues, such as resistance or effects on soil fauna not studied here.

Acknowledgements

This experiment was part of the project 'New knowledge to improve the timing of pest management decisions in grain crops', CSE00059, 1 March 2015–30 June 2020. This project is a collaboration between CSIRO, cesar, SARDI and WA DPIRD.

Germination biology of button grass (*Dactyloctenium radulans*) (R.Br.) P.Beauv.: An emerging summer grass weed in cotton farming systems

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

Key findings

- The random survey found that button grass infests approximately 45% of cotton fields.
- The species shows a high level of physical seed dormancy.
- Seedlings of this species can survive a moderate level of water stress.
- Southern populations of this species are sensitive to saline conditions.

Introduction

Weeds are detrimental to any crop production system and heavy infestations can lead to a significant yield reduction. Button grass (*Dactyloctenium radulans*) (R.Br.) P.Beauv is a native, widely spread summer grass weed species found in many crops in Australia. Due to its early emergence and vigour, it can outcompete many crops. It is also found in non-cropped areas and tolerates a wide range of climates and habitats. *D. radulans* is difficult to control, and has a dormancy period (DPIRD 2017). Despite the ecological significance of *D. radulans* in Australian cropping systems, very limited information is available on its germination and emergence. The objectives of this study were to assess the current level of infestations of *D. radulans* both in dryland and irrigated cotton farming systems and also to investigate the germination biology for future phenology/biology studies of this species.

Methodology

Survey locations

In the 2017–18 cotton seasons, a survey was conducted in cotton fields located in the Darling Downs, the McIntyre region (southern Queensland), Macquarie (central), Murrumbidgee, and Lachlan River (northern NSW) areas. A total of 43 commercial cotton fields were visited. The *D. radulans* infestations at each field were evaluated based on an ecological scale. Only mature *D. radulans* seeds were collected. A representative population from a farm located at Darlington Point (under southern cotton region) was collected in early February 2018 and used for this study.

Dormancy test

The germination and dormancy of non-scarified seeds was examined at laboratory conditions (12 hours light/dark cycle at 28/22 °C for 12 days) within five days of seed collection. *D. radulans* is known to have dormant seeds and therefore 100% germination was not expected. Hence, the proportion of germinated seeds was incorporated as a parameter into the event–time analysis model. After 12 days, non-germinated seeds were incubated with a tetrazolium chloride solution to evaluate seed dormancy.

Optimising seed scarification techniques

Different scarification techniques, including potassium nitrate (KNO_3), gibberellic acid, absolute ethanol, sulfuric acid (H_2SO_4; concentration 98%), and hot and cold water were used to test breaking dormancy. A series of different concentrations and durations of these scarification methods was applied.

Germination biology of *D. radulans*

The *D. radulans* germination biology was examined through controlled environment experiments, where different environmental factors, including salinity using sodium chloride (mM), osmotic potential or water stress using polyethylene glycol (PGE 600) and durations of waterlogging conditions were imposed on seeds to observe the *D. radulans* adaptive and persistent ability. The incubated seeds were observed at 12 hours light/dark cycle at 28/22 °C for 12 days. A simple linear regression and a non-linear log-logistic dose response model (Seefeldt et al. 1995) were applied where it was appropriate.

Results and discussion

In the northern regions such as the Darling Downs, Dalby, Pittsworth, Goondiwindi, St George, 47% of cotton farms had a *D. radulans* infestation (Table 1). In the southern valleys a total of 42% of cotton fields had a *D. radulans* infestation. The *D. radulans* incidence was often found to be very high in the northern regions such as Pittsworth, Jondaryan, St George and Goondiwindi compared with the southern regions (Figure 1).

Table 1. Number of cotton farms visited and the levels of *D. radulans* infestations.

Location		Total farms surveyed	Farm infested (%)
Southern region	Griffith, Darlington Point, Coleambally, Carrathool, Hay, Hillston	12	42
Northern region	Dalby, Pittsworth, Jondaryan, Nandi, Boggabilla, Mungindi, St George, Goondiwindi	31	47

The time–event analysis model indicated that only 6% of seeds were germinated by 14 days without any seed scarification. The tetrazolium chloride confirmed that 90% of non-germinated seeds were viable (data not shown), which indicates that the species has a high level of seed dormancy.

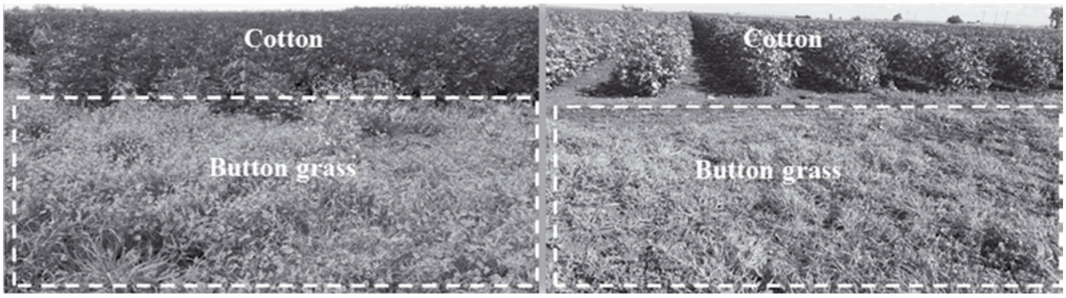


Figure 1. Photos depicting the pressures of *D. radulans* at two different cotton fields located in the northern cotton region.

Among the scarification techniques, chemical scarification with H_2SO_4 broke more seed dormancy and stimulated germination most effectively, followed by seeds treated with KNO_3 (2M>1M), absolute ethanol (100%) and others. The fitted model suggests 4–5 minutes of scarification with H_2SO_4 is required to achieve maximum (90%) germination, indicating that the species has physical dormancy (Figure 2). Therefore, in the subsequent experiments, seeds were scarified with H_2SO_4 for four minutes.

A sigmoid response was observed in the *D. radulans* seed germination for salt concentrations. Germination was greater than 50% in a sodium chloride (NaCl) concentration of 12.5 mM (Figure 3). The model suggests that more than 50% seed germination was reduced by 25 mM NaCl to a maximum inhibition at 100 mM NaCl. This study revealed that *D. radulans* seeds from the southern region can germinate in low saline conditions, but are sensitive to medium to high saline conditions.

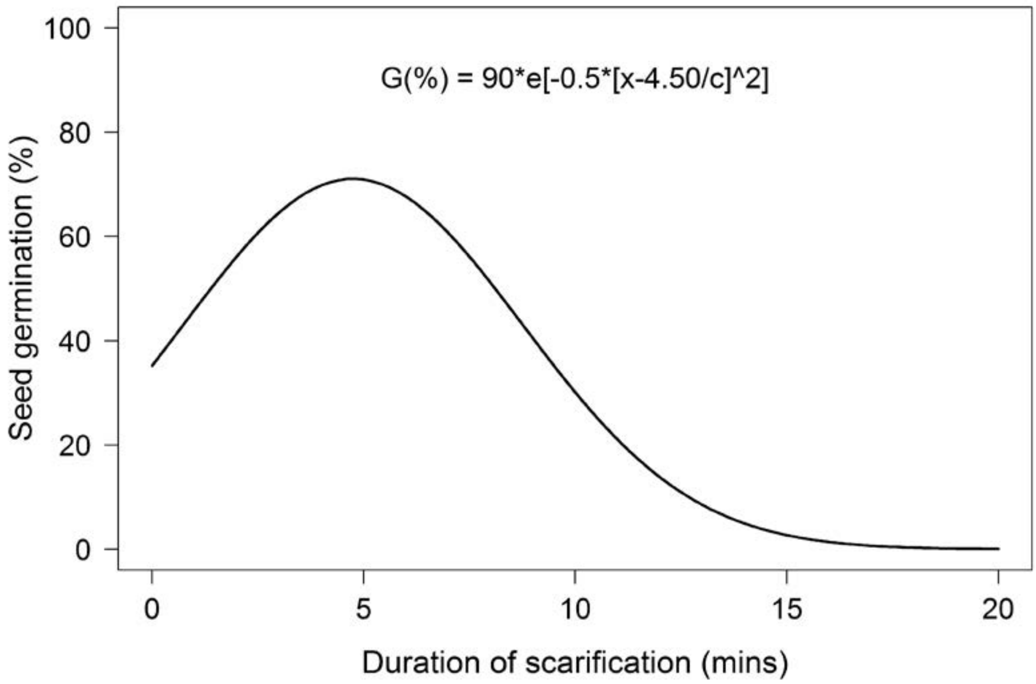


Figure 2. Effect of scarification time with sulfuric acid (H_2SO_4) on *D. radulans* seed germination after 12 days of incubation at 28/22 °C alternating day/night temperature. The solid line represents a three-parameter Gaussian model fitted to the data.

The *D. radulans* seed germination and growth decreased with increased water stress (Figure 4). For the irrigation water with osmotic potential –0.01, –0.2, –0.4 and –0.6 megapascals (MPa), the seed germination rate was 24%, 21%, 14% and 6% respectively. It is assumed that seeds can germinate under moderate to high stress water conditions, which can occur temporarily between rainfall or irrigation events at the start of the cotton season in the southern region.

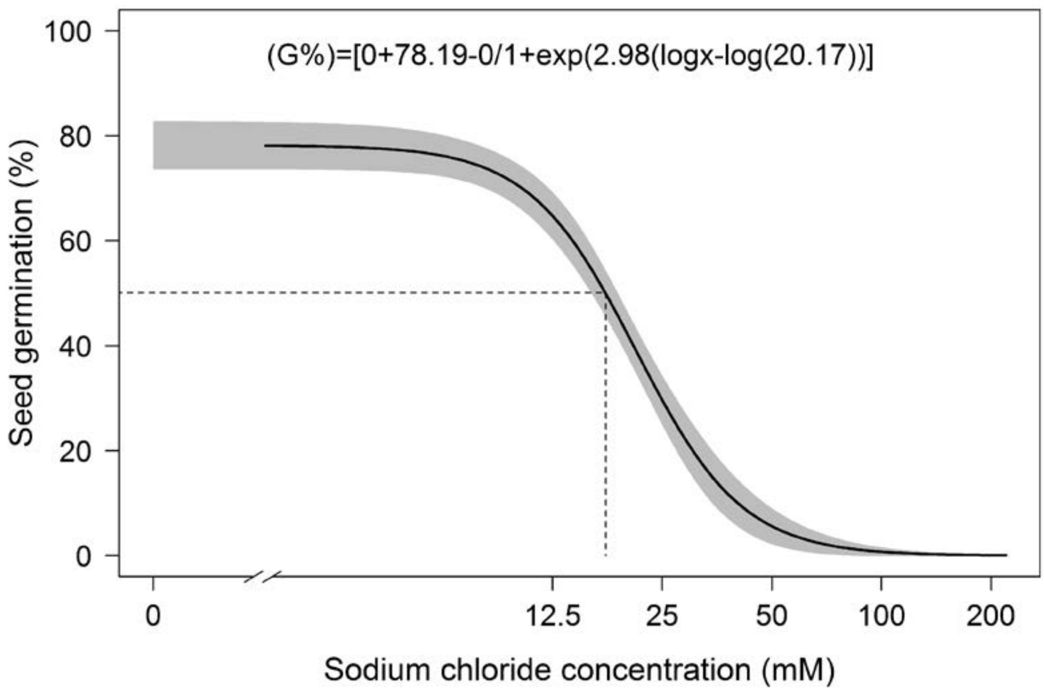


Figure 3. Effect of sodium chloride concentration on germination of scarified seeds of *D. radulans* after 12 days of incubation in light/dark at 28/22 °C alternating day/night temperature. The solid line represents a three parameter non-linear log-logistic model fitted to the data with a confidence span.

Seed germination was not significantly affected from being submerged for up to 2 days (>50% germinated) (Figure 5). However, the germination rate declined significantly (75%) after five days of being submerged – the lowest emergence rate in this experiment. This lower seed emergence might be due to lower oxygen and carbon dioxide accumulation or toxic gases produced from anaerobic decomposition. The effect from the longer submergence might also be osmotic stress on small seeds preventing germination.

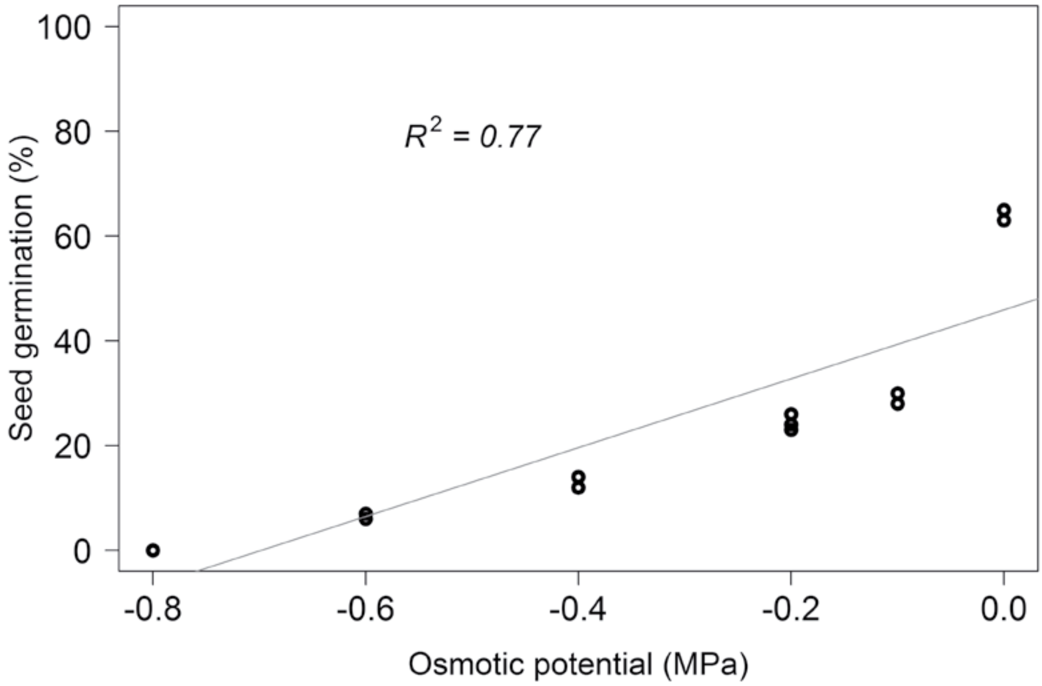


Figure 4. Effect of osmotic potential on *D. radulans* scarified seed germination after 12 days of incubation in light/dark at 28/22 °C alternating day/night temperature. The solid line represents a linear model fitted to the data. The circles represent the experimental data.

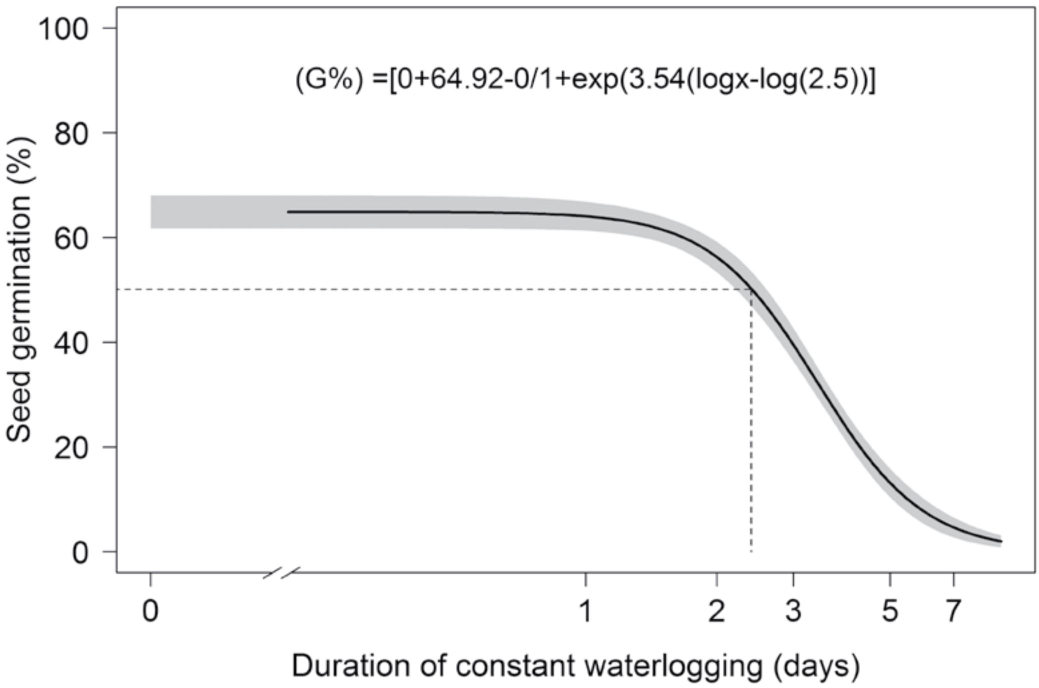


Figure 5. Effect of constant waterlogging on *D. radulans* scarified seed germination incubated in light/dark at 28/22 °C alternating day/night temperature. The solid line represents a three parameter log-logistic model fitted to the data with a confidence span.

Crop protection

Conclusion

The wide spread of *D. radulans* might be due to its dormancy mechanisms – dormancy is the capacity of seeds to remain in a suspended state in unfavourable conditions. We established that physical dormancy has a major influence on seedling emergence timing. Once dormancy is broken, environmental conditions determine the rate of germination. Populations of *D. radulans* from the southern region are moderately tolerant to water stress, but sensitive to saline conditions during germination. Germination behaviour can also differ among seeds produced in different seasons, years and locations, although additional research is required for this to be established. The study of phenology and current level of herbicide sensitivity in different populations of *D. radulans* are under way. These results will provide a benchmark for better understanding the persistence of *D. radulans* as an emerging weed in cotton farming systems and contribute to developing an effective management tool.

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Acknowledgements

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Crop competition in chickpea and faba bean against sowthistle – Wagga Wagga 2017

Dr Aaron Preston, Dr Hanwen Wu, Adam Shephard and Michael Hopwood (NSW DPI, Wagga Wagga)

Key findings

- Decreasing row spacing and increasing plant density improved chickpea and faba bean competitive abilities.
- The improved competitive abilities improved yields and reduced sowthistle biomass and seed production, which will improve weed control in subsequent crops.

Introduction

Common sowthistle (*Sonchus oleraceus*) is a common weed in winter pulses. Sowthistle is difficult to manage as it produces a high number of wind-dispersed seed (up to 68,000/m^2) which can readily germinate on the soil surface throughout the year. Controlling sowthistle in pulse crops is difficult due to limited effective herbicide options and poor crop competitiveness. It has been demonstrated that enhancing crop competitiveness through increased crop density and reduced row spacing in cereals reduces weed biomass and seed production. In this experiment, we investigated whether competitiveness can be increased in chickpea and faba bean to reduce sowthistle biomass and seed production, and how this affects crop yield.

Site details

Location	Wagga Wagga Agricultural Institute
Soil type	Brown clay
Previous crop	Wheat
Fallow rainfall	140 mm (November 2016–March 2017)
In-crop rainfall and irrigation	222 mm (April 2017–October 2017)
Starter fertiliser	Grain legume starter 150 kg/ha (Nitrogen 0: Phosphorus 13.5: Potassium 0: Sulfur 6.5)
Soil analysis	see Table 1

Treatments

Varieties	Chickpea: PBA Slasher⟑ Faba bean: PBA Samira⟑
Row spacings	23 and 46 cm
Crop densities	Chickpea: 20, 40 and 80 plants/m^2 Faba bean: 15, 30 and 60 plants/m^2 Each treatment was applied to weedy (sowthistle) and weed free plots
Sowing date (SD)	SD chickpea: 22 May SD faba bean: 25 May

Crop protection

Table 1. Soil characteristics of the 2017 experiment site at Wagga Wagga.

Characteristic	Depth	
	0–10 cm depth	10–20 cm depth
pH_{Ca}	5.3*	5.7*
Aluminium (KCl) (cmol(+)/kg	0.4	0.4
Nitrate NO_3 (mg/kg)	43.0	13.0
Ammonium N (KCl) (mg/kg)	5.0	2.0
Sulfur (mg/kg)	6.0	7.0
Phosphorus (Colwell) (mg/kg)	83.0	23.0
Organic carbon (%)	1.3	0.6

* pH following amelioration with lime at 3 t/ha

Results

Chickpea

Narrow row spacing (23 cm) reduced sowthistle biomass/m^2 and seed production/m^2 by 55% and 12% respectively when compared with the wider row (46 cm) treatment (figures 1 and 2). However, sowthistle plant height and seed heads/plant did not significantly differ between narrow or wide rows. Increasing crop density reduced sowthistle plant height, biomass, seed heads/plant, seeds/plant and seeds/m^2 at both row spacing treatments.

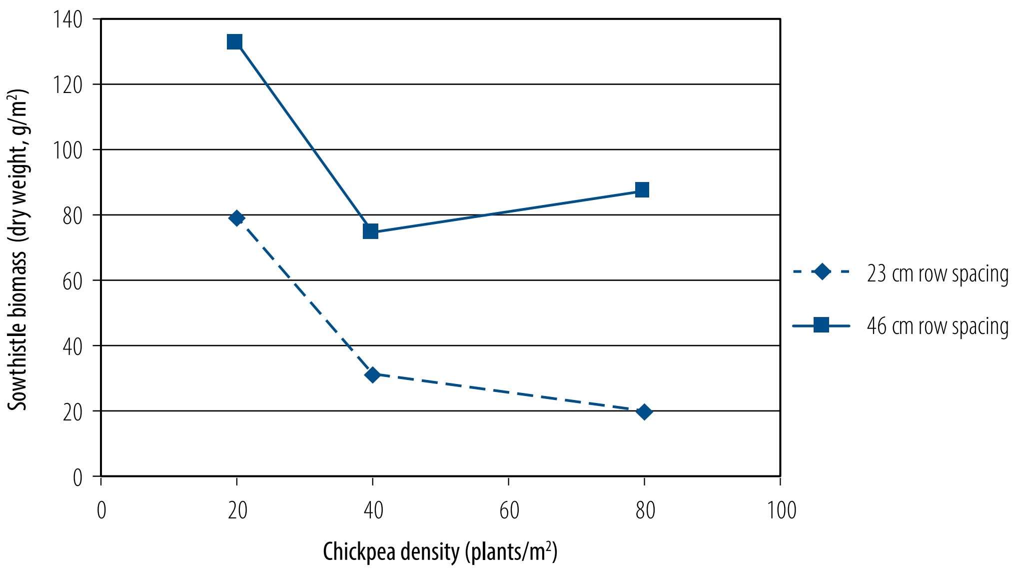

Figure 1. Reduced sowthistle biomass with increased chickpea density at 23 cm and 46 cm row spacing.

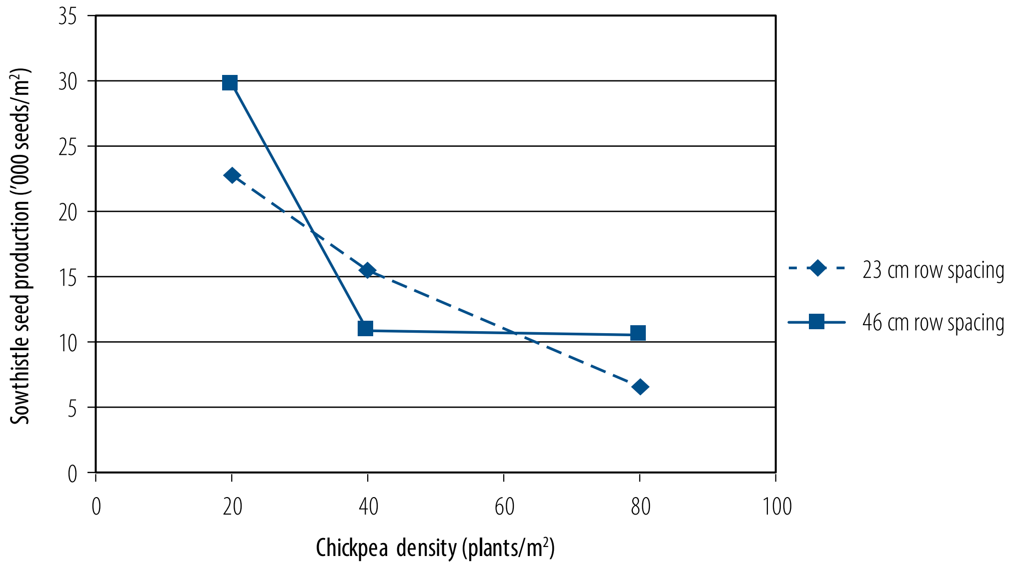

Figure 2. Reduced sowthistle seed production with increased chickpea density at 23 cm and 46 cm row spacing.

Greater harvest yields were attained with narrow row spacing. High chickpea densities resulted in a 44% higher harvest yield than wide row spacing. Plant density had a lesser effect on the yield at the wider row spacing (Figure 3).

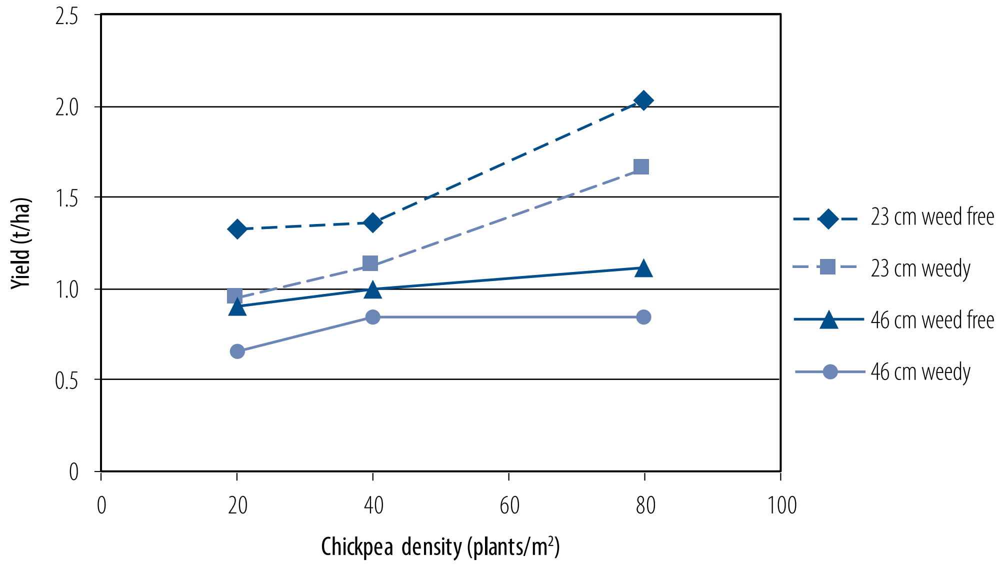

Figure 3. Yield response of chickpea with increasing density across wide and narrow row spacing in weedy (sowthistle) and weed free plots.

Faba bean

As with chickpea, increasing the plant density reduced sowthistle biomass and seed production. Sowthistle biomass/m^2 and seed produced/m^2 were reduced by 16% and 26% respectively using narrow row spacing when compared with wide row spacing (figures 4 and 5). Higher faba bean populations reduced weed plant height and biomass in both row spacing treatments. Additionally, the highest crop density tested (60 plants/m^2) significantly reduced sowthistle seed heads/plant, seeds/plant and seeds/m^2 compared with the lowest density (15 plants/m^2).

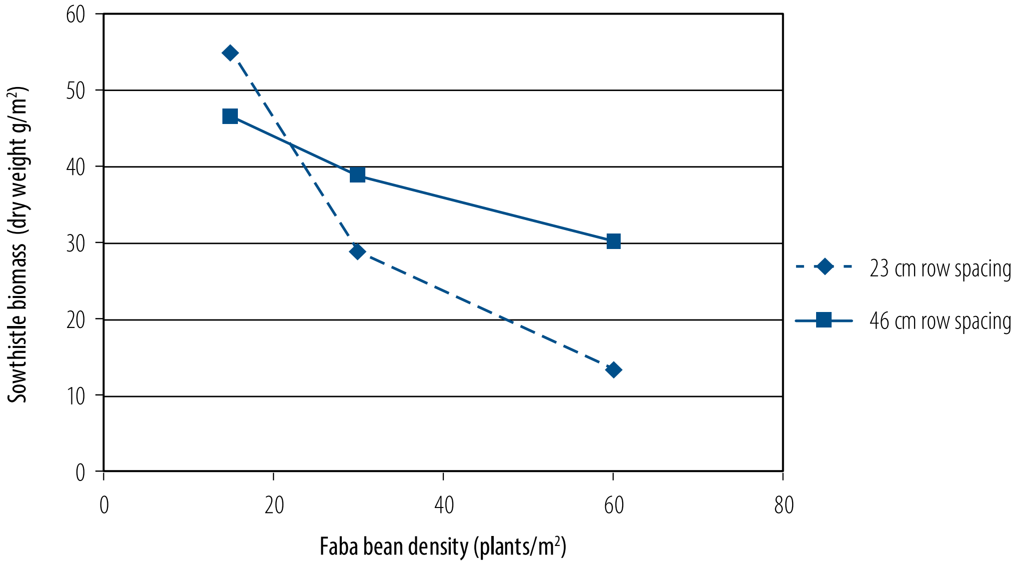

Figure 4. Reduced sowthistle biomass with increased faba bean density at 23 cm and 46 cm row spacing.

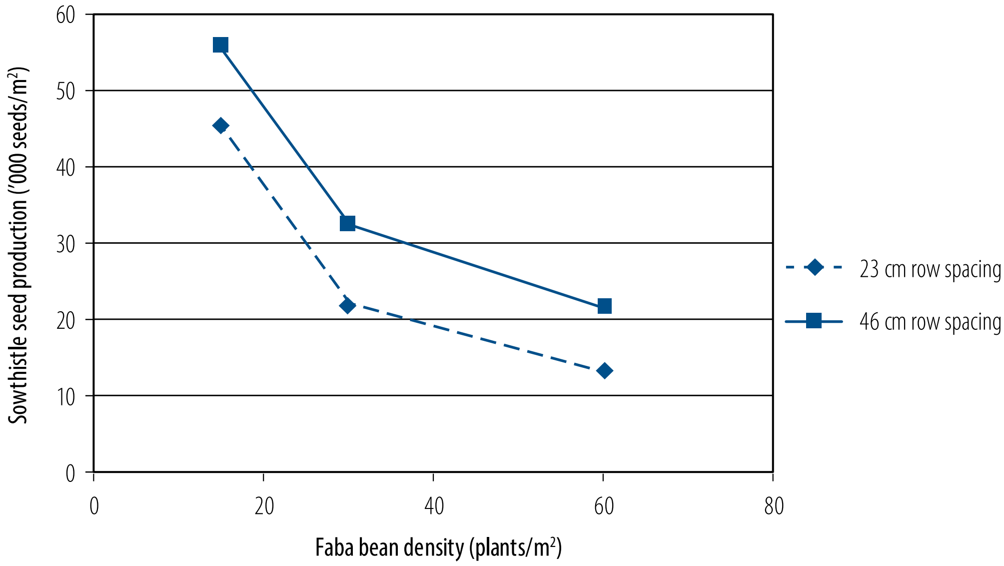

Figure 5. Reduced sowthistle seed production with increased faba bean density at 23 cm and 46 cm row spacing.

Higher faba bean yields were produced with narrow row spacing. The greatest differences were at higher plant densities (36% higher yield at 60 plants/m^2). Conversely, plant density did not significantly affect yield in the wider row spacing (Figure 6).

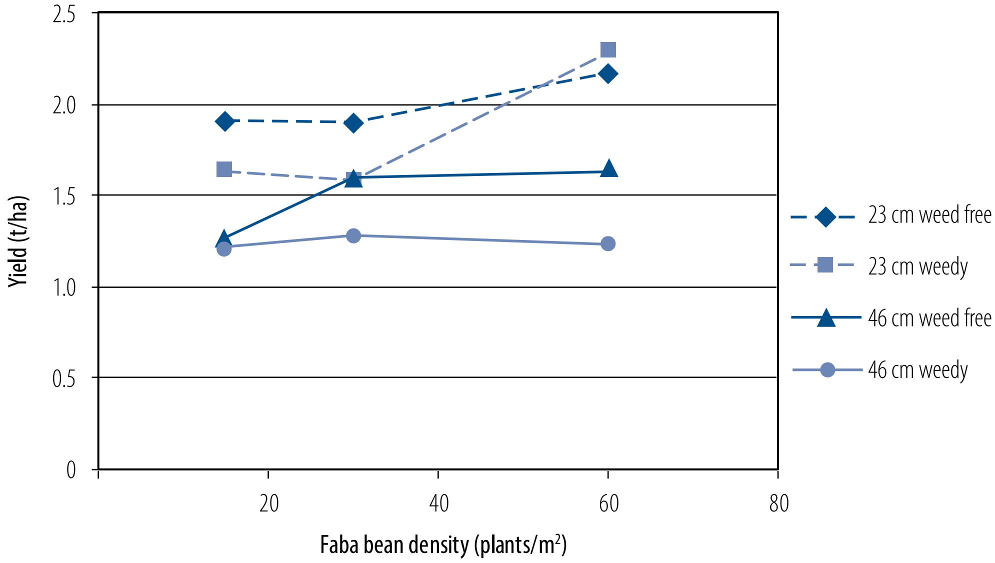

Figure 6. Yield response of faba bean with increasing density across wide and narrow row spacing in weedy (sowthistle) and weed free plots.

Conclusion

- Crop competition in chickpea and faba bean can be improved by increasing plant density and using narrow row spacing.
- In both faba bean and chickpea experiments, increasing crop populations resulted in fewer weed seeds/head. However, there were no differences in seed number/head between the wide- and narrow-row treatments in both experiments.
- Higher faba bean and chickpea populations resulted in lower sowthistle height, biomass, seed heads/plant, seeds/plant and seeds/m^2. Narrow-row spacing in both crops also significantly reduced sowthistle biomass and seeds/m^2.

Acknowledgements

This experiment was part of the project 'Innovative crop weed control for northern region cropping systems', US00084, 2016–21, with joint investment by GRDC and NSW DPI.

Irrigation & climate

Lodging in rice

Brian Dunn and Tina Dunn (NSW DPI, Yanco)

Key findings

- Lodging is becoming a significant problem in rice as growers push for maximum grain yields, but some varieties are more prone to lodging than others.
- Management practices such as drill sowing, reduced sowing rate, reduced pre-permanent water nitrogen rate and draining on time reduce the potential for lodging.

Introduction

As growers push for maximum grain yield, lodging is becoming a significant factor in rice production, increasing the time and cost of harvest and often resulting in significant yield loss and reduced grain quality.

Several factors influence lodging susceptibility including seasonal weather, variety, sowing method, nitrogen rate and timing, plant density, water depth, time of draining and wind or rain as the crop nears maturity. Some of these factors can be managed, thus providing the opportunity to reduce crop lodging potential.

Factors that influence lodging susceptibility

Variety

Rice varieties vary considerably in their physical plant structural characteristics, which directly influence their lodging potential. Plant characteristics such as plant height, stem strength, sturdiness of the lower part of the plant and potential grain yield influence their ability to stand up at maturity, even with high grain yields.

Data collected on rice varieties in the 2015–16 and 2016–17 seasons show that varieties that are more prone to lodging are generally taller and have thinner stems as shown by decreased stem weight per centimetre (Table 1). Varieties such as Doongara, Topaz$^{\phi}$ and Reiziq$^{\phi}$ are relatively tolerant to lodging while Koshihikari and YRK 5 are highly susceptible (Table 1).

Sowing method

Aerial-sown crops are more prone to lodging than drill-sown crops, with delayed permanent water the most tolerant to lodging. Published research has found the lodging resistance under drill sowing was due to better root anchorage in the soil, as well as resistance to stem bending and breaking.

Water management also affects lodging resistance as crops that are fully flooded from germination grow taller and have thinner stems than rice crops grown with intermittent irrigation during the establishment and tillering periods.

Varieties that are very sensitive to lodging such as Koshihikari and YRK 5, should not be aerial sown.

Table 1. Average lodging score (1 = standing, 10 = fully lodged), plant height (cm) and stem weight (g/cm), for current rice varieties collected from experiments in the 2015–16 and 2016–17 seasons.

Variety	Lodging score (1 = less lodging)	Plant height (cm)	Stem weight (g/cm)
Doongara	1.0	75	0.028
Topaz	1.0	81	0.022
Reiziq	1.1	80	0.024
Sherpa	1.2	83	0.022
Opus	2.0	81	0.022
Langi	2.1	86	0.022
Viand	2.6	85	0.019
YRK 5	5.6	93	0.018
Koshihikari	6.1	91	0.018

Plant density

Higher plant densities can lead to increased lodging. Recent research on Viand and YRK 5 varieties has shown that higher plant densities (150 kg/ha seed ~ 250 plants/m^2) tend to be more prone to lodging than lower plant densities (50 kg/ha seed ~ 100 plants/m^2).

To reduce lodging potential it is important not to use higher than recommended sowing rates, especially for the small grain varieties, which also have many more seeds per kilogram.

Table 2 shows the recommended sowing rates for rice varieties, based on seed size and average varietal establishment percentages from field experiments. The smaller seed size varieties (e.g. Opus$^{\phi}$) have many more seeds per kilogram so should be sown at a lower rate to achieve the same plant population.

Table 2. Sowing rates (kg/ha) required to meet plant population recommendations based on seed size and average varietal establishment percentages.

Variety	Sowing rate (kg/ha)
Reiziq, Illabong, Topaz	150
Sherpa, Langi, Doongara, Viand	130
Opus, Koshihikari, YRK 5	120

Nitrogen rate and timing

Nitrogen is very important in achieving high grain yields, but excessive nitrogen applied pre-permanent water (PW) increases lodging, especially for lodging-susceptible varieties.

Straw breaking strength and bending stress are both reduced due to lower stem cellulose and lignin content at higher nitrogen rates. High nitrogen rates also result in increased lodging susceptibility in rice by increasing tiller numbers, the length of lower internodes and plant height.

A nitrogen rate and timing experiment conducted on drill-sown YRK 5 at Finley in 2016–17 highlighted the effect that high rates of nitrogen applied pre-PW have on increasing lodging in susceptible rice varieties (Figure 1).

For varieties that are very susceptible to lodging (Koshihikari and YRK 5) it is important to reduce the rate of nitrogen applied pre-PW by up to 50% of the normal application for a Reiziq$^{\phi}$ crop grown in the same field.

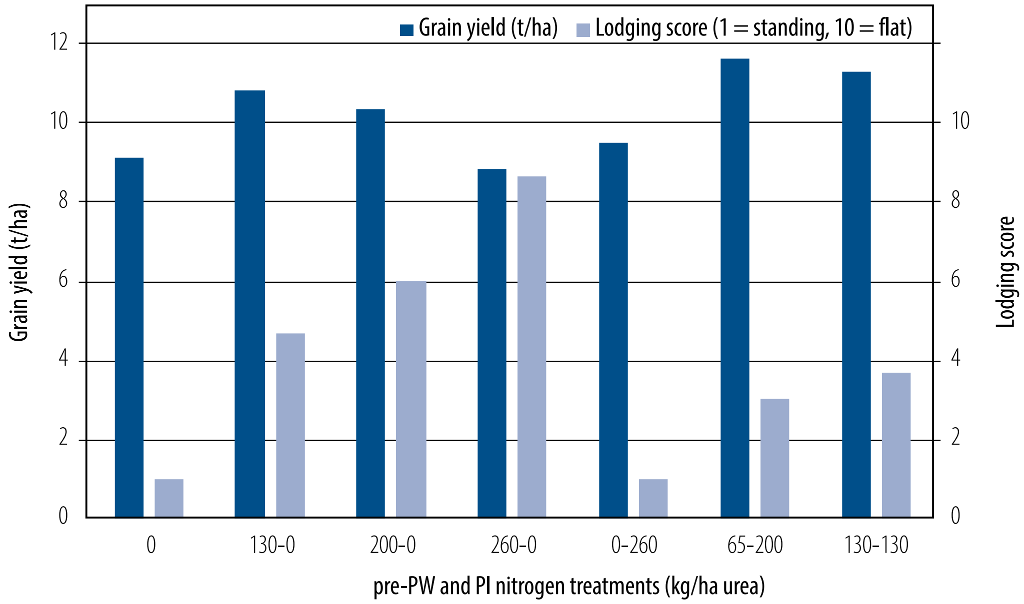

Figure 1. YRK 5 nitrogen rate and timing experiment grain yield (l.s.d. (P<0.05) = 3.8) and lodging score (l.s.d. (P<0.05) = 1.07) results for a range of pre-PW and panicle initiation (PI) nitrogen treatments (kg/ha urea). First number is pre-PW and second number PI applied urea (kg/ha).

Water depth during establishment

The need for the seedling to emerge from the water and intercept sunlight for photosynthesis, combined with the buoyancy provided by the water, result in taller and weaker plants in deeper water. It is important to keep water depth shallow during establishment and through to mid-tillering so plant height is not increased, which will increase crop lodging potential.

Draining

When to drain the water from a rice crop for harvest is a very important and difficult decision. If the field is drained too early, not providing sufficient soil moisture to take the plants to physiological maturity, the crop will 'hay off'. Haying off makes the stem very weak, resulting in considerable lodging, reducing grain yield and whole grain millout.

Weather

A high yielding crop is often finely balanced as it nears maturity, so anything that upsets the balance such as heavy rain or strong winds can cause it to lodge. You cannot control the weather, but harvesting as soon as the crop is mature helps to reduce the chance of lodging and also ensures good grain quality.

Acknowledgements

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

Thank you to Craig Hodges and Chris Dawe (Technical Assistants) for their assistance.

Soil water content by EM38

Dr Iain Hume, Brad Baxter, Helen Burns, Dr Andrew Milgate and Mark Richards, (NSW DPI, Wagga Wagga); Patrick Hawkins (Charles Sturt University, Wagga Wagga)

Key findings

- Soil water can be predicted from EM38 measurements made on the soil surface in southern dryland cropping soils.
- It is possible to estimate the amount of water and its distribution in the top 50 cm of soil.
- Rapid surveys of large areas and/or high numbers of experiment plots will be possible.

Introduction

Traditional soil moisture measurements using neutron moisture meters (NMM) are expensive, laborious and highly regulated. The EM38 offers an attractive alternative; it measures the electrical conductivity of the soil and is portable, allowing time and cost effective surveys of large areas. Electromagnetic (EM) methods have been applied to estimate soil water in irrigated vertosols in northern NSW and southern Queensland. This project tests the ability of the EM38 to predict soil water in rainfed agricultural systems in southern NSW.

Site details

Location	NSW DPI, Wagga Wagga Agricultural Institute
Soil type	Red Kandosol
Experiment design	Measurements were made to coincide with the field activities of two existing experiments: 1. Neutron moisture meter (NMM) access tubes installation on a plant pathology experiment. 2. Soil sampling of a pulse field trial to evaluate soil pH stratification. An additional experiment was conducted to measure changes in soil water and soil conductivity measured by the EM38 following lucerne irrigation.

Treatments

Soil sampling and processing

In all three experiments soil was sampled using a tractor-mounted push corer. The sampling depth and increments sampled varied between experiments. Soil was dried to a constant weight in either an oven or dehydrator and the gravimetric soil water content calculated. Soil bulk density was estimated from knowledge of the soil core diameter and length, and the dry weight of each soil sample.

EM38 measurements

A series of measurements was made at each soil sampling location using a Geonics™ EM38 MkII dual coil instrument. Before measurements started, the instrument was zeroed according to the manufacturer's instructions. The soil's apparent conductivity (ECa) was measured with the instrument placed on the soil surface with its coils in both vertical and the horizontal orientation. This resulted in four measures of ECa:

1. vertical coils and 100 cm coil spacing (EMv100)
2. vertical coils and 50 cm coil spacing (EMv050)
3. horizontal coils and 100 cm coil spacing (EMh100)
4. horizontal coils and 50 cm coil spacing (EMh050).

Pathology experiment

Eight access tubes were installed to a depth of 150 cm; four were in plots containing disease susceptible wheat varieties and four in plots of disease tolerant varieties. The cores were subsampled into 10 cm lengths centred on the depths where NMM measurements were to be made; 5, 15, 40, 65, 90 and 115 cm.

Pulse experiment

These samples were taken from an experiment designed to demonstrate the performance of commercial pulse varieties. Three soil profiles were sampled immediately pre-harvest beneath chickpea, lentil and faba bean crops and the bare ground between plots.

Irrigated lucerne

Two plots of dryland lucerne were irrigated using domestic soaker hoses. Soil profiles were wetted up over five days, with water applied for six hours every 12 hours. Two 150 cm deep soil cores were taken in each plot and sub-sampled in 10 cm intervals to 50 cm and 25 cm intervals to 150 cm. EM measurements were made between the two soil sampling locations.

Analysis

Soil water stored to 10, 20, 30, 40, 50 and 100 cm deep in the soil was calculated for each sampling location. Correlation was used to assess relationships between soil water and EM38 measurements.

Results

The plots had a range in soil water storage from a low beneath the chickpea in the pulse experiment to the fully watered profile under the lucerne (Figure 1).

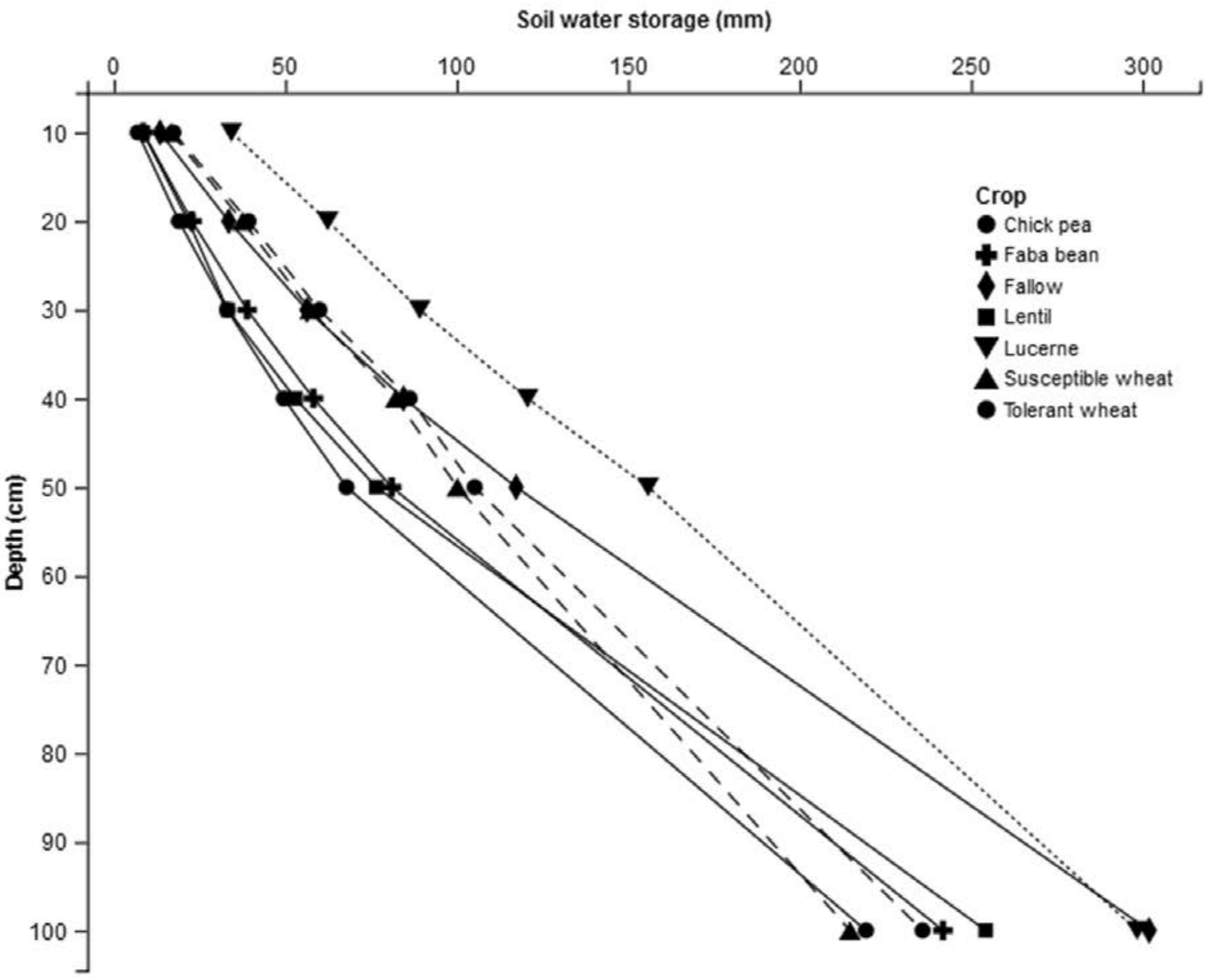

Figure 1. Variation of soil water storage with depth for the different crops and experiments. The lucerne experiment is shown as the dotted line the pathology experiment the dashed lines and the pulse experiment the solid lines.

Soil water storage was most highly correlated with the instrument in the horizontal orientation (Table 1). At depths less than 50 cm, soil water storage was more highly correlated with the ECa measured by the 50 cm coil separation (EMh50). Below 50 cm, a coil separation of 100 cm (EMh100) was more correlated with soil water storage. The correlation between soil water storage in the top 100 cm of the profile and ECa measurements was poor for all coil configurations.

Table 1. Pearson correlation coefficients between ECa measured with the EM38 in different coil orientations and spacing and soil water stored to different depths.

Coil		Depth (cm)					
Orientation	Spacing (cm)	10	20	30	40	50	100
Horizontal	100	0.773	0.787	0.791	0.769	0.824	0.395
	50	0.807	0.878	0.871	0.866	0.739	0.123
Vertical	100	0.540	0.602	0.604	0.586	0.544	0.131
	50	0.267	0.355	0.345	0.358	0.201	0.019

Soil water stored in the top 50 cm of the soil is predictable by ECa measurements made with the instrument on the soil surface (Figure 2). These have an accuracy of ±12 mm in the top 50 cm, ±8 mm in the top 40 cm, ±5 mm in the top 20 cm and ±4 mm in the top 10 cm.

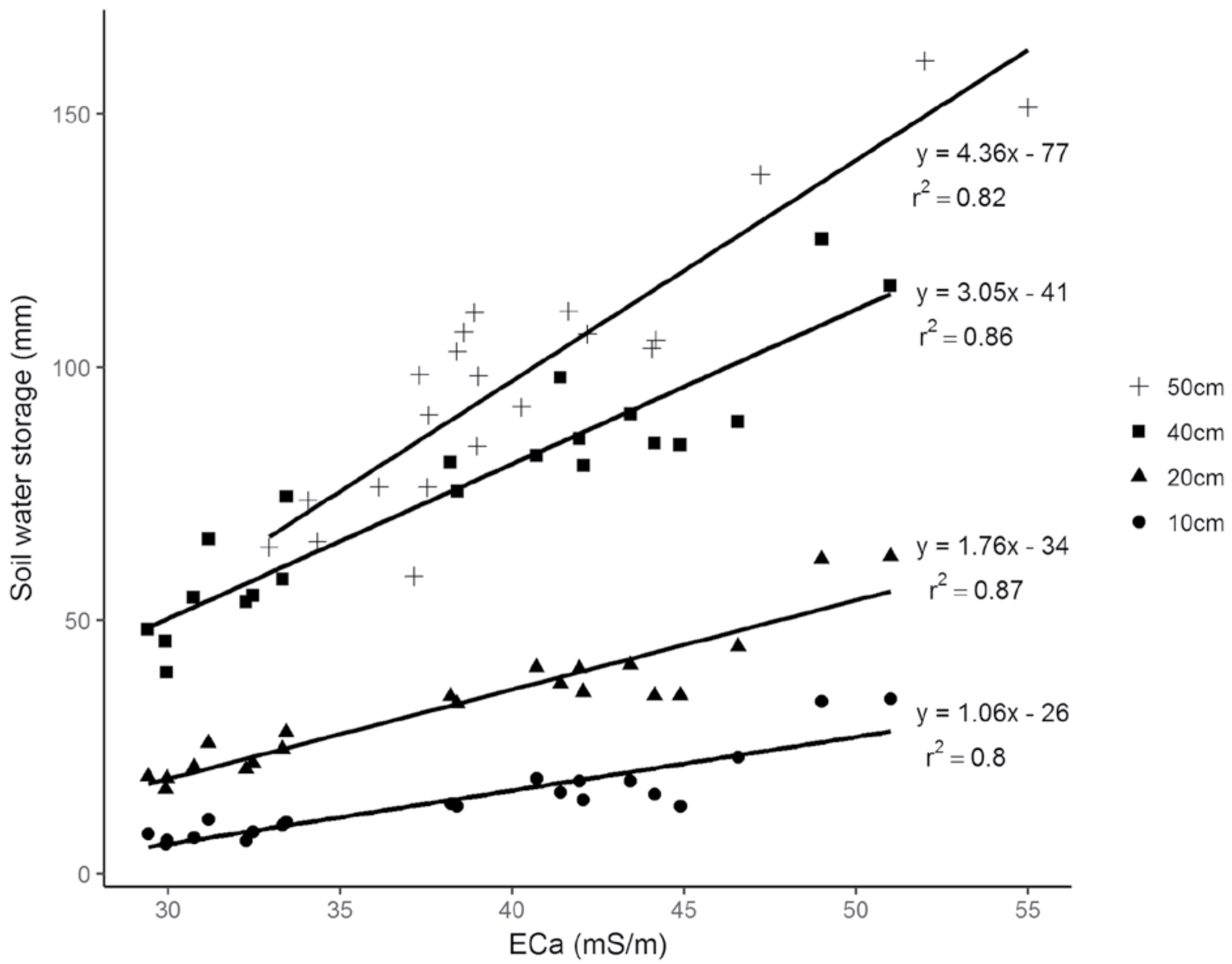

Figure 2. Water stored to four depths in the soil vs ECa measured at the soil surface with the EM38 instrument with the coils oriented horizontally. Storage in the top 50 cm is plotted against EMh100 the other depths are plotted against EMh50. The equations and adjusted r^2 of the least squares regression of each ECa storage relationship is shown.

Irrigation & climate

Summary

The EM38 successfully predicted water stored in the top 50 cm of soils typically used for dryland cropping in southern NSW. These predictions were possible with a single measurement made using a dual coil EM38 instrument in the horizontal orientation. The time and cost of surveying will be much reduced as a single measurement is all that is needed to estimate stored soil water at a location.

Acknowledgements

This work is a NSW DPI investment but relies on the field experiments of investments by GRDC under projects DAN00175 – National crown rot epidemiology and management program and DAV00113 – Expanding the use of pulses in the southern region to test the EM methods.

Effect of sowing date on irrigated soybean varieties in southern NSW, 2016–17

Mathew Dunn and Alan Boulton (NSW DPI, Yanco)

Key findings

- The early (16 November) and middle (1 December) sowing dates resulted in significantly higher grain yields than the late (15 December) sowing date, averaged across all varieties.
- N005A-80, Djakal and P176-2 achieved significantly higher grain yields than Snowy$^{\phi}$ and Bidgee$^{\phi}$, averaged across all sowing dates.
- Later sowing dates resulted in hastened soybean development.

Introduction

An experiment was conducted to assess the effect of early, mid and late sowing dates on the grain yield, phenology and seed quality of soybeans grown in southern New South Wales.

Soybeans are both thermal and photoperiod responsive and, as a result, sowing date can have a major effect on both plant phenology and growth characteristics.

A range of commercial soybean varieties suited to the region were evaluated, including two breeding lines for potential release, N005A-80 and P176-2. Three sowing dates were evaluated with early (16 November) and late (15 December) sowing dates bracketing the ideal sowing window of 1 December.

Site details	Location	Leeton Field Station, Yanco NSW
	Soil type	Grey self-mulching clay (vertosol)
	Previous crop	Barley
	Fertiliser	125 kg/ha legume starter (N = 13.3%, P = 14.3%, S = 9%, Zn = 0.81%)
	Inoculation method	Peat slurry in-furrow injection
	Paddock layout	Raised beds (1.83 m centres) with furrow irrigation
Treatments	Varieties	Djakal, Snowy$^{\phi}$, Bidgee$^{\phi}$, N005A-80 and P176-2
	Sowing dates	16 November 2016, 1 December 2016 and 15 December 2016
	Harvest date	4 May 2017

Results

Development and biomass accumulation

Soybeans are photoperiod sensitive and as a result their development is partially determined by day length. As a facultative short day plant, progression through growth stages is hastened under shorter day lengths (longer dark periods) and slowed under longer day lengths (shorter dark periods). As a result of this effect, in combination with temperature effects, soybeans sown earlier in the sowing window have an extended vegetative growth period compared with those sown later in the sowing window.

As seen in Figure 1, the extended vegetative growth periods associated with earlier sowing dates can result in higher plant biomass accumulation. While higher biomass accumulation does not necessarily result in increased grain yield, low biomass accumulation can limit grain yield.

Soybean maturity (days from sowing to 95% physiological maturity) varied significantly ($P = 0.05$) between both sowing date and variety, however, no significant interaction was detected. Averaged across varieties the first sowing date (16 November) was the slowest to reach 95% physiological maturity at 128 days after sowing (DAS) followed by the middle (1 December) and late (15 December) sowing dates, at 117 and 110 DAS respectively. Averaged across sowing dates, Bidgee$^{\Phi}$ was the quickest variety to reach physiological maturity at 112 DAS, followed by Djakal, N005A-80, P176-2 and Snowy$^{\Phi}$ at 116, 120, 121, 123 DAS respectively.

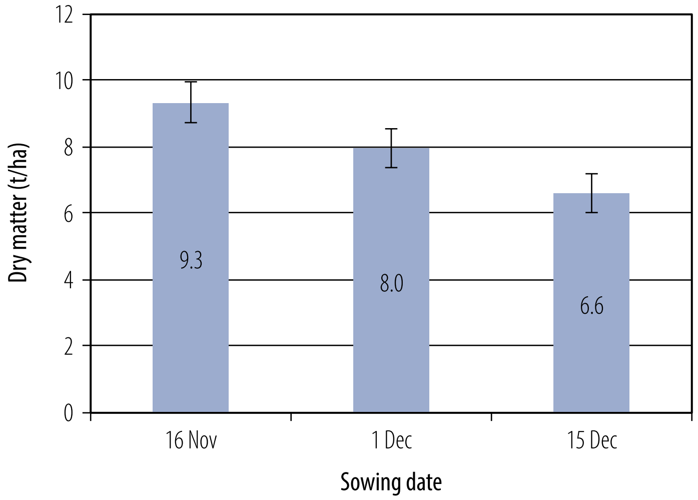

Figure 1. Effect of sowing date on soybean dry matter (t/ha) at maturity averaged across varieties. Bars denote l.s.d. ($P = 0.05$) = 0.60 t/ha.

Grain yield

Both sowing date and variety significantly affected grain yield, however, no significant interaction between them was detected ($P = 0.05$). Averaged across varieties the highest grain yield occurred in early (16 November) and middle (1 December) sowing dates, while the late (15 December) sowing date resulted in a significantly lower grain yield (Figure 2).

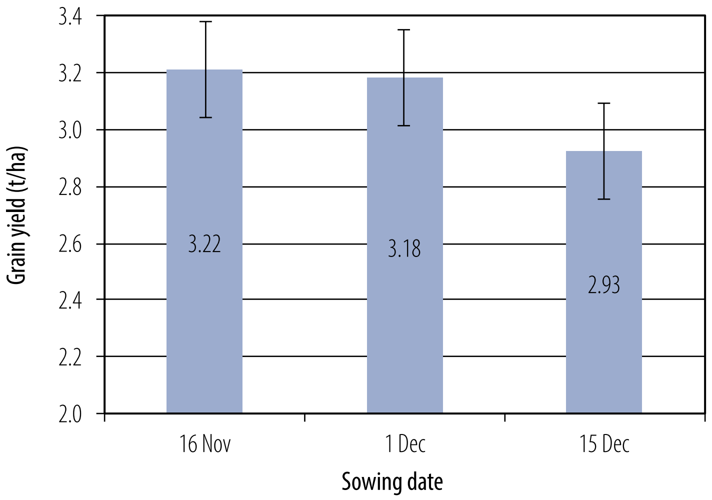

Figure 2. Effect of sowing date on soybean grain yield averaged across all varieties. Bars denote l.s.d. ($P = 0.05$) = 0.17 t/ha.

Averaged across sowing dates, N005A-80, Djakal and P176-2 achieved the highest grain yields at 3.62 t/ha, 3.61 t/ha and 3.56 t/ha respectively, while Snowy$^{\Phi}$ and Bidgee$^{\Phi}$ achieved significantly lower grain yields of 2.80 t/ha and 1.96 t/ha respectively (Figure 3).

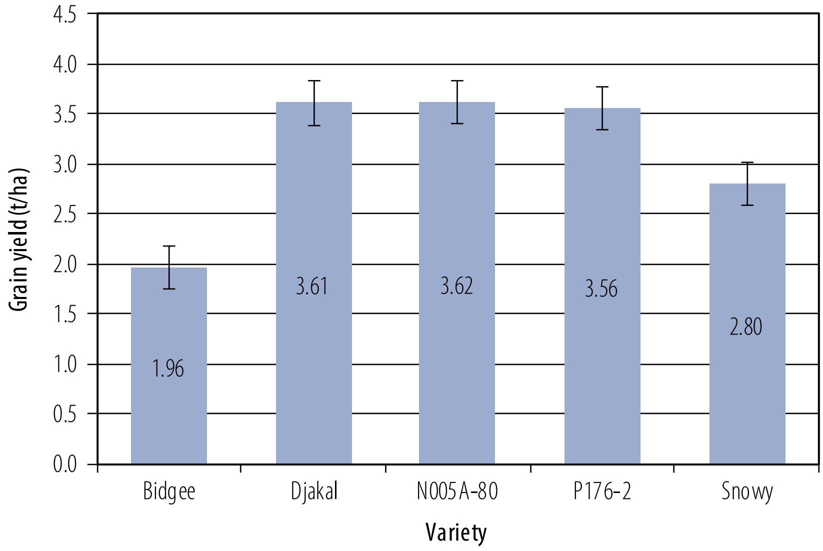

Figure 3. Effect of variety on soybean grain yield averaged across all sowing dates. Bars denote l.s.d. ($P = 0.05$) = 0.37 t/ha.

Summary

This experiment demonstrated that delaying soybean sowing into the second half of December has the potential to reduce grain yield. The late sowing date resulted in shorting the vegetative growth period, reducing biomass accumulation and, in turn, limiting grain yield. As a result, in order to maximise yield potential, earlier sowing dates are recommended where possible.

Acknowledgements

This experiment was part of the 'Southern NSW Soybean Agronomy Project', DAN00192, 2014–18 with joint investment by NSW DPI and GRDC.

Thank you to John Dando, Paul Morris and Gabby Napier for their technical assistance.

Effect of plant density on irrigated soybean varieties in southern NSW, 2016–17

Mathew Dunn and Alan Boulton (NSW DPI, Yanco)

Key findings

- Grain yields were maximised for all varieties when sown at the recommended target sowing densities (30–45 plants/m^2).
- Averaged across target sowing densities Djakal, N005A-80 and P176-2 yielded the highest at 3.7 t/ha, 3.8 t/ha and 3.9 t/ha respectively, while Snowy⁽ᶦ⁾ achieved a significantly lower grain yield of 3.3 t/ha.
- Lodging was exacerbated at higher target sowing densities for all varieties, with N005A-80 demonstrating the strongest lodging resistance, supporting previous findings in this environment.
- Higher target sowing densities resulted in longer maturity times.

Introduction

Seeding rate is an easily manipulated agronomic decision that producers can use to maximise soybean yield and economic return. An experiment was conducted at the NSW DPI Leeton Field Station to test the response of two commercial soybean varieties and two numbered lines for potential release, to four target sowing densities.

Site details

Location	Leeton Field Station, Yanco NSW
Soil type	Grey, self-mulching clay (vertosol)
Fertiliser	125 kg/ha legume starter (N = 13.3%, P = 14.3%, S = 9%, Zn = 0.81%)
Inoculation method	Peat slurry in-furrow injection
Paddock layout	Raised beds (1.83 m centres) with furrow irrigation
Sowing date	5 December 2016
Harvest date	4 May 2017

Treatments

Varieties	Djakal, Snowy⁽ᶦ⁾, N005A-80 and P176-2
Target sowing densities	15, 30, 45 and 60 plants/m^2 All treatments achieved plant densities ±20% of their target sowing density.

Results

Maturity length

Soybean maturity (days from sowing to 95% physiological maturity) varied significantly ($P = 0.05$) between both target sowing density and variety, however, no significant interaction was detected. Averaged across varieties, higher target sowing densities resulted in increased maturity lengths. Plant density targets of 15, 30, 45 and 60 plant/m^2 resulted in maturity lengths of 114, 115, 115 and 117 days after sowing (DAS) to physiological maturity respectively. Averaged across target sowing densities, Djakal matured the quickest followed by N005A-80, P176-2 and then Snowy⁽ᶦ⁾ at 112, 115, 117 and 118 DAS to physiological maturity respectively.

Lodging

Lodging in soybeans has the potential to reduce harvestability, increase harvest losses and reduce yields. Both target sowing density, variety and the interaction between them had a significant ($P = 0.05$) effect on the severity of lodging at harvest (Figure 1).

Higher target sowing densities resulted in increased plant lodging at harvest for all varieties. Djakal, Snowy[⦶] and P176-2 all incurred similar levels of lodging, while N005A-80 incurred significantly (P = 0.05) lower levels of lodging at all target sowing densities (Figure 1).

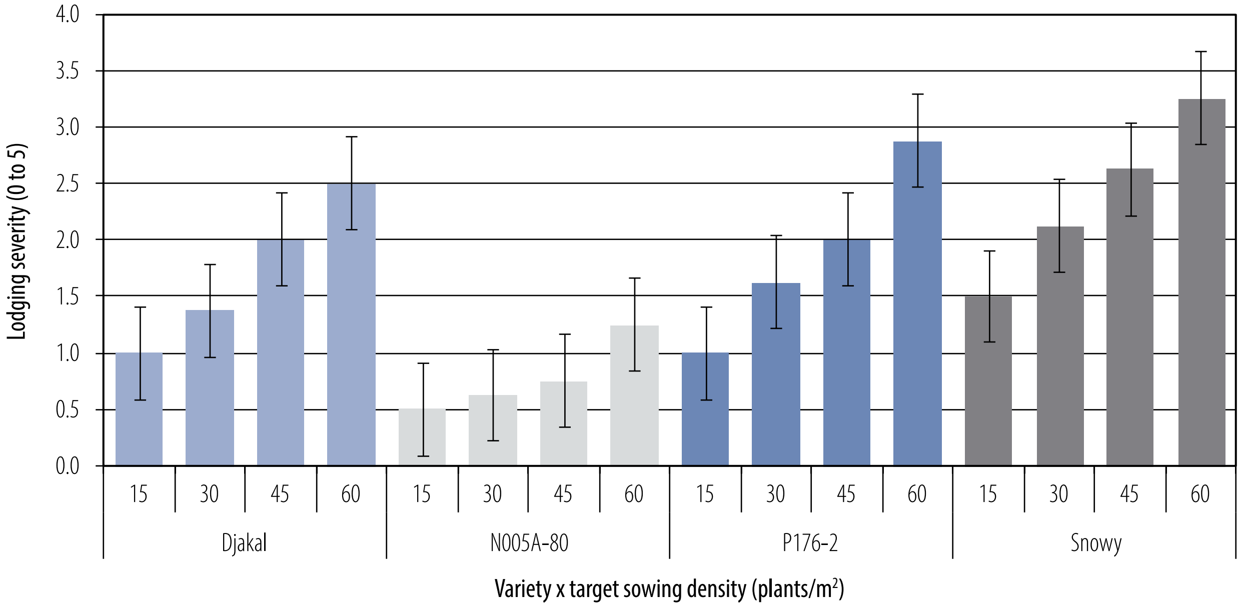

Figure 1. Effect of variety and target sowing density on the lodging severity at harvest of four soybean varieties (0 = no lodging, 5 = severe lodging). Bars denote l.s.d. (P = 0.05) = 0.41.

Grain yield

Target sowing density, variety and the interaction between them was found to have a significant (P = 0.05) effect on grain yield (Figure 2). Grain yield was maximised for Djakal at 15, 30 and 45 plants/m^2 with a reduction occurring at 60 plants/m^2. Both N005A-80 and Snowy[⦶] suffered reduced grain yield at the lowest target plant density (15 plants/m^2) with maximum grain yield occurring at 30, 45 and 60 plants/m^2. Unlike the other varieties, P176-2 achieved consistent grain yields across all four target sowing densities.

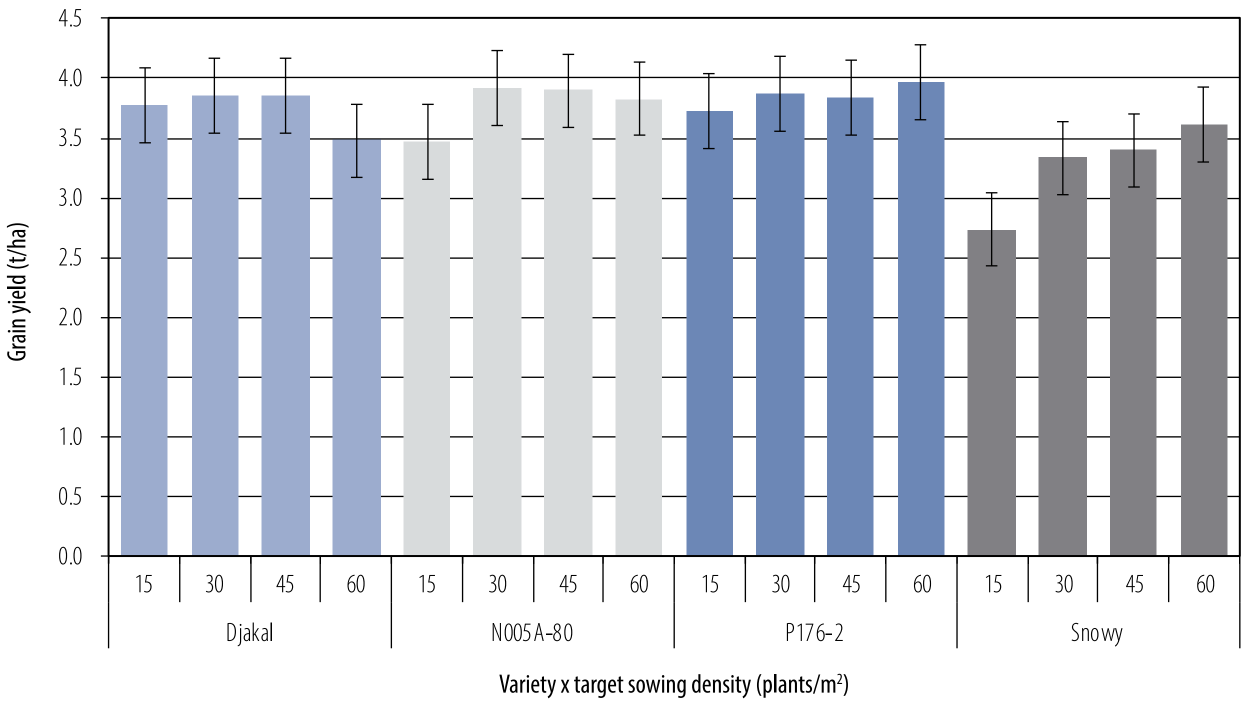

Figure 2. Effect of variety and target sowing density on grain yield of four soybean varieties. Bars denote l.s.d. (P = 0.05) = 0.31 t/ha.

Averaged across varieties, P176-2, N005A-80 and Djakal achieved the highest grain yields at 3.9 t/ha, 3.8 t/ha and 3.7 t/ha respectively, while Snowy$^{\Phi}$ yielded significantly lower at 3.3 t/ha.

Summary

Current target sowing density recommendations for the southern NSW soybean growing regions are 35–50 plants/m^2. High yields can be achieved at a less than 35 plants/m^2 targeted sowing density, however, this is not recommended. Targeted sowing densities above 50 plants/m^2 can, although not always, lead to increased lodging and, as a result, increased harvest difficulty, particularly in varieties susceptible to lodging, such as Snowy$^{\Phi}$.

Acknowledgements

This experiment was part of the 'Southern NSW Soybean Agronomy Project', DAN00192, 2014–18, with joint investment by NSW DPI and GRDC.

Thank you to John Dando, Paul Morris and Gabby Napier for their technical assistance.

Effect of sowing date on phenology and yield of eight canola varieties – Leeton 2017

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

Key findings

- The winter canola varieties SF Edimax CL and Hyola® 970CL achieved consistently high yields for all three sowing dates (late March to early May).
- All spring varieties (except Victory® V7001 CL) were penalised by early sowing due to frost damage, with yields increasing as sowing time was delayed.
- The yield of the slowest-developing spring variety, Victory® V7001 CL, was stable but relatively low across sowing dates.
- Early sowing fast-developing spring varieties exposes them to a greater risk of frost damage.

Introduction

This experiment was designed to improve the understanding of canola's yield potential and the effect from abiotic stress at different growth stages in the high-yielding irrigated zone of southern NSW. Improved understanding will help growers to select the appropriate plant type and sowing date so that environmental stresses are minimised and the critical growth period coincides with the most favourable conditions. Eight canola varieties with differing phenology were evaluated over three sowing dates from late March to early May.

Site details

Location	Leeton Field Station, Yanco
Soil type	Grey self-mulching clay
Previous crop	Barley (irrigated)
In-crop rainfall	145 mm (1.45 ML) (April 2017–October 2017)
Irrigation (estimate)	440 mm (4.4 ML)
Soil nitrogen (N)	64 kg/ha (0–60 cm, 29 April)
Nitrogen applied	20 March: 250 kg urea/ha = 115 kg N/ha 20 March: 100 kg Gran-Am/ha = 20 kg N/ha At sowing: 100 kg/ha mono-ammonium phosphate (MAP) = 10 kg N/ha First topdressing (8 leaf, 17 May to 22 June): 150 kg/ha urea = 65 kg N/ha Second topdressing (visible bud, 14 June to 1 September): 150 kg/ha urea = 65 kg N/ha

Treatments	Varieties	Nuseed® Diamond	Fast developing, conventional herbicide hybrid variety (spring type)
		Pioneer® 44Y90 (CL)	Mid–fast developing, Clearfield® (CL) hybrid variety (spring type)
		ATR Bonito⊕	Mid–fast developing, triazine tolerant (TT), open-pollinated (OP) variety (spring type)
		Pioneer® 45Y25 (RR)	Mid–slow developing, Roundup Ready® (RR) hybrid variety (spring type)
		ATR Wahoo⊕	Mid–slow developing, TT OP variety (spring type)
		Victory® V7001 CL	Slow developing, CL hybrid variety (spring type)
		SF Edimax CL	Very slow developing, CL hybrid variety (winter type)
		Hyola® 970CL	Very slow developing, CL hybrid variety (winter type)
	Sowing date (SD)	SD1: 27 March 2017 SD2: 11 April 2017 SD3: 2 May 2017	

Results

Phenology

Nuseed® Diamond was the fastest developing variety from the first sowing date and started flowering on 1 June, only 65 days after sowing (Figure 1). The development of Nuseed® Diamond is driven only by thermal time, (has no vernalisation requirement), therefore warmer temperatures hasten its development. Hyola® 970CL was the slowest variety to start flowering from the first sowing date, taking 176 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® V7001 CL was the slowest spring variety to start flowering from the first sowing date, taking 131 days from sowing to flowering. Slower developing spring varieties have a response to both thermal time and vernalisation. Most spring varieties have only a small response to vernalisation, but this will delay flowering when conditions are warm (i.e. from early sowing). The stronger the influence of vernalisation, the greater the delay to flowering.

There were three major frosts during winter: 1 July, 22 July and 29 August. The temperature on 29 August fell to –4.5 °C when most of the early-sown spring varieties were podding and susceptible to frost damage.

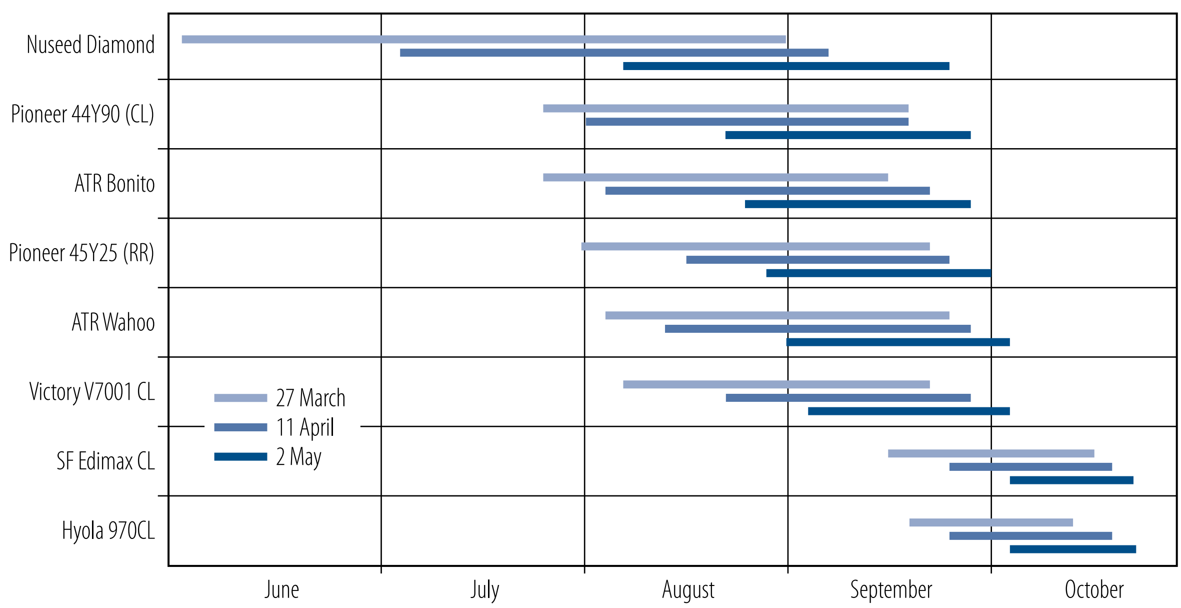

Figure 1. Flowering window of eight canola varieties sown on three sowing dates at Leeton, 2017.

Grain yield

Pioneer® 45Y25 (RR) (SD3) achieved the highest yield, 4.7 t/ha, while Nuseed® Diamond (SD1) recorded the lowest yield, 2.27 t/ha (Table 1). The two winter varieties, SF Edimax CL and Hyola® 970CL, and the slowest developing spring variety Victory® V7001 CL, had no yield response to sowing time with a consistent yield across all three sowing dates. The faster developing spring varieties showed a strong response to sowing time with a significant yield increase as sowing time was delayed. Frost penalised the early sown spring varieties, but as sowing was delayed, yield increased to match that of the winter varieties.

Harvest index

ATR Wahoo⫼ achieved the highest harvest index (HI) of 0.32 from SD2, while Nuseed® Diamond recorded the lowest HI of 0.15 from SD1 (Table 1). The HI of the two winter varieties, SF Edimax CL and Hyola® 970CL, and the slowest developing spring variety Victory® V7001 CL, had no response to sowing time and maintained a consistent HI across all sowing dates. The faster developing spring varieties had a strong response to sowing time with a significant increase in HI as sowing time was delayed.

Table 1. Grain yield (t/ha) and harvest index of eight canola varieties sown on three sowing dates at Leeton, 2017.

Variety	Grain yield (t/ha)			Harvest index		
	27 March	11 April	2 May	27 March	11 April	2 May
Nuseed Diamond	<u>2.27</u>	3.04	4.30	<u>0.15</u>	0.18	0.28
Pioneer 44Y90 (CL)	3.26	4.05	3.95	0.20	0.25	0.27
ATR Bonito	3.00	3.38	3.80	0.22	0.26	0.31
Pioneer 45Y25 (RR)	3.37	4.42	**4.71**	0.21	0.26	0.30
ATR Wahoo	2.99	3.65	4.02	0.21	**0.32**	0.30
Victory V7001 CL	3.16	3.54	3.57	0.21	0.23	0.23
SF Edimax CL	4.70	4.61	4.21	0.28	0.30	0.29
Hyola 970CL	4.16	4.55	4.23	0.27	0.31	0.29
l.s.d. (P<0.05)		0.77			0.047	

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

Number of viable grains per pod

Hyola® 970CL achieved the highest seed number with 24 viable grains per pod from SD1, while Nuseed® Diamond recorded the lowest seed number with 2.5 viable grains per pod at SD1. There was a significant relationship of viable grains per pod to sowing time across all varieties. The two winter varieties, SF Edimax CL and Hyola® 970CL, had a significant reduction in grains per pod as sowing time was delayed, whilst the spring varieties had a strong response to sowing time, but with an increase in grains per pod as sowing time was delayed.

Frost assessment

Twenty pods were collected from each plot (main stem only) at the end of flowering then opened and assessed for the number of viable seeds and the number of potential seed sites. Hyola® 970CL had the highest proportion of viable grains per pod at 74.7% from SD1 as it flowered after the last damaging frost in late winter. Nuseed® Diamond recorded the lowest proportion of viable grains per pod at 8.6% from SD1 as it was the earliest flowering variety and the most affected by frost. The two winter varieties, SF Edimax CL and Hyola® 970CL had a significant reduction in the proportion of viable grains per pod as sowing time was delayed, however, the spring varieties had a significant increase in the proportion of viable grains per pod as sowing time was delayed and frost was avoided.

Table 2. Grains per pod and percentage of viable grains per pod of eight canola varieties sown on three sowing dates at Leeton, 2017.

Variety	Viable grains (number per pod)			Proportion of viable grains per pod (%)		
	27 March	11 April	2 May	27 March	11 April	2 May
Nuseed Diamond	2.5	3.7	14.7	8.6	12.8	46.1
Pioneer 44Y90 (CL)	8.5	11.2	16.1	30.0	39.1	53.5
ATR Bonito	7.2	10.4	18.0	24.2	31.4	52.1
Pioneer 45Y25 (RR)	8.4	13.2	15.5	27.9	42.0	50.5
ATR Wahoo	14.4	15.7	21.8	45.3	46.1	64.5
Victory V7001 CL	10.0	12.9	14.0	36.8	48.9	51.8
SF Edimax CL	21.5	16.5	17.5	66.4	54.2	56.1
Hyola 970CL	**24.0**	21.2	19.6	**74.7**	67.3	61.0
l.s.d. (P<0.05)		3.71			11.37	

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

Conclusion

Sowing time did not affect yield for the two winter varieties, SF Edimax CL and Hyola® 970CL with a >4.0 t/ha yield from all sowing dates. The yield for the slowest developing spring variety (Victory® V7001 CL) was also unaffected by sowing time, but did not achieve more than 3.6 t/ha from any sowing date. Yields from all five remaining spring varieties were significantly affected by sowing date with yield increasing as sowing date was delayed.

Sowing time also affected grains per pod. All spring varieties had an increase in grains per pod as sowing was delayed, while both winter varieties demonstrated a decrease in grains per pod as sowing was delayed.

The major frosts in 2017 occurred when all the spring varieties were susceptible to some level of frost damage. Assessing the proportion of viable seeds per pod provided a measure for the damage. Frost damage was greatest in early-flowering varieties, especially early-sown fast-developing varieties such as Nuseed® Diamond, ATR Bonito$^{\phi}$ and Pioneer® 44Y90 (CL). These varieties should not be sown before mid April and still yielded very well when sown in early May. The winter varieties flowered after the frosts of winter and generally had a lower proportion of viable seeds per pod as sowing time was delayed.

The performance of the winter varieties Hyola® 970CL and SF Edimax CL showed potential for these varieties for early sowing canola in south-western NSW irrigation regions. There was a heat stress event of 37 °C on 23 September when these varieties were flowering, but grain yield was still very high.

Acknowledgements

This experiment was part of the 'High yielding canola' project, BLG 107, 2017–20, with joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

We would like to thank Michael Hately for his technical support.

Assessing waterlogging tolerance in wheat varieties

Sam North, Alex Schultz, Don Griffin (NSW DPI, Deniliquin); Damian Jones (Irrigated Cropping Council, Kerang)

Key findings

- Measuring redox potential and soil water potential helps to explain crop responses to waterlogging in different soils.
- Current varieties vary in their response to irrigation and waterlogging on heavy, sodic clays. As these soils occupy 40–60% of some irrigation districts, variety experiments on them are needed so lines better suited to irrigation on heavy, sodic clays can be selected.

Introduction

Heavy, sodic clays are the predominant soil type in 40–60% of some irrigation districts. There is evidence of varietal differences in waterlogging tolerance. Local variety experiments on waterlogging-prone soils are recommended as the best way to identify tolerant varieties (Setter & Waters 2003). However, not all soils become anoxic when waterlogged, so it is important to select experiment sites where waterlogging treatments will lead to anoxia. Combined measurement of soil redox (reduction-oxidation) potential and water potential can provide an objective measure of the timing, duration and intensity of waterlogging (North 2012).

The aim of this experiment was to determine:

- an experimental methodology for assessing the waterlogging tolerance of irrigated wheat varieties
- whether there is sufficient variability in the tolerance of current wheat varieties to justify further experiments to identify lines best suited to irrigation on waterlogging-prone soils.

Site

The experiment was conducted on two sites in contour basin layouts on soils with low final infiltration rates:

1. non-self-mulching clay (NSMC) 20 km west of Jerilderie, NSW
2. transitional red–brown earth (TRBE) 20 km west of Moulamein, NSW.

Methodology

It was intended to subject the plots to multiple ponding events to coincide with scheduled spring irrigations, thereby creating waterlogged conditions. The control plots were to be drained after 12 hours, the waterlogged plots were to be drained after 40–50 hours to simulate the effect of slow-draining irrigation layouts. However, the winter–spring period in 2016 was exceptionally wet and the first irrigation planned for September was not possible. Instead plots to be waterlogged were subjected to a single prolonged period of waterlogging (14 days) to coincide with flowering.

Control plots were irrigated (water applied and drained within 12 hours) at the start of the waterlogging treatment and again when the waterlogged plots were drained. This ensured both the waterlogged and control plots started grain filling with full moisture profiles.

Soil water potential and redox potentials were measured at 5 cm, 15 cm and 30 cm depths from two weeks before waterlogging started through to physiological maturity.

Varieties

Condo⁽ᵖ⁾ and LongReach Dart (early season); Corack⁽ᵖ⁾, LongReach Cobra⁽ᵖ⁾ and Scepter⁽ᵖ⁾ (early–mid season); Chara⁽ᵖ⁾, Suntop⁽ᵖ⁾ and Elmore CL PLUS⁽ᵖ⁾ (mid season); EGA Gregory⁽ᵖ⁾ and LongReach Trojan⁽ᵖ⁾ (mid–late season).

Sowing and fertiliser management

Plots were sown on 18 May 2016 at Moulamein and 20 May 2016 at Jerilderie at a seeding rate for each variety to achieve a 175 plants/m^2 with 70% establishment target plant density (90–115 kg/ha depending on seed weight). DAP (di-ammonium phosphate) at 125 kg/ha was drilled with the seed. Both experiments were top-dressed with 250 kg/ha urea in split applications, with the first on 20 July at Jerilderie and 23 July at Moulamein.

Results

Grain yield

Average header yields from the two sites (Figure 1) demonstrated:

- In the control plots, yields at Jerilderie were lower than those at Moulamein, indicating an effect caused by soil type. This effect was greatest in Condo⌽, which fell from the third highest yield in the control plot at Moulamein to the lowest yield in the control plot at Jerilderie.
- At Moulamein there was no significant difference in yields between control and waterlogged plots for all varieties except Scepter⌽. The two highest yielding varieties from the control plots were LongReach Trojan⌽ and Scepter⌽.
- Waterlogging had a significant effect on most varieties at Jerilderie, with higher proportionate losses in the better-yielding varieties. LongReach Cobra⌽, Suntop⌽ and LongReach Dart⌽ were least affected by the waterlogging treatment, while Chara⌽, Scepter⌽ and EGA Gregory⌽ were the most affected.

Soil redox potentials

Although both sites were subjected to the same irrigation and waterlogging events, the results from each experiment site varied significantly. This indicates a difference in the two soils susceptibility to become anaerobic when saturated.

Control

Redox potential measurements showed that in the control plots, the soil at Moulamein remained aerobic throughout the treatment period, but not at Jerilderie. The researchers concluded this effect was caused by rainfall in October at Jerilderie and the sodic nature of the soil at that site.

Experiment

The waterlogged plots at Jerilderie were anaerobic for longer than the control and had a slower recovery to aerobic conditions compared with the Moulamein site.

Conclusion

The differences in yield responses between Moulamein and Jerilderie are due to differences in the soil redox potential at the two sites. The longer duration of anoxic conditions at the Jerilderie site, in both the control and waterlogged plots, is attributed to sodicity-induced dispersion and blocked soil pores. The more stable soil at Moulamein ensured higher levels of soil oxygen, even with prolonged waterlogging, so no treatment effect was observed. This result highlights the importance of, firstly, selecting sites that become anoxic when waterlogged, and secondly, obtaining an objective measure of the timing, duration and intensity of waterlogging.

This experiment can only be considered a pilot and no variety inferences should be drawn because of the limited capacity for replication over time. However, the research does provide clear evidence that current varieties differ in their yield response to both irrigation on heavy, sodic clays and to waterlogging. The results also indicate there is a variety × soil type × waterlogging duration interaction. Experiments will be needed on local soils to provide recommendations to irrigators with soils prone to waterlogging.

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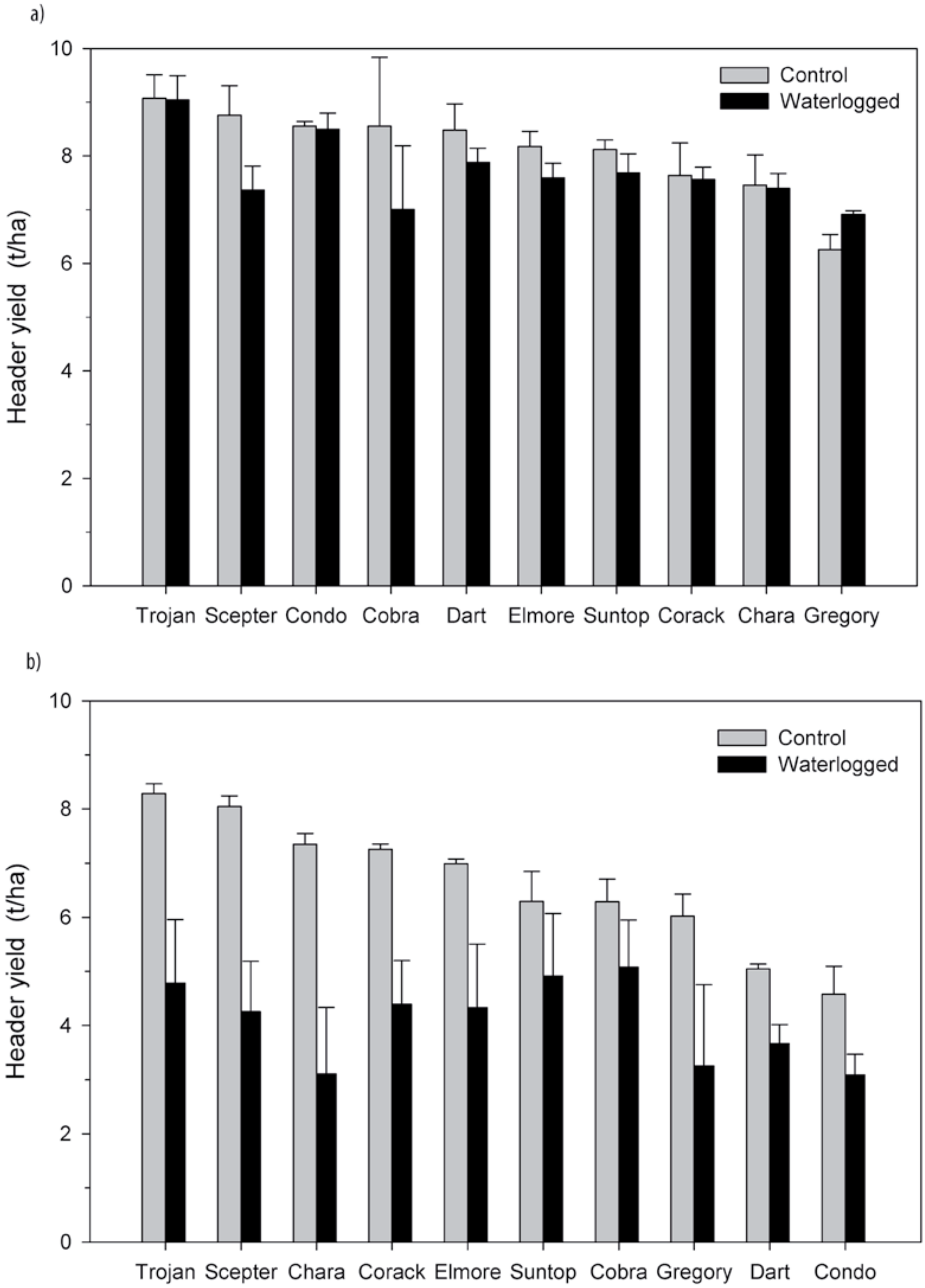

Figure 1. Treatment mean grain yield at 12% moisture for 10 wheat varieties subjected to short duration (12 hour) surface irrigation (control) and prolonged ponding (two weeks) at flowering. Varieties have been ranked in order of highest control yield (left) to lowest (right) at a) Moulamein and b) Jerilderie. Error bars show the standard error (n = 3).

Acknowledgements

This experiment was part of the project 'Soils under an irrigated environment', ICF00008, 2014–17, with joint investment by GRDC and NSW DPI. Project partners were Deakin University, Irrigated Cropping Council, Precision Agriculture and Murray Local Land Services.

Thank you to the site cooperators without whom this information could not have been collected.

Crop monitoring identifies key constraints and management strategies in irrigated wheat

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

Key findings

- Sixty percent of irrigated wheat crops in southern NSW and northern Victoria are not achieving close to their water-limited yield potential.
- Four key yield constraints have been identified: waterlogging, drought stress, late sowing and wide row spacing.

Introduction

Commercial irrigated wheat yields of 8 t/ha are possible in southern NSW and advisory materials show how to achieve this yield level (Fisher et al. 2014). However, a grower survey conducted for the GRDC project 'Soils under an irrigated environment' (ICC00008) showed 'average' expected irrigated wheat yields are considerably lower (5–6 t/ha) and that a 2 t/ha "yield gap" exists between "average" and "best ever" yields.

The objective of this project was to determine the reasons for this discrepancy and identify key management strategies to overcome yield limitations.

Methodology

Sixty-four commercial wheat crops were monitored over a three-year period (2014–2016) across a range of soil types and irrigation systems in the irrigation areas and districts of the Murray and Murrumbidgee valleys.

Soil water (matric) potential (ψ_m) sensors were installed at each site to monitor the occurrence and duration of waterlogging and water stress. Sites were visited at least twice (at the end of tillering and at anthesis) to record crop development, the presence or absence of disease, weeds, and waterlogging/water stress. At physiological maturity, quadrat cuts were taken to measure yield components (number of tillers per m^2, grains per spike and grain weight) and grain yield. Paddock input and header yield data were collected from cooperators at the end of each season.

Two yield potentials were calculated for each crop:

1. The physiological yield potential – based on average photothermal quotient over the 30 day period before anthesis (Peake & Angus 2009).
2. Water-limited yield potential – based on the French and Schultz (1984) equation.

Results

Yields from the 64 commercial crops ranged between 2 t/ha and 8.5 t/ha. Only one crop in the three years had a yield over 8 t/ha. There was no correlation between yield and either soil type or irrigation system type. The strongest correlation was between yield and the total depth of water (rain + irrigation) applied ($R^2 = 0.52$). Plotting grain yield against total season applied water for each year, together with the average and minimum physiological yield potential and the water-limited potential (Figure 1), shows:

- Average physiological potential yield varied each year, being 10.0 t/ha, 9.9 t/ha and 8.5 t/ha in 2014, 2015 and 2016 respectively. One crop in 2015 and two in 2016 achieved yields close to the minimum physiological potentials calculated in those years.
- Twenty-three of the 64 crops monitored (i.e. 36%) achieved close to their maximum possible yield, with yields greater than 80% of the water-limited yield potential.

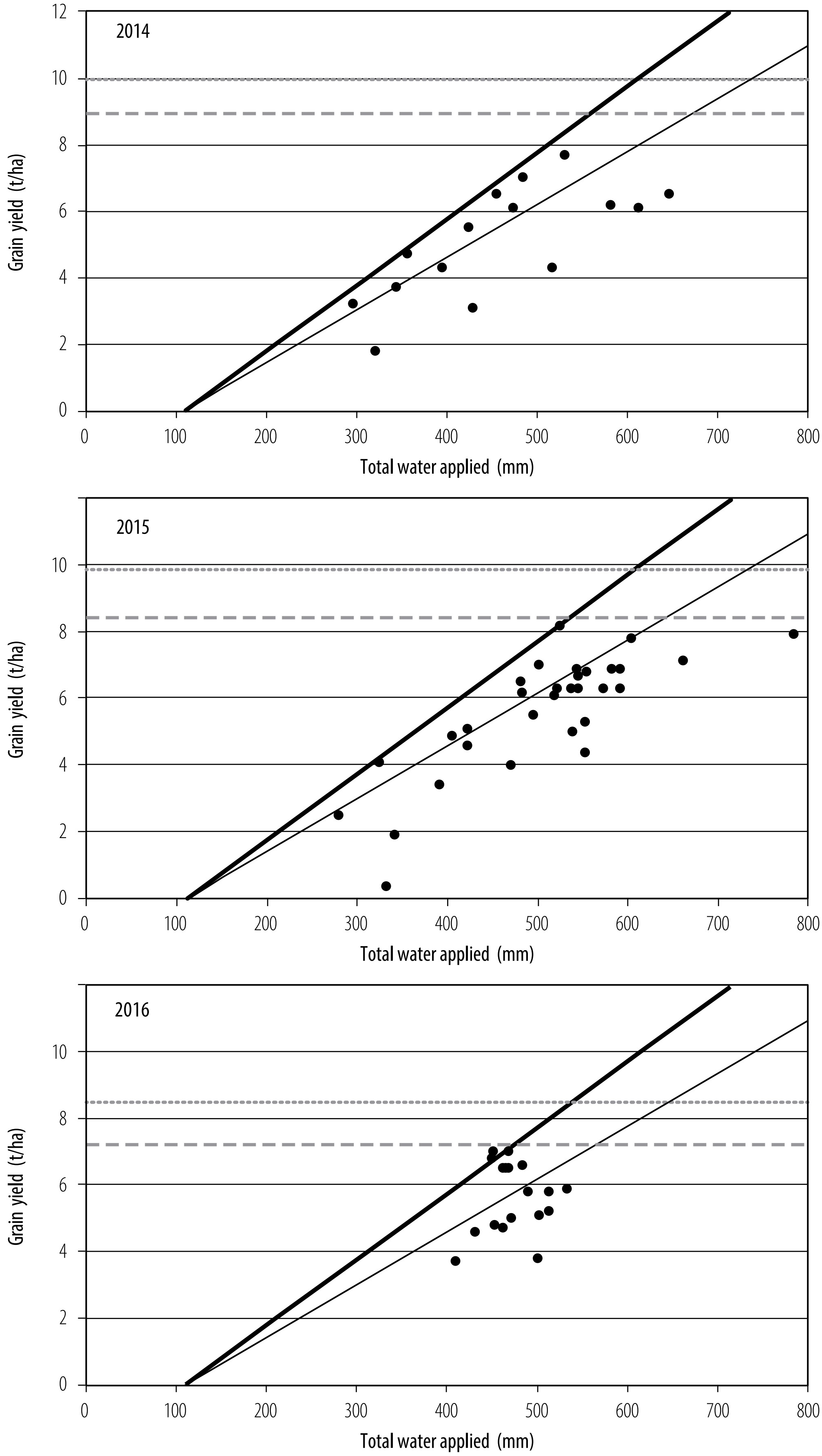

Figure 1. Plots of paddock grain yield on total, growing season applied water (rain + irrigation) for 64 commercial wheat crops monitored in 2014, 2015 and 2016.

Note: Horizontal lines show the average (dotted grey) and minimum (dashed grey) physiological potential (Peake & Angus 2009) for the crops monitored each year. The diagonal black lines define the water-limited yield potential (thick black line) and 80% of the water-limited yield potential (thin black line).

Examination of the soil water potential and yield component data revealed waterlogging and water stress to be responsible for a major reduction in two key yield components:

1. Cumulative days waterlogged ($\psi_m > -6$ kPa at 5 cm depth) from 40 to 20 days before anthesis accounted for 46% of the variation in tiller density in 2016 (Figure 2 top).
2. Cumulative days waterlogged from 40 to 20 days before anthesis plus cumulative days drought stressed ($\psi_m < -100$ kPa at 5 cm depth AND < –60 kPa at 30 cm depth) from 20 days before 10 days after anthesis accounted for 66% of the variation in grains/m² in 2014 and 2015 (Figure 2 bottom).

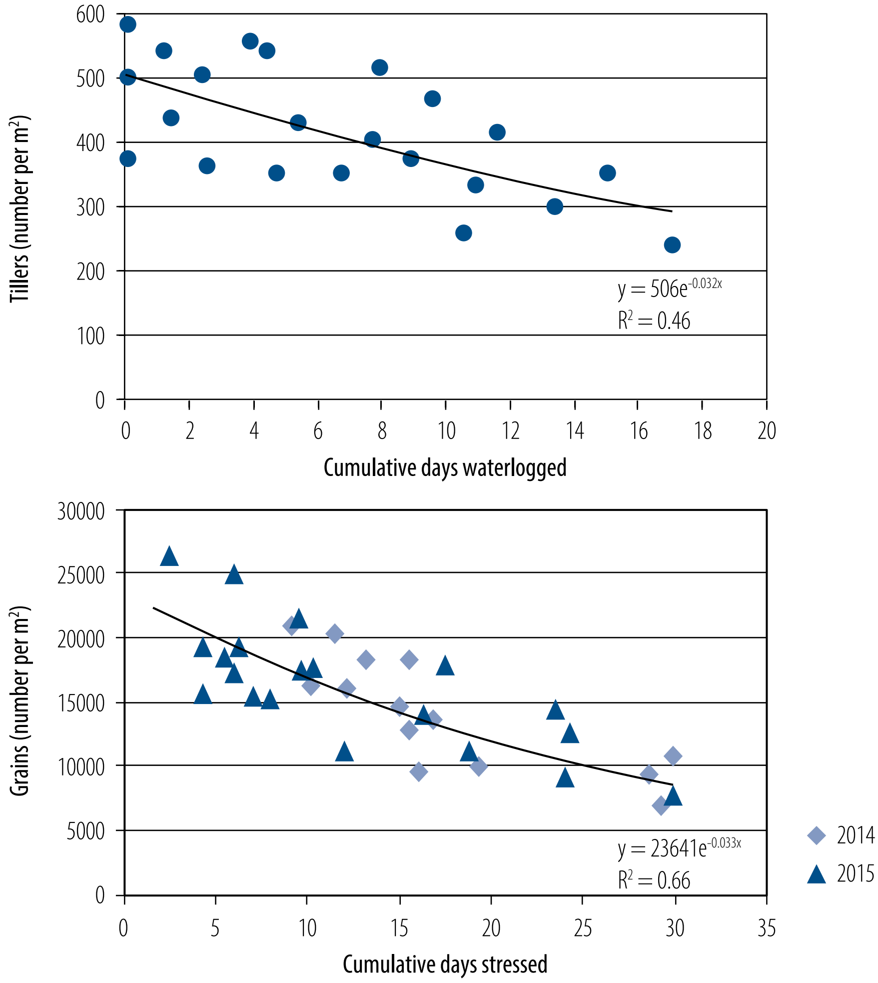

Figure 2. The relationships between tillers per m² and cumulative days waterlogged from 40 to 20 days before anthesis in 2016 (top); and grains per m² and cumulative days waterlogged from 40 to 20 days before anthesis and/or drought stressed from 20 days before to 10 days after anthesis in 2014 and 2015 (bottom).

The different response in 2016 was due to the exceptionally wet conditions during that season. This led to waterlogging in late August–early September, but negated the need to spring irrigate as crops had sufficient soil water to avoid water-stress leading up to, and after, anthesis. This was not the case in 2014 and 2015 when crops that were not irrigated on time had periods of drought stress.

Two other yield-reducing factors were identified: sowing date (Figure 3 top) and row spacing (Figure 3 bottom). For well managed main season lines, sowing at the end of May resulted in a 1 t/ha lower yield than sowing at the start of May, while no crop achieved more than 7 t/ha if sown on a row spacing greater than 0.24 m (9").

Conclusion

Commercial irrigated wheat crops in southern NSW and northern Victoria can attain yields close to their physiological potential, but they are mainly water limited. While the amount of water applied to a crop is a commercial decision, a major proportion (64%) of the crops that were monitored should have produced higher yields from the amount of water that was applied. Better paddock drainage, more timely and better scheduled irrigations, sowing early in the window, and matching row spacing to the target yield (i.e. don't sow on rows >0.24 m for a 7+ t/ha yield target), are the key advisory messages to have come out of this project.

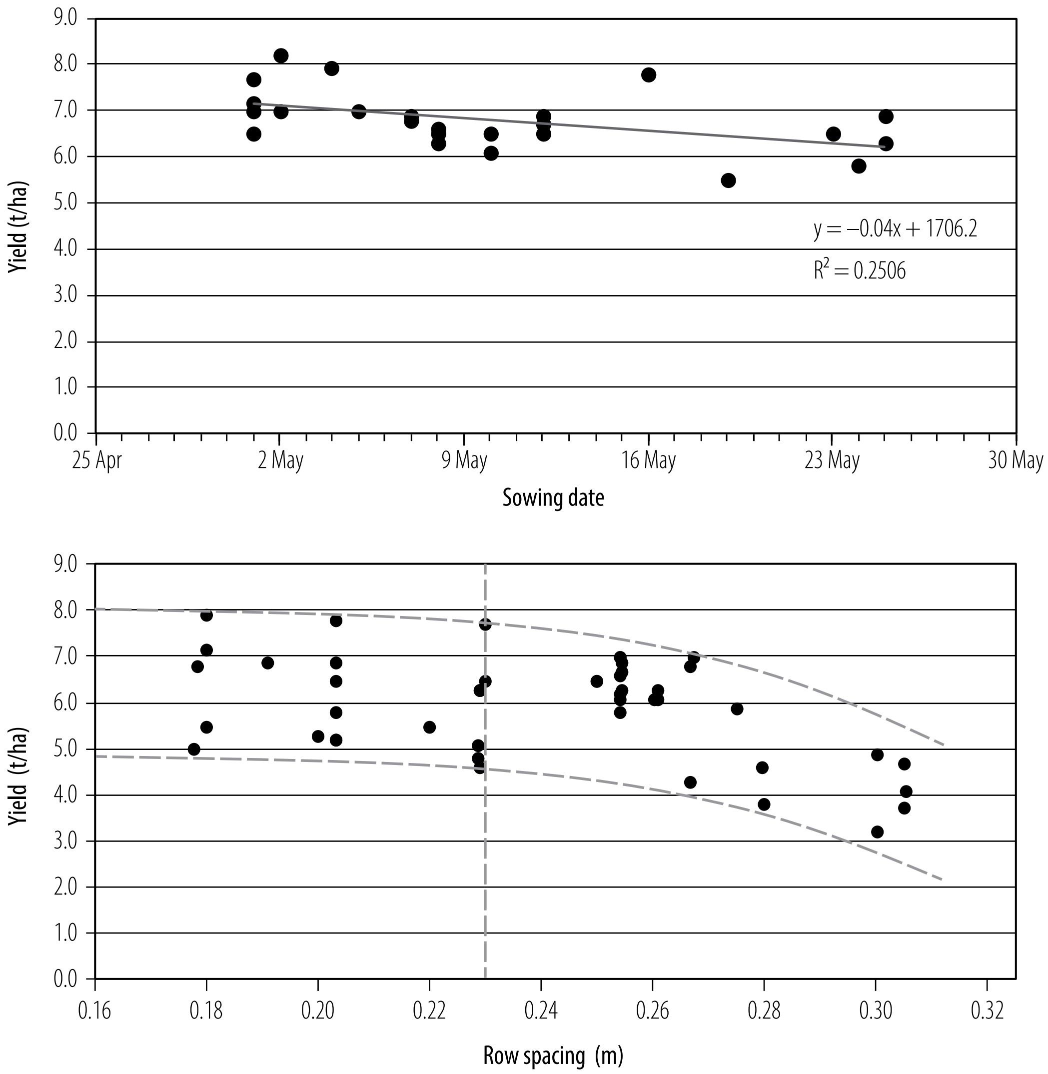

Figure 3. The relationship between wheat yield (t/ha) of well managed crops and sowing date for main season varieties (top); and row spacing for all monitored crops (bottom) in 2014, 2015 and 2016.

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Acknowledgements

This experiment was part of the project 'Soils under an irrigated environment', ICF00008, 2014–17, with joint investment from GRDC and NSW DPI. Project partners included Irrigated Cropping Council, Deakin University, Precision Agriculture, and Murray Local Land Services.

Thank you to the cooperators who participated and without whom this information could not have been collected.

Hard soils constrain irrigated cropping options in the Murray Valley

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

Key findings

- Hard subsoils occur widely in the Murray Valley.
- These hard subsoils:
  - greatly restrict the plant available water range
  - can be managed under winter crops with good irrigation management
  - present an impediment to successful surface irrigation of summer crops.

Introduction

Soils in the Murray Valley are known to have dense subsoils with low final infiltration rates. These soils are suited to growing rice, but restricted infiltration and low water-holding capacity present difficulties for other crops. This experiment investigated the nature and extent of the problem.

Methodology

The non-limiting water range (NLWR) is the soil moisture range between the limits to maximum plant growth set by aeration, water availability and root penetration resistance (Letey 1985). The NLWR concept was adopted by the project team as the best way to assess the effect of soil structure on crop growth due to its simplicity and ease of measurement at crop monitoring sites. Although soil water content was suggested by Letey (1985), soil matric potential (ψ_m) was used in this experiment because it provides a measure of both aeration status (soils are waterlogged at $\psi_m > -10$ kPa) and plant water stress without requiring calibration for different soil types.

Matric potential (ψ_m) and cone penetrometer resistance (PR) readings were made at depths of 3, 15, and 30 cm over a wide range of moisture contents under wheat crops at 17 sites in the Murray Valley. The PR readings were correlated with ψ_m readings. Quadrat cuts at each site were used to assess the effects on wheat yields.

Results

Most soils fitted a common ψ_m – PR relationship at each of the three depths (diamonds in Figure 1). However, two of the self-mulching clay (SMC) soils had a markedly lower PR across the range of ψ_m measured at all depths, and at 15 and 30 cm the rate of increase in PR with soil drying was lower (black triangles in Figure 1). Consequently, these two soils had a greater NLWR and root growth would not have been restricted at any of the depths measured at moisture contents up to the irrigation refill point: i.e. $\psi_m = -60$ kPa to -70 kPa at the bottom of the active root zone (Haise & Hagan 1967).

The ψ_m – PR relationship in one of the non-self-mulching clay (NSMC) soils that had been saturated in another experiment was very different to all other soils at 15 and 30 cm (Saturated NSMC light grey squares in Figure 1). The markedly low penetration resistance in this soil indicates a loss of structural stability at depth when these sodic, heavy clays are saturated.

There was poor correlation between ψ_m and PR at 15 cm depth in the main group of soils (Figure 1 C. 15 cm) due to differences between the duplex soils (red brown earths and transitional red brown earths [TRBE]) and the uniform clays (NSMC). Most duplex soils had a zone of very high soil strength at 10–15 cm, whereas the uniform clays did not. This zone limited root penetration (i.e. PR >2500 kPa) as the duplex soils dried (Figure 2).

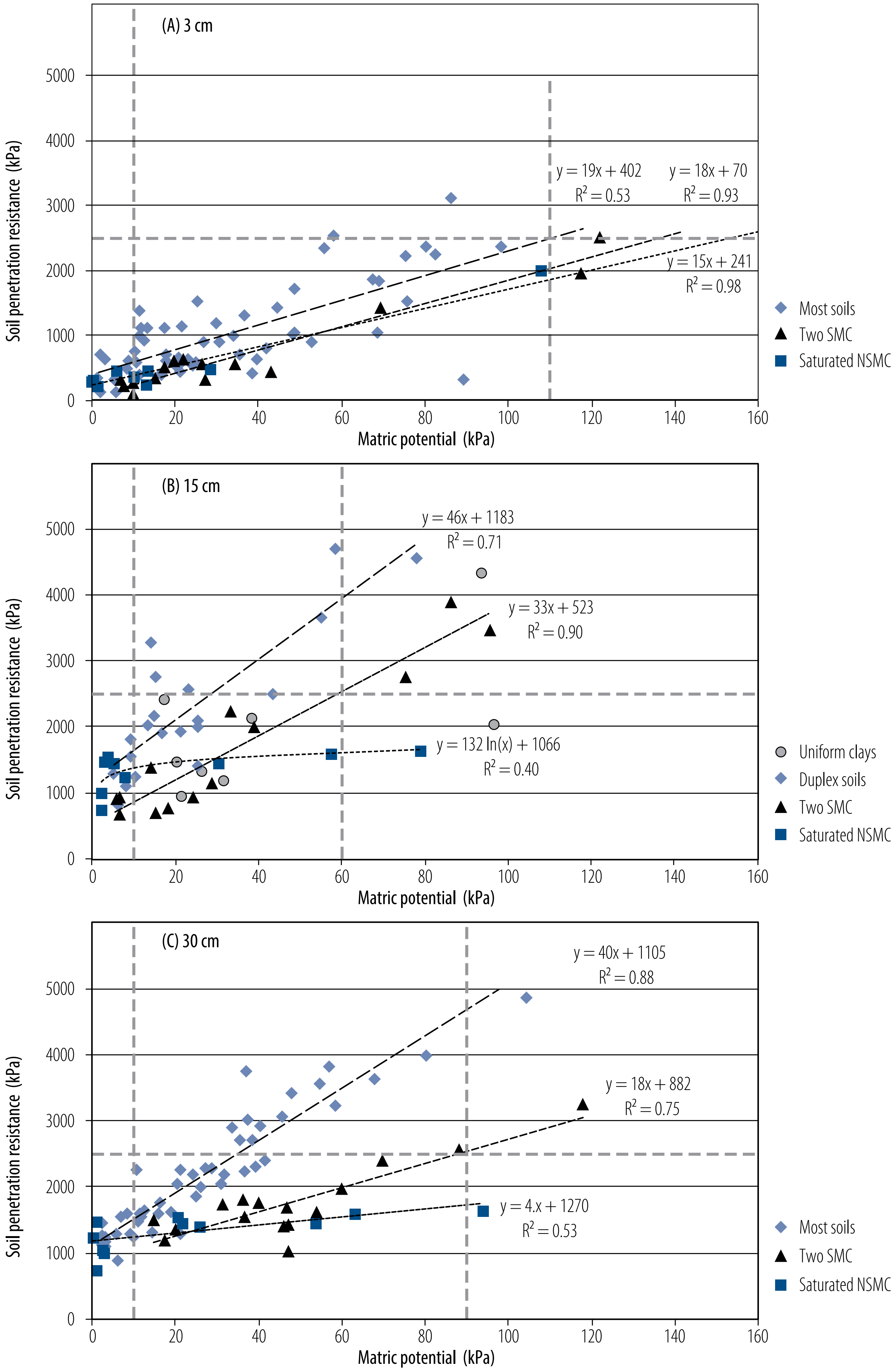

Figure 1. Soil penetration resistance at three depths; 3 cm (A.), 15 cm (B.) and 30 cm (C.), obtained over a range of matric potentials during 2015 and 2016, at 17 sites in the Murray and Murrumbidgee valleys. Sites have been seperated based on penetrometer resistance response to matric potential. *Note: Vertical dashed lines indicate the matric potential at the drained upper limit (-10 kPa) and the irrigation trigger point at each depth for the "best" soils. The horizontal dashed line indicates the limit for root penetration (2500 kPa). The NLWR at each depth for the "best" soils is the zone bounded by these lines.*

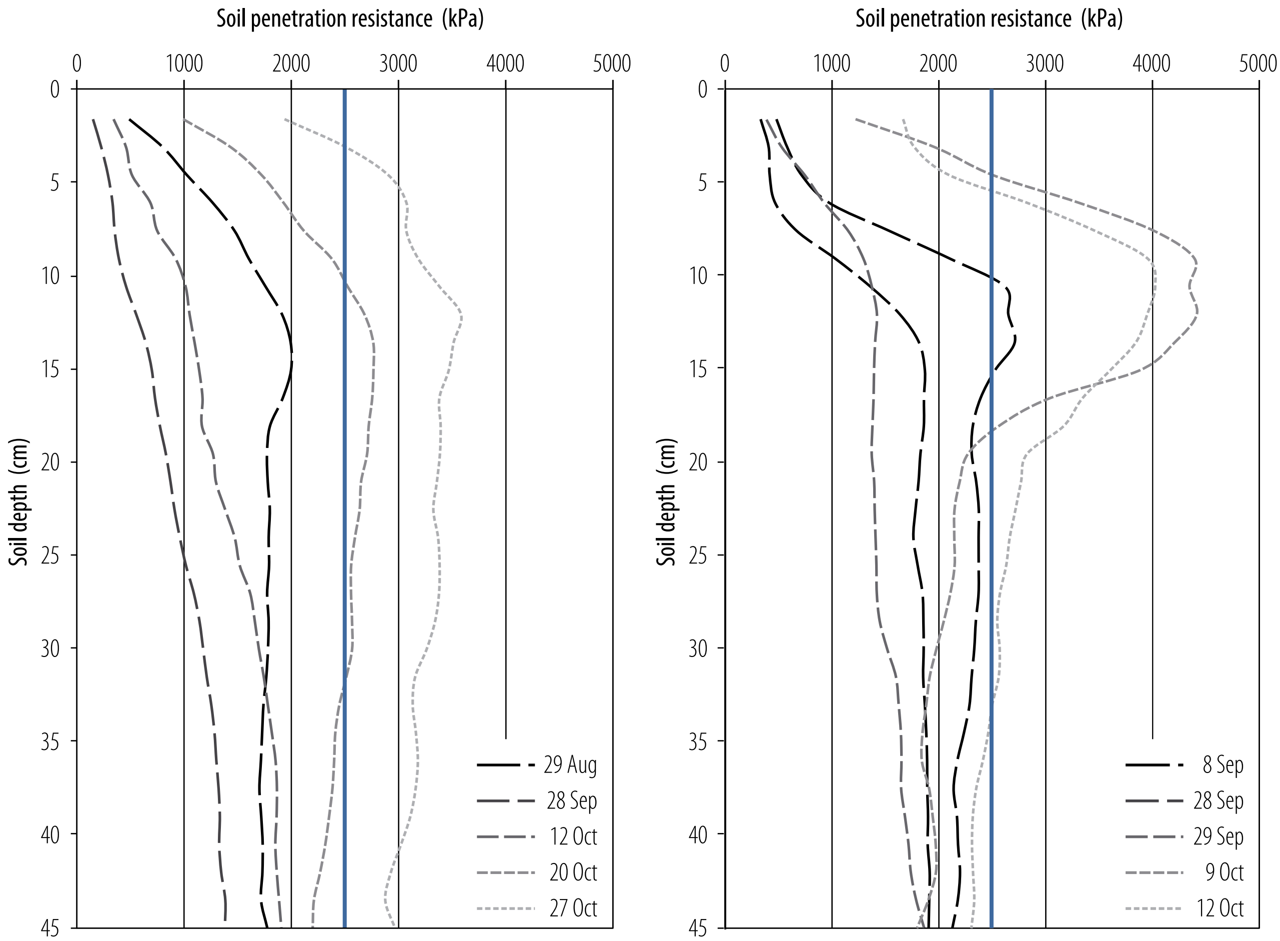

Figure 2. Soil penetration resistance in a uniform grey clay (SMC: left) and a red, duplex soil (TRBE: right) showing changes in soil strength with drying and wetting that were typical of these two soil types.

Conclusions

The strength of most soils at 30 cm was limiting at a matric potential of only –35 kPa. This is well short of the –60 kPa irrigation trigger point recommended for surface-irrigated, broadacre crops (Haise & Hagan 1967; North 2004), indicating that the majority of irrigated clay soils in the Murray Valley need to be irrigated more frequently to maximise productivity.

The restricted NLWR did not limit wheat yields at the monitor sites, presumably because roots were able to grow through the subsoil during winter when soils were wet, and soil strength and evaporative demand were low. Spring irrigation ensured that good yields were achieved.

This may not be the case for summer crops as they have higher evapotranspiration rates and depend on irrigation rather than rainfall. Frequent irrigation (e.g. every 4–5 days when irrigating at a trigger point of –35 kPa) in these clay soils would likely result in waterlogging.

Conversely, limitations in the irrigation supply system, or labour constraints, might make frequent summer crop irrigation impractical, resulting in delayed irrigations that can cause short periods of water stress in each irrigation cycle. This water stress would arise, in part at least, because of the low porosity and predominance of fine pores in these dense soils. These factors restrict the rate of water transport to roots so that on hot days the soil cannot supply water to the plant to meet transpiration requirements causing midday wilt (North 2007). This is likely to be more of a problem in the duplex soils than in the uniform clays.

Roughly 90% of the sites investigated had soils that reached PR levels which inhibit root growth before the recommended irrigation trigger point of –60 kPa. This highlights the prevalence of hard subsoils in all soil types commonly found in surface-irrigated systems in southern NSW. The effect of this on productivity, its cause, and possible solutions requires further investigation.

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Acknowledgements

This experiment was part of the project 'Soils under an irrigated environment', ICF00008, 2014–17, with joint investment from GRDC and NSW DPI. Project partners included Deakin University, Irrigated Cropping Council, Precision Agriculture and Murray Local Land Services.

Thank you to the site cooperators, without whom this information could not have been collected.

Other research

Quinoa growing in NSW: sowing rates and varieties best suited for the Riverina

David Troldahl (NSW DPI, Yanco)

Key findings

- Six varieties have been selected for further testing.
- Optimum seeding rates are important to maximise yield potential.
- Further experiments are needed to establish the best sowing time for quinoa in the Riverina.

Introduction

Quinoa can be grown in Australia as either a summer or winter crop and it is seen as a good fit within existing cropping programs depending on soil type, rainfall and environment. The experiments carried out by NSW DPI at the Leeton Field Station are part of a national project 'Quinoa as a new crop in Australia' a co-investment by AgriFutures Australia and state departments of primary industry or agriculture. Other experiment sites are in South Australia (Naracoorte), the Northern Territory (Katherine and Alice Springs) and Western Australia (Kununurra, Northam and Perth).

At Leeton, we are looking at evaluating seeding rate (plant density) and varieties in the field. The density experiment investigates the effects of plant density with seeding rates of 2 kg/ha, 4 kg/ha and 8 kg/ha. The variety experiment evaluates 13 different varieties to identify the best performing variety for the Riverina area and on the soil type at the research site, which is a heavy, grey self-mulching soil typical of the surrounding area. This soil is very different from the lighter soils that quinoa is normally grown on, compared with the other national sites, and the soils in its native South America.

The quinoa industry currently has no industry body and there are currently no varieties registered or that have Plant Breeder's Rights (PBR). The varieties being tested are from selections made by the Department of Primary Industries and Regional Development (DPIRD), Western Australia which is leading this project.

Site details

Location	Leeton Field Station, Yanco
Soil type	Grey self-mulching soils
Previous crop	Fallow
Starter fertiliser	Fertiliser was applied pre sowing under rows: 110 kg/ha Granulock Z (11% N, 21.8% P, 4% S, 1% Zn).
Sowing method	Precision cone seeder, 4 rows, 30 cm apart onto 1.8 metre beds. Seeds were dropped onto the soil surface and covered using individual chains dragged behind the sowing boot, then followed by a press wheel.
Sowing date	16 March 2017

Irrigation method	Furrow irrigation post sowing. Each irrigation was timed using evapotranspiration figures to calculate irrigation needs; only three irrigations were required.

Experiments

Variety	There were 13 varieties provided by DPIRD. The varieties were chosen as the most promising lines to be grown in a national experiment. For one variety there was only enough seed for one plot. The experiment was to evaluate the viability of growing quinoa in southern NSW and to learn about the agronomy, nutritional and herbicide needs to grow this crop and to develop best practices in the process. There were 12 varieties that were replicated and one unreplicated due to shortage of seed. The variety experiment was sown at 4 kg/ha. *Varieties*: BEW, BET, JC1, CD, V1, V2 (unreplicated), V2T, V3, V4, V5, V6, V7 and V8.
Plant density	The seeding rates used for quinoa vary around the world due to the differing soil and environmental conditions. The seeding rates in this experiment were 2 kg/ha, 4 kg/ha and 8 kg/ha. *Varieties*: BEW and JC1.

Results

Plant density

The varieties JC1 and BEW sown at the lowest rate of 2 kg/ha did not differ significantly in established plant density. JC1 and BEW at 4 kg/ha and also BEW at 8 kg/ha did not differ significantly in plant density. The plant density of JC1 at sown at 8 kg/ha was significantly higher than all other treatments, including BEW sown at 8 kg/ha (Figure 1).

The yields showed a significant difference between the 2 kg/ha seeding rate of both varieties compared with the 4 kg/ha and 8 kg/ha rates (Figure 2).

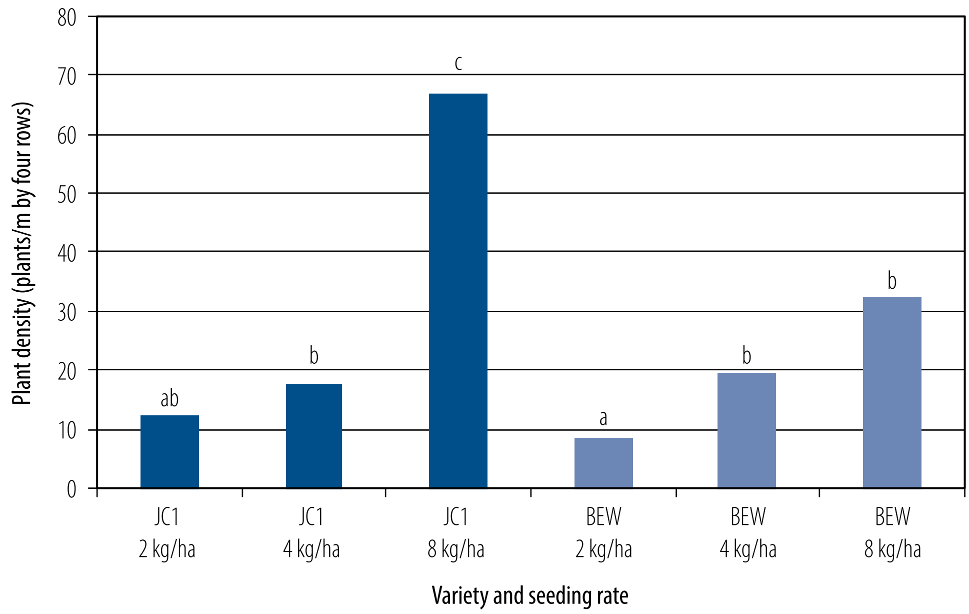

Figure 1. Plant density achieved (number of plants per metre in four rows (one bed)) for two quinoa varieties sown at three seeding rates, Leeton Field Station 2017. Significant difference is indicated by different letters (*P*<0.05).

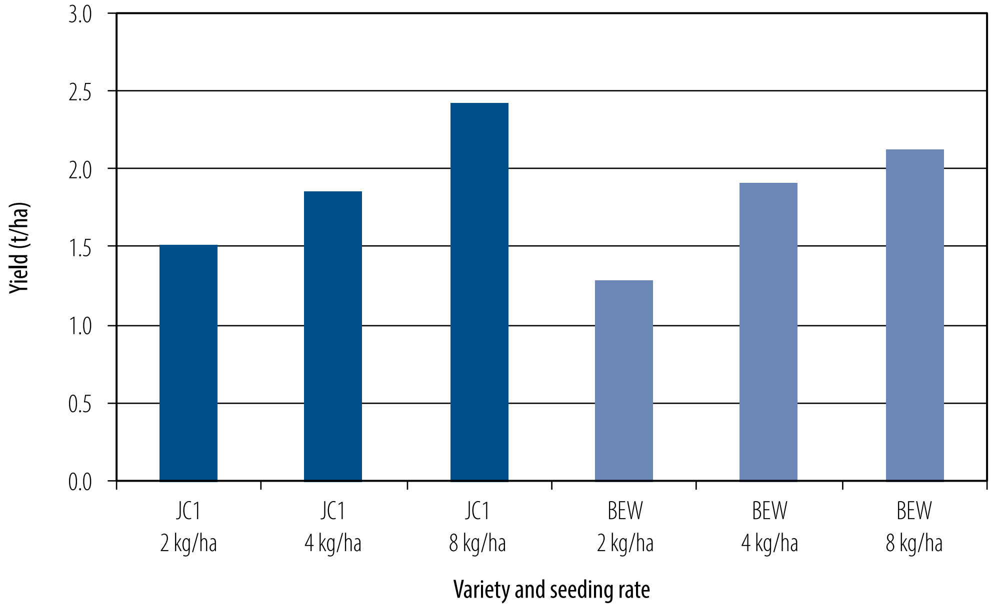

Figure 2. Yield of two quinoa varieties sown at three seeding rates, Leeton Field Station 2017.

Variety

The variety experiment separated those that were suited to the growing conditions and those that were not. The V2T variety was badly affected by frost at flowering whereas most of the other varieties had finished flowering by the time the frosts occurred. Average yields are shown in Figure 3.

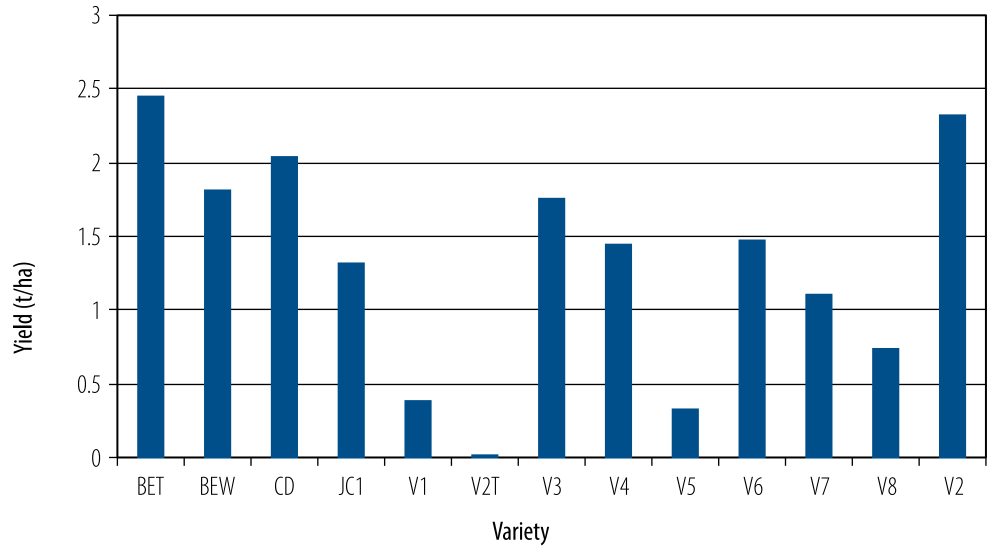

Figure 3. Yield of 13 quinoa varieties (V2 not replicated), Leeton Field Station 2017.

Conclusion

These experiments are very important for understanding the growing conditions and challenges for quinoa crops in south-eastern Australia. The experiments have shown that quinoa is a crop that can be grown in the Riverina.

The next experiments will be the six best varieties for the Riverina which have been selected and sown at the most suited seeding rate, both of which have been determined from this season's experiment. The development of an agronomy package that will set out the best growing practices along with nutritional needs, irrigation requirements and pest and weed management options needs further investigation.

Acknowledgements

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

Thank you Owen O'Callaghan for technical support and Rachelle Ward for literature review and discussion. Thank you to Beverly Orchard for biometric support.

Cracking and breakage in rice grains: implications for the rice industry

Dr Mark Talbot, Dr Prakash Oli and Dr Peter Snell (NSW DPI, Yanco)

Key findings

- Cracked rice grain can break when milled, reducing post-milling quality and affecting the rice industry as a whole.
- Collaborative research between NSW DPI Yanco and SunRice aims to standardise crack measurement to support quality analysis throughout the supply chain.
- Research will focus on understanding why grain cracks to mitigate cracking and breakage and improve the crack-resistance of future varieties.

Introduction

Rice is primarily consumed and processed as a whole grain. Maintaining the structural integrity of the grain throughout maturation in the field, harvesting, transport, drying, storage, milling and post-milling handling, is critical. Cracked rice significantly affects breakage during milling and subsequently reduces the value of the rice throughout the supply chain; every 1% increase in whole grain yield is equivalent to $2.5 million in revenue to SunRice.

Rice grains are hygroscopic, and will readily equilibrate with environmental moisture levels, especially when milled. Grains can potentially crack under adverse conditions (e.g. rapid changes in relative humidity and temperature), either before or after milling. While the significant contribution of cracked grain to the amount of breakage during milling is well known, very little is known about post-milling cracking and breakage. Research at NSW DPI Yanco, in collaboration with SunRice, aims to understand post-milling cracking and develop imaging methods to incorporate into quality tests performed at different stages in the rice processing industry.

Measuring and monitoring cracks

There is currently no standard method for measuring cracks or monitoring their formation over time, either in a research or industrial capacity. Aligning procedures to measure/monitor cracking will support breeding varieties with crack-resistance traits through the Quality Evaluation Program (QEP) at Yanco, and will benefit industry, e.g. as a quality test at receivals, monitoring cracking and breakage during milling, handling and transport, and as a quality test for rice-based food production. Standardised testing will ensure consistent delivery of premium quality Australian rice varieties to consumers.

Cracks in milled grains can either form internally or on the surface (Figure 1), depending on whether the grain absorbs or loses moisture, respectively. There is little knowledge on how the different types of cracks affect grain breakage during milling and/or processing.

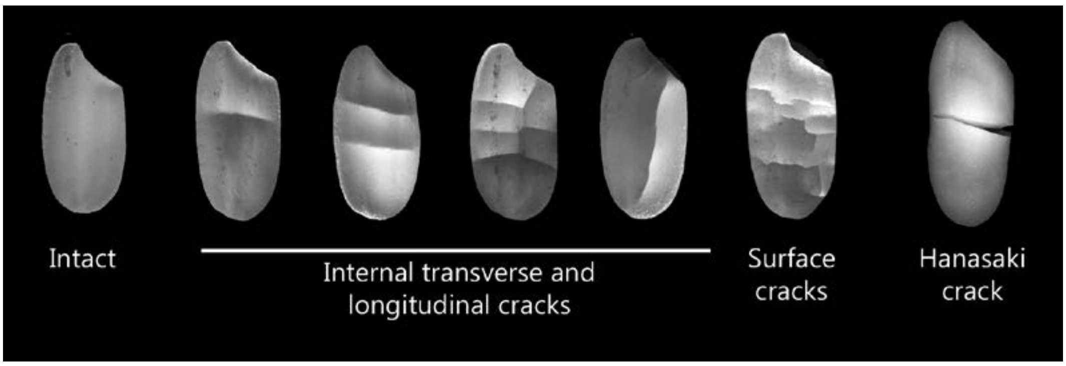

Figure 1. Cracks formed in dry, milled grains (transverse, longitudinal and surface cracks), and soaked milled grains (Hanasaki cracks) of Sherpa⁽ᶲ⁾. Similar crack patterns can appear in other varieties.

Soaking-induced crack formation

A procedure to semi-automatically determine the percentage of cracked grain in a soaked rice sample has been implemented and further developed at DPI. The Hanasaki test, used by SunRice and DPI, measures the formation of large cracks (see Figure 1), which can occur when rice is soaked in water before cooking, e.g. in sushi production. The Hanasaki test gives a better indicator of cooking quality for sushi than measuring cracks in dry, milled grains. DPI has automated measurement by developing an image analysis algorithm (Figure 2), and the improved test has been incorporated into the QEP for certain varieties.

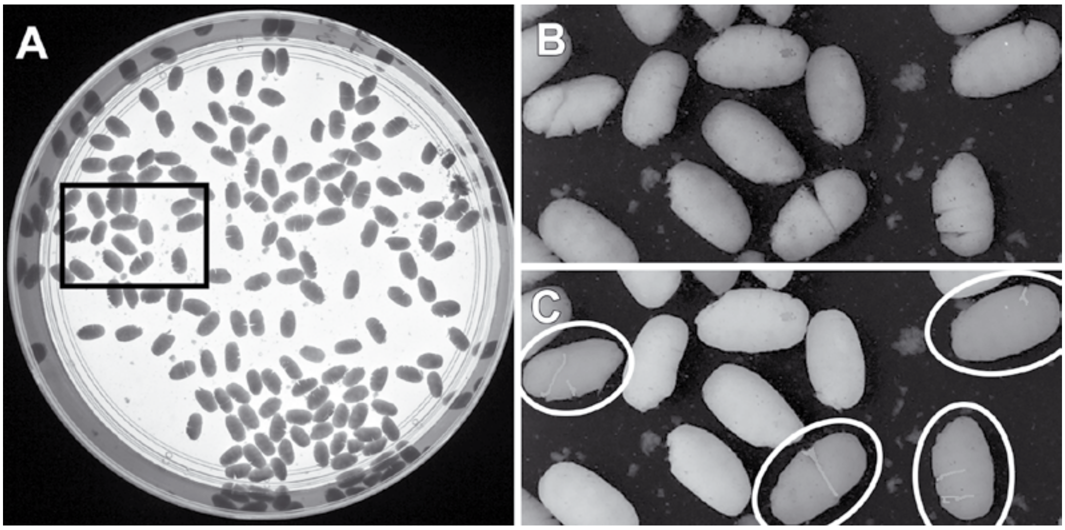

Figure 2. Detecting cracks in grains soaked in water (Hanasaki cracks). A – original Petri dish with 100 grains soaked for 1 hour in water. B – enlarged portion of dish from boxed area in A. C – cracked grains are circled with cracks showing as lighter marks.

Future research

The focus for future research into cracking will be on:

- understanding the biological and physical causes of cracking, leading to varieties with enhanced crack resistance
- standardising methods for measuring and monitoring cracking, and incorporating these into the QEP and industry quality assessment
- determining the contribution of grains with different crack types on milling and post-milling breakage, and processing
- investigating conditions in rice handling, milling and processing that contribute to cracking and breakage, allowing industry to maximise whole grain yield and returns to growers and processors.

Acknowledgements

This research was part of the RIRDC (AgriFutures Australia) project 'Australian Rice Partnership II', PRJ-009950, June 2015–May 2020. We would like to thank SunRice for their involvement and supply of samples.

Value addition of NSW lupin: inclusion of NSW lupin in bread making

Dr Mahsa Majzoobi and Denise Pleming (NSW DPI, Wagga Wagga and Graham Centre for Agricultural Innovation, Wagga Wagga Agricultural Institute)

Key findings

- NSW lupin has great potential for use in bread production.
- Acceptable bread can be produced incorporating 20% lupin flour.
- Optimising processing conditions and bread formulation is required to obtain best bread quality with high lupin substitution level.

Introduction

Lupin is a legume belonging to the Fabaceae family grown across a diverse range of countries and climates (Mohamed & Rayas-Duarte 1995). Australia, as the largest producer and exporter of lupin, produces about 1.6 million tonnes of lupin seed annually accounting for 85% of world production. The two main species grown in Australia are narrow leafed lupin (*Lupinus angustifolius*) and sweet albus lupin (*Lupinus albus*). Western Australia, New South Wales (NSW), South Australia and Victoria are the main lupin production areas. NSW produces on average 75,000 tonnes of lupin annually, and is the main producer of albus lupin (50%). Lupin can tolerate frost, drought, and poor soils and can be used as a rotating crop to fix the nitrogen content of the soil (Pulse Australia 2018). Unlike other legumes, lupin contains negligible amounts of starch (about 2–3%), however it is a rich source of nutrients including protein (32–36%), crude fibre (10–15%), lipids (6–9%), ash (~3%) and bioactive compounds such as polyphenols and flavonoids (0.32–0.37%) (Jayasena & Quail 2004; Martínez-Villaluenga et al. 2009).

Besides its superior nutritional profile, lupin is a gluten-free seed making it attractive for use in gluten-free and nutraceutical products. Accordingly, there is a growing interest in lupin food applications around the world, including Australia. For instance, lupin flour has been incorporated into bread to improve its nutritional value (Jayasena & Quail 2004). Human clinical tests have shown positive health benefits from lupin breads such as reducing the risk factors for obesity, diabetes and cardiovascular diseases. However, from a technological point of view, incorporating lupin flour into bread can result in quality loss including low loaf volume, poor crumb texture and reduced customer acceptability. The detrimental effects at higher substitution levels appeared to be associated with the lupin protein's low elasticity, effects from the non-protein components of the lupin flour on the wheat flour components, and gluten weakening and dilution (Dervas et al. 1999; Kohajdová et al. 2011). To avoid these issues, many studies have added only low concentrations of lupin flour in bread. For example, Pollard et al. (2002) could obtain the best bread quality with up to 5% lupin flour, while Doxastakis et al. (2002) produced acceptable bread quality with less than 10% lupin flour. Nevertheless, higher levels are required to obtain nutritional and health benefits from the lupin bread. Therefore finding applicable strategies to maintain acceptable bread quality at increased concentrations of lupin flour is of great importance.

With the aim of adding value to NSW lupin, in this research high quality bread was produced with albus 20% lupin flour.

Materials

De-hulled *L. albus* grains were supplied by Conqueror Milling, Cootamundra, NSW. The grains were milled using a Perten 3100 laboratory mill fitted with a 0.8 mm sieve to obtain lupin flour with a final particle size of 250–300 µm. Wheat flour (Perfection baker's flour, Allied Mills, Australia), salt, caster sugar, solidified vegetable fat and active dry bakery yeast were purchased from local supermarkets, and malt flour was supplied by Blue Lake Milling (Bordertown, SA). In addition, bread improvers from various sources were used in the bread formulation.

Proximate analysis of lupin flour

The chemical composition of the flours were measured according to the American Association of Cereal Chemists (AACC) approved methods (ash, moisture, crude protein, crude fibre), or in house methods (crude fat by hexane soxtec extract).

Bread making

Bread was produced using a sponge and dough process with either 100% wheat flour (control) or 80:20% wheat:lupin flour (lupin). The formulation included salt (2%), yeast (3%), fat (3%), caster sugar (5%), malt flour (0.5%), and bread improvers (control 0.315%, lupin 5.315%). Water addition (control 57.7% and lupin 68.5%) was based on farinograph water absorption as determined by a 4 g micro-doughLAB (Perten Instruments Australia). The finished doughs were baked in a rotary electrical oven at 215 °C for 15 minutes (control) or 12 minutes (lupin). Loaves were removed and cooled at ambient temperature for 40 minutes before weighing and volume determination (rapeseed displacement). Internal loaf texture, structure and colour were judged the next day.

Bread quality tests

Bread samples were stored in sealed containers for three days at about 23 °C and tested each day for firmness using a Texture Analyser – TA-TX2 (Stable Micro Systems, UK) – fitted with a flat based solid cylinder compressing to 50% of sample height.

Instrumental crust and crumb colour parameters of brightness (L-value), redness–greenness (a-value) and blueness–yellowness (b-value) were measured using a Minolta CR200 chromometer (Konica Minolta Sensing Inc, Japan) fitted with an 8 mm head.

Results and discussion

Chemical analysis

Lupin flour contained 10.1% moisture (control 13.9%), 39.8% protein (control 14.3%), 15.4% dietary fibre, 4.2% ash (control 0.7%) and 8.8% fat, all parameters that can vary due to genetic and environmental differences.

Bread quality

Increasing bread firmness over storage time is anticipated due to the bread staling. Figure 1 shows that control and lupin bread had similar firmness after one day of storage at ambient temperature. However, with increasing storage time, the lupin retained greater softness than the control, indicating better keeping properties. This could be attributable to the higher protein and fibre content of the lupin flour and its increasing water binding capacity, hence delaying staling in the lupin bread.

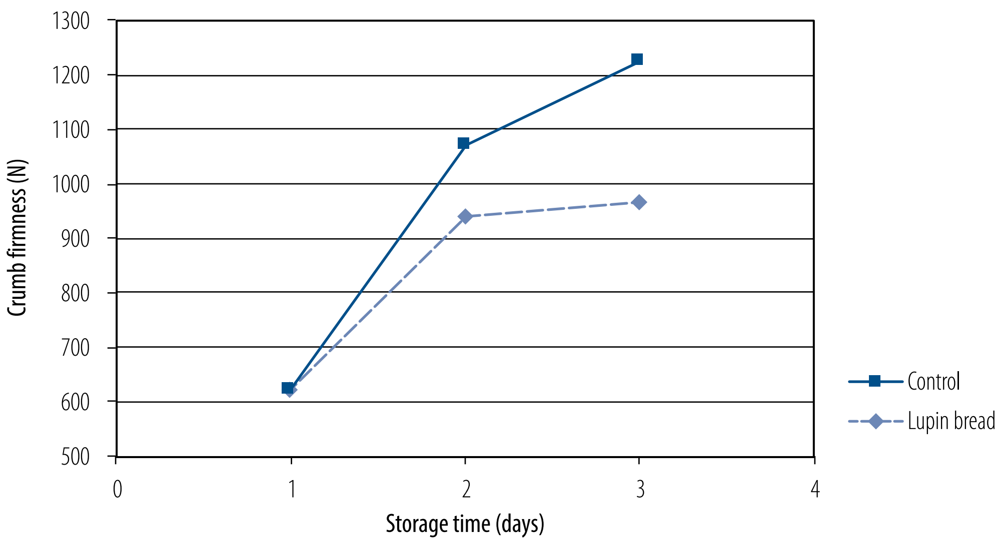

Figure 1. Crumb firmness of the control and lupin bread measured after 1, 2 and 3 days of storage at 23 °C.

Other research

Instrumental crust colour parameters showed that the control had brighter (L-value of 74.3 vs 40.7), less reddish (a-value of 10.8 vs 12.0) and more yellowish (b-value of 29.2 vs 21.0) colour than the lupin. The darker crust colour in the lupin bread could be attributed to increased Millard and caramelisation reactions during baking due to the higher protein and reduced sugar content of the lupin flour (Figure 2). Although the darker crust colour of the lupin bread is still acceptable, it may be possible to adjust the oven temperature and baking time in order to obtain more comparable colour.

Figure 2. Appearance of control (left) and lupin bread (right).

The control produced higher volume loaves than the lupin (168 cc vs 148 cc), indicating a reduction in volume of approximately 12%. Nevertheless, in the present work, loaf quality can still be viewed as acceptable at slightly reduced loaf volumes as there is not a considerable difference in the crumb structure and air bubble distribution between the two samples (Figure 3). This indicates that an adequate amount of air was captured in the lupin dough during mixing and baking to produce an open, soft crumb structure.

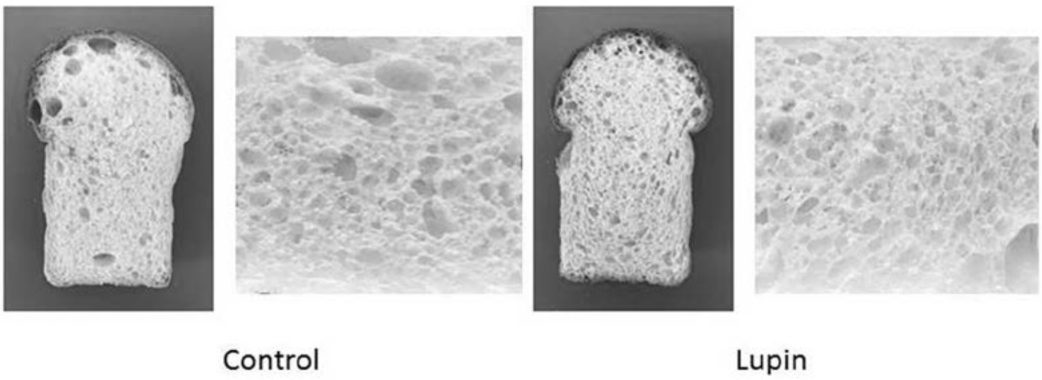

Figure 3. Cross section and crumb structure of control (left) and lupin bread (right) showing the crumb structure and air bubble distribution.

Summary

Although lupin (*L. angustifolius*) from WA has been studied widely and incorporated in various food products, albus lupin has received less attention as a food component. This current research showed the great potential of albus lupin grown in NSW to be used in bread making with successfully incorporating 20% lupin flour, a higher level than has previously been reported in the literature. However, to produce acceptable bread, bread formulation optimisation, including improvers, and processing conditions are of great importance. Compared with the control sample, lupin bread had a browner crust and lower volume; however, it showed acceptable crumb structure and softer texture over extended storage time. Further research is required to show the applications of NSW lupin in other food products to encourage the food industry to consider albus lupin as a valuable food ingredient.

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Acknowledgments

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Light interception and radiation-use efficiency in wheat varieties with contrasting heat stress tolerance

Dr Livinus Emebiri and Shane Hildebrand (NSW DPI, Wagga Wagga); Dr Nicholas Collins (School of Agriculture Food and Wine, University of Adelaide)

Key findings

- Wheat varieties that differ in heat tolerance also differ in their ability to capture incident light energy and to convert the energy into biomass.
- Radiation-use efficiency was more closely related to grain yield in the heat-tolerant varieties than in the sensitive varieties.
- The results suggest that breeding for heat tolerance would deliver benefits for wheat growers, even under optimal growing conditions.

Introduction

Heat stress is estimated to cost Australian wheat growers $1.1 billion annually in yield losses (Thomas 2015). During daylight hours, the rising temperature in the field can result in heat stress, especially in dry conditions when cooling by evaporation is no longer able to keep pace with incident radiation (incoming radiation from the sun). The leaf canopy temperatures at midday can often be higher than that of the surrounding air. This can cause irreversible damage to the photosynthetic apparatus (the chloroplast), resulting in:

- rapid loss of chlorophyll (Shirdelmoghanloo et al. 2016a)
- reduced grain filling period (Shirdelmoghanloo et al. 2016b)
- shrivelled grains that significantly reduce grain yield and marketable quality.

Heat stress tolerance has been shown to vary in some Australian wheat varieties (Collins et al. 2017; Sissons et al. 2018). However, the physiological mechanism underlying the variability in tolerance is not fully understood. From a grower perspective, this knowledge is relevant for targeting tolerant varieties to two aspects of heat stress:

1. the gradual increase in temperature that reduces grain yield potential through reduction of photothermal quotient
2. the extreme, heat-shock events that disrupt reproductive process and reduce grain number (Sadras & Dreccer 2015).

It has often been noted that at midday, plants can change their architecture by folding the leaves or by changing the leaf orientation from horizontal to vertical. There is anecdotal evidence to suggest that they can avoid heat stress damage in this way. However, regulating the amount of incident radiation absorbed by the canopy could affect grain yield, since biomass production is dependent on the crop canopy's ability to intercept radiation.

In this experiment, we sought to determine whether wheat varieties that differ in heat tolerance also differ in their ability to capture incident light energy and to convert the energy into biomass. Delayed sowing was used to expose the crop to rising temperatures.

Site details

Site	Wagga Wagga Agricultural Institute
Sowing dates	5 June (early sowing) and 1 August (late sowing) 2015
Disease management	Fungicide: Bumper® 625EC 200 mL/ha, @ 250 L water rate.

Weed control	Knockdown: Spray.Seed® 2 L/ha, Roundup 1.25 L/ha, 100 L/ha water rate Pre-emergent: Boxer Gold® 2.5 L/ha, TreflanTM 480 2 L ha, 100 L/ha water rate In-crop: first post-emergent: Terbutrex® 600 g/ ha, Lonestar® 13 g/ha, 100 L/ha water rate Second post-emergent: Affinity® 100 mL/ha, Agritone® 750 330 mL/ha, 100 L/ha water rate
Treatments	Wheat varieties of contrasting tolerance to heat stress
Sowing dates	Early (June) and late (August)
Experiment design	Spatially optimised incomplete block design

Glossary of terms

PAR = Photosynthetically active radiation. This is the part of the solar radiation spectrum that is used for photosynthesis (in the 400 to 700 nanometer wavelength range).

fPAR = Fraction of PAR received at the crop canopy surface.

IPAR = Amount of PAR intercepted by the crop.

RUE = Radiation-use efficiency. The above-ground dry matter produced per unit of intercepted PAR.

PTQ = Photothermal quotient. Ratio of intercepted PAR and mean temperature.

PTQvpd = Photothermal quotient (PTQ) adjusted for moisture stress.

Method

Wheat varieties were selected on the basis of greenhouse and chamber screening for variation in heat tolerance. Field experiments were conducted under irrigation, using two planting dates in 2015. Ceptometer readings were taken once a week for each plot using the AccuPAR LP-80 (Decagon Devices Inc.). Measurements were confined to midday (10 am to 2 pm) during the period of Zadok growth stage 33–65. At each measurement time, three readings were taken per plot, one above the canopy (PAR_{above}), and two below the canopy (PAR_{below}). From these measurements, the fraction of photosynthetically active radiation received by the crop (fPAR) was calculated as the ratio of the difference between PAR_{above} and PAR_{below} to PAR_{above}, and the intercepted radiation (IPAR) was determined as the product of fPAR and total solar radiation (MJ m^{-2}) derived from the Scientific Information for Land Owners (SILO) climate database (https://silo.longpaddock.qld.gov.au). A photothermal quotient (PTQ) was calculated for each variety as the ratio between intercepted PAR and mean daily temperature above a base temperature of 4.5 °C. The PTQ was also adjusted for vapour pressure deficit (PTQvpd) calculated according to Dreccer et al. (2007).

To determine above-ground biomass, a quadrat sample of each variety was taken at maturity. Radiation-use efficiency (RUE) was calculated as the ratio of plant biomass at maturity and cumulative IPAR during the period of ~20 days before and 10 days after anthesis.

Results and discussion

The varieties used for this experiment showed high harvest indices, most likely due to using full irrigation to ensure no drought stress. Late sowing exposed the crops to rising temperatures, which had a significant effect on varietal trait expression. The IPAR, biomass production and RUE were all significantly higher in the early sown treatment compared with the late-sown treatment. Sowing date also significantly affected grain yield being higher in the early-sown (4.98 t /ha) than the late-sown (3.01 t/ha) treatment. However, grain size (1000 grain weight) was not affected (37.9 g vs 37.4 g) and the harvest index was higher in the late-sown than in the early-sown treatment (0.66 vs 0.58, respectively).

The photothermal quotient adjusted for vapour pressure deficit (PTQvpd), which summarises the weather conditions (temperature and moisture) for different sowing dates into a single value, ranged from 3.8 to 5.2 in the early sowing, and from 1.3 to 2.2 in the late sowing. It was linearly related to grain yield, and highly responsive to sowing dates (Figure 1A).

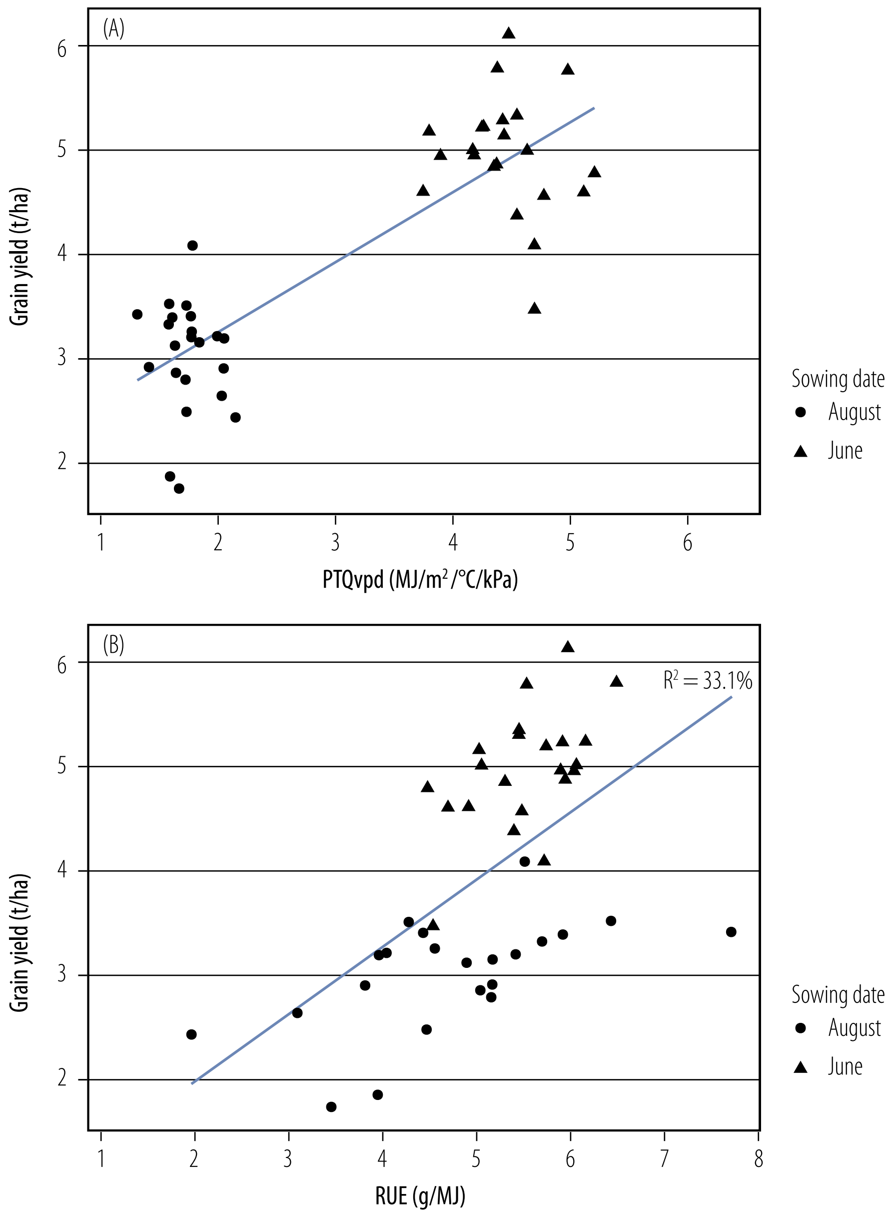

Figure 1. Relationships of grain yield with (A) PTQvpd, and with (B) RUE in experiments conducted at Wagga Wagga in 2015.

Across varieties and sowing dates, RUE explained ~33% of the variability in grain yield (Figure 1B). The relationship was consistent across sowing dates, but not when varieties were classified as heat tolerant (HT) versus sensitive (HS). In the early-sown treatment, 56% of the grain yield produced by heat tolerant varieties was explained by RUE, compared with 6.4% in the sensitive varieties (Figure 2A). Under heat stress conditions induced by late-sowing, the contribution of RUE to grain yield was ~50% in the heat-tolerant varieties, and 20% in the sensitive varieties (Figure 2B).

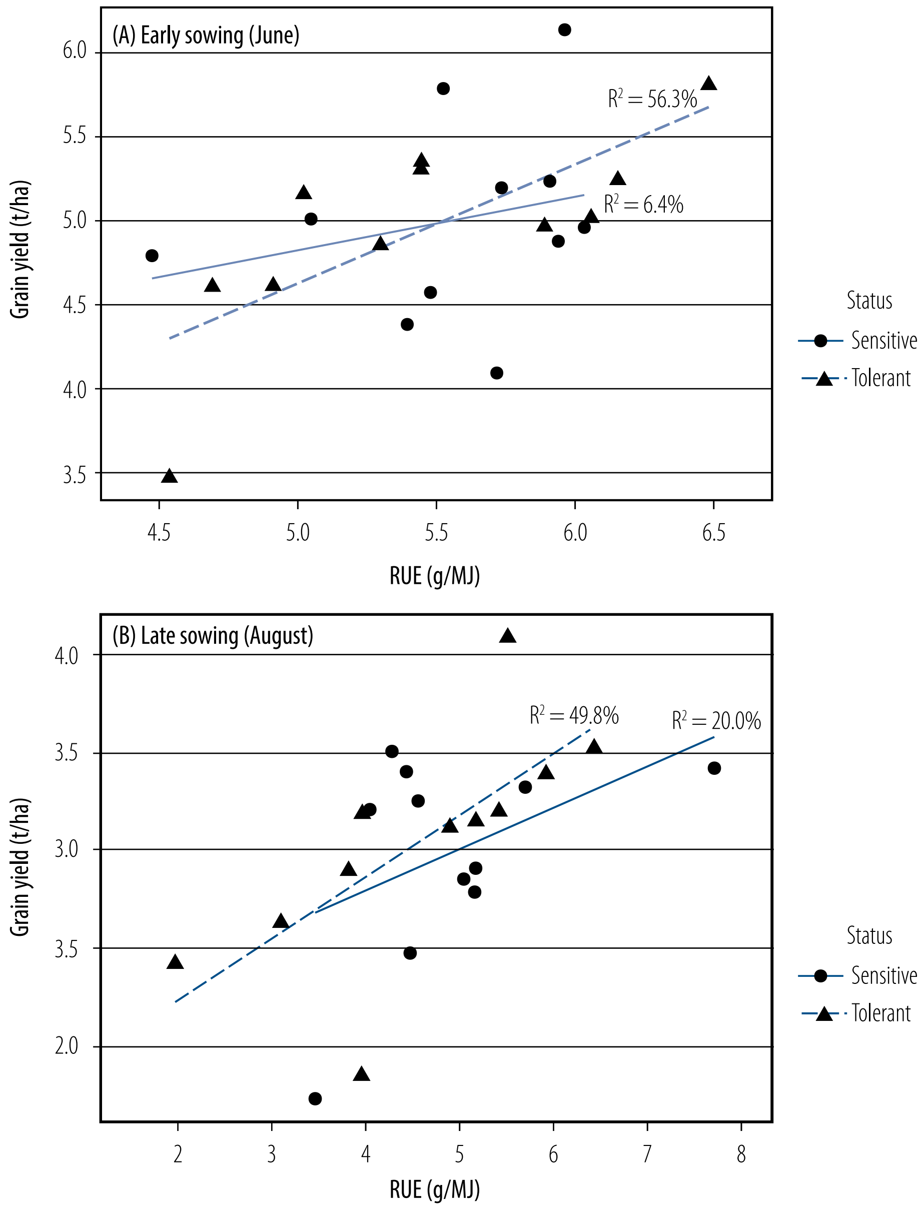

Figure 2. Relationships of grain yield (t/ha) with RUE in wheat varieties differing in heat tolerance, for the early (A) and late (B) sowing dates.

Summary

Although this is a preliminary experiment, the results suggest that wheat varieties that differ in heat tolerance also differ in their ability to capture incident light energy and to convert the energy into biomass. The heat tolerant varieties were better able to use intercepted photosynthetically active radiation for grain yield production compared with the sensitive group. The large difference observed under normal sowing (56% vs 6.4%) suggests that breeding for heat tolerance would deliver benefits for wheat growers even under optimal growing conditions. The experiments will be repeated to confirm results.

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